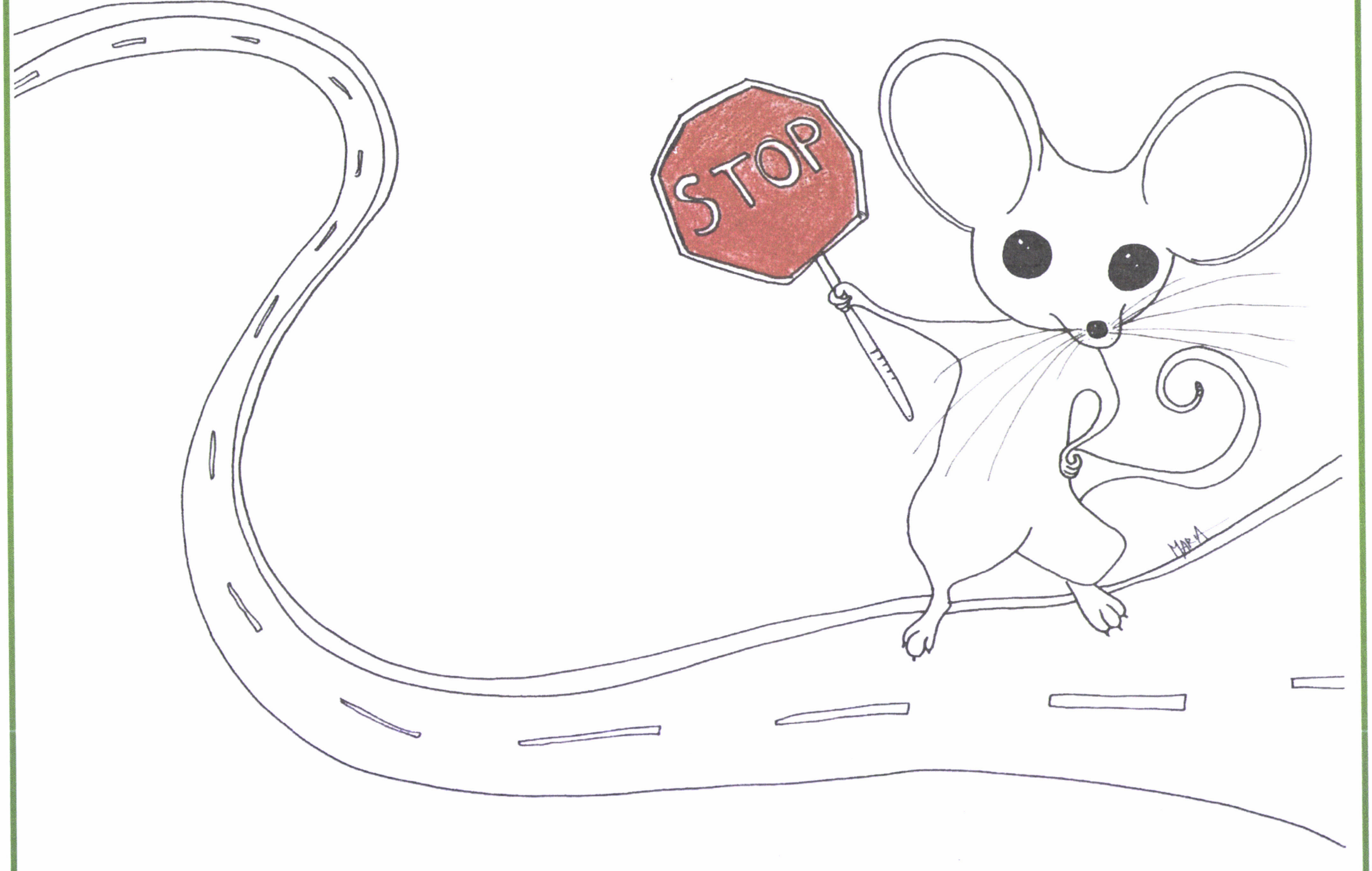
UNIVERSIDADE DE ÉVORA

Mestrado em Biologia da Conservação

# AVALIAÇÃO DO EFEITO BARREIRA DAS ESTRADAS NA ABUNDÂNCIA E USO DO ESPAÇO DO RATO-DO-CAMPO (*Apodemus sylvaticus*)




Dissertação realizada por:

**Sofia Raquel Lavado Eufrázio**

Évora 2010

Orientador: **Prof. Dr. António Mira**

Co-Orientadora: **Mestre Ana Galantinho**

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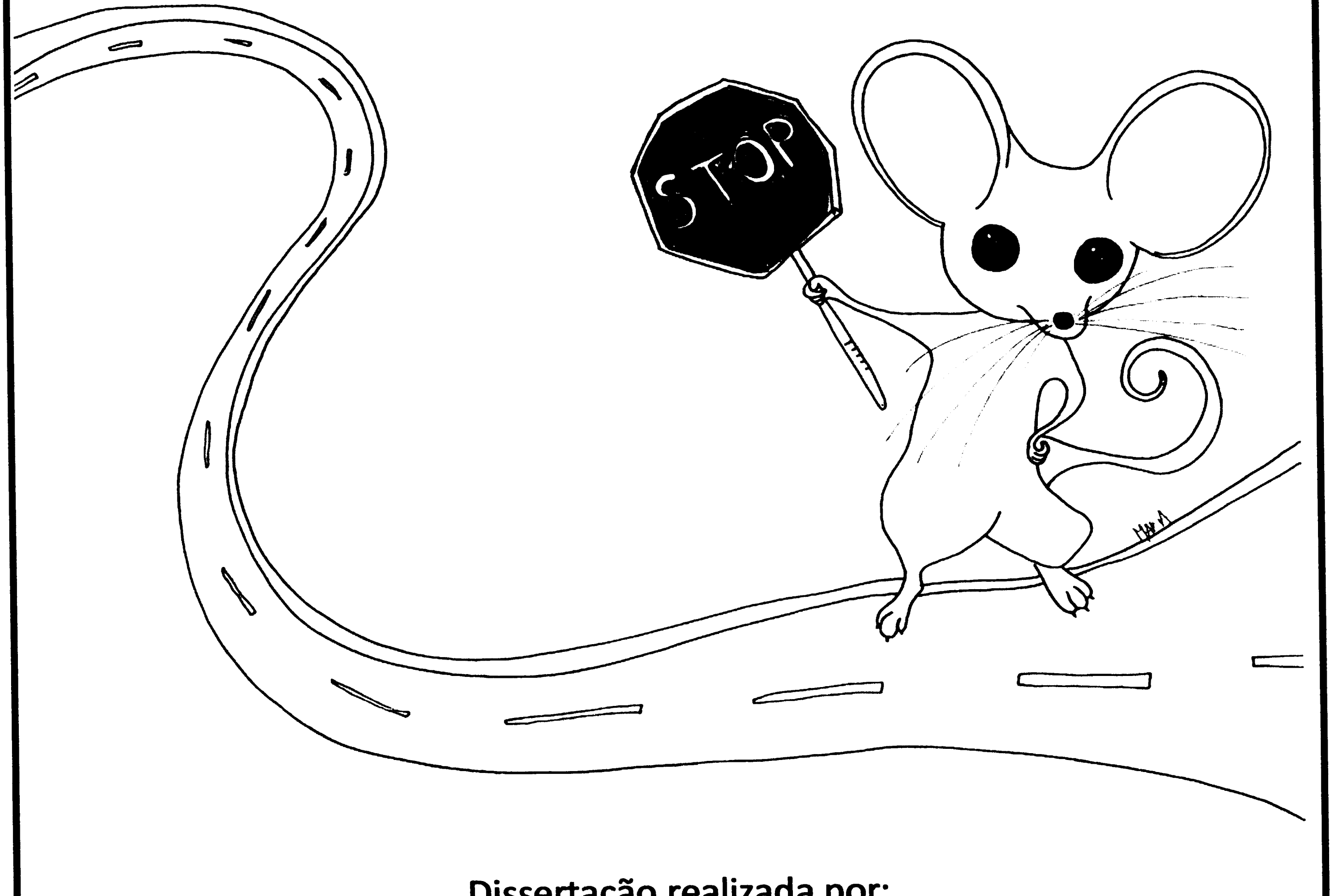


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### Artigo

# Avaliação do efeito barreira das estradas na abundância e uso do espaço do rato-do-campo (*Apodemus sylvaticus*)

**Resumo:** As estradas são essenciais ao desenvolvimento da economia mas também um dos maiores problemas de conservação. Porém, os seus efeitos nas populações de micromamíferos são controversos. Este estudo pretendeu quantificar o efeito da estrada nos parâmetros populacionais e no padrão espacial do rato-do-campo (*Apodemus sylvaticus*) incluindo os efeitos do microhabitat. Uma área de montado atravessada por uma estrada e outra sem o efeito de estrada (controlo) foram comparadas no sul de Portugal. Os parâmetros populacionais avaliaram-se pelo modelo robusto de Pollock. O efeito do microhabitat no uso do espaço verificou-se através de modelos lineares mistos generalizados (GLMM). Os resultados sugerem que a presença da estrada afecta negativamente os parâmetros populacionais do rato-do-campo. Contudo, na presença da estrada, as bermas parecem ser mais benéficas para esta espécie do que as áreas sem efeito de estrada. Os resultados revelam também a importância de diferentes características de microhabitat para cada população de *Apodemus sylvaticus*.

**Palavras-chave:** efeito das estradas, parâmetros populacionais, intensidade do uso do espaço, micromamíferos, *Apodemus sylvaticus*, modelo robusto de Pollock, GLMM

# Effects of roads on population parameters and space use of the wood mouse (*Apodemus sylvaticus*)

**Abstract:** Roads are essential for economic development but they are also a global concern in wildlife conservation. Nevertheless, there is a controversy about the effects of roads on small mammals. The main goal of this study was to quantify the effect of the road in the population parameters and in the spatial pattern of the wood mouse (*Apodemus sylvaticus*) including microhabitat effects. We compared populations of two areas: one crossed by a national road and other without the effect of a road in southern Portugal. We used Pollock's robust design to evaluate population parameters. Generalized linear mixed models were used to analyse the microhabitat effect. Our results suggest that the presence of the road negatively affects population parameters of wood mouse. However, in the presence of the road, road verges seem to be more suitable for the species than roadless areas. Our results also revealed the importance of different microhabitat characteristics, for each population of wood mouse.

**Keywords:** road effect, population parameters, intensity of space use, small mammals, *Apodemus sylvaticus*, Pollock's robust design, GLMM

# Introdução

A dissertação de Mestrado aqui apresentada encontra-se estruturada em três capítulos principais: introdução, artigo científico e conclusão. A introdução inclui um enquadramento e objectivos do estudo. O artigo científico refere-se ao estudo realizado, que de futuro será submetido a uma revista científica internacional na área da conservação da biodiversidade. As considerações finais contêm um resumo dos principais resultados e conclusões, bem como as limitações encontrados no presente estudo. As referências bibliográficas apresentadas no final da dissertação referem-se apenas às citações realizadas ao longo da Introdução e Conclusão.

Este estudo faz parte do projecto "MOVE – Avaliação dos impactes das rodovias na vida selvagem", desenvolvido na Unidade de Biologia da Conservação da Universidade de Évora.

## Enquadramento

Para além de todos os benefícios que as infra-estruturas lineares possam trazer às populações humanas, estas são actualmente um dos maiores problemas de conservação a nível mundial. O grande objectivo da recente corrente da ecologia - "ecologia de estradas" - é tornar mais harmonioso o conflito entre as infra-estruturas lineares e todo o ambiente envolvente. Um dos maiores e mais recentes desafios dos ecologistas, arquitectos e engenheiros é precisamente desenvolver ferramentas adequadas para a prevenção e mitigação dos impactos das infra-estruturas (Iuell *et al.*, 2003).

### ***Importância das estradas***

As estradas são actualmente uma das mais importantes vias de comunicação e estão estabelecidas na maior parte dos locais onde o Homem se encontra. Estas infraestruturas são manifestações físicas das relações sociais, da economia e das decisões políticas (Coffin, 2007). As estradas são essenciais para o desenvolvimento da economia promovendo uma deslocação segura e eficiente das mercadorias e pessoas (Forman *et al.*, 2003). Nalguns países, os economistas atribuem a grande relação entre as infraestrututuras e a productividade (Rosser, 2005). Contudo, as estradas são uma problemática generalizada no que diz respeito à conservação da natureza (Oxley *et al.*, 1974; Mader, 1984; Jaeger *et al.*, 2005; Ramp *et al.*, 2006; Coffin, 2007; Mcgregor *et al.*, 2008; Bissonette & Rosa, 2009; Fahrig & Rytwinski 2009). Em Portugal, aproximadamente 25% do país encontra-se sobre o efeito das estradas (Mira, 2005). O efeito das estradas não se restringe apenas à área afecta à estrada pavimentada mas sim toda uma área à volta da mesma.

## ***Efeitos negativos das estradas na fauna***

Durante as últimas três décadas, a mortalidade de vertebrados por atropelamentos provavelmente excedeu a caça como a maior causa humana para a mortalidade de vertebrados (Forman & Alexander, 1998). A mortalidade por atropelamentos é aparentemente significativa para algumas espécies classificadas como ameaçadas em vários países (Forman & Alexander, 1998). Este é o caso do Lince-Ibérico (*Lynx pardinus*) que tem a classificação de "Criticamente em Perigo", em Portugal (Cabral *et al.*, 2006; IUCN, 2010). A população de linces em Doñana é especialmente afectada pela elevada taxa de atropelamentos (Delibes *et al.*, 2000). Embora os animais de médio e grande porte (e.g. javalis (*Sus scrofa*), raposas (*Vulpes vulpes*), doninhas (*Mustela nivalis*) e genetas (*Genetta genetta*)) sejam mais fáceis de detectar na estrada, uma grande biomassa de animais pequenos é morta nas estradas. Num estudo levado a cabo no sul de Portugal por Carvalho & Mira (2010), os anfíbios e os passeriformes são um dos grupos de animais que mais frequentemente morrem por atropelamento.

Contudo, as mortes por atropelamento não são o único efeito negativo das estradas nos animais selvagens. As estradas, estruturas adjacentes (acessos pedestres, pontes, bermas empedradas, etc) e o tráfego afectam os animais de várias formas: provocam a perda e diminuição da qualidade do habitat, evitam o acesso aos recursos, dividem as populações em pequenas fracções que se tornam mais vulneráveis a eventos estocásticos negativos (Jaeger *et al.* 2005) e impedem ou dificultam o movimento dos animais (Forman *et al.*, 2003). As populações mais pequenas são uma grande fonte de problemas genéticos, tal como a perda de diversidade genética (Hale *et al.*, 2001; Keller & Largiadèr, 2003; Dixon *et al.*, 2006) e o aumento da possibilidade de extinção local (Forman *et al.*, 2003).

Os animais podem ainda evitar as estradas devido ao ruído provocado pelos veículos, pavimento das estradas ou volume do tráfego (Jaeger *et al.*, 2005). Ao ruído associa-se também a poluição provocada pelos veículos e a emissão de luzes (Jaeger *et al.*, 2005). As condições inóspitas (e.g. ausência de vegetação para abrigo) do pavimento das estradas pode inibir certas espécies de atravessarem a estrada (Jaeger *et al.*, 2005). Por fim, o facto de os animais evitarem um maior volume de tráfego previne-os de se aproximarem da estrada, evitando o seu atravessamento e diminuindo a mortalidade por atropelamento, mas aumentando a inacessibilidade dos recursos (Jaeger *et al.*, 2005).

***O caso específico dos micromamíferos***

No caso de alguns micromamíferos, estes evitam as estradas pelo facto destas estruturas apresentarem condições inóspitas, como: falta de abrigo, pavimento artificial não permeável, condições microclimáticas diferentes das ideais e alterações na vegetação das bermas (Jaeger *et al.*, 2005).

No entanto, outros autores descreveram vários benefícios das estradas na fauna, especialmente as vantagens das bermas para algumas espécies de micromamíferos (Bellamy *et al.* 2000; Forman *et al.*, 2003; Santos *et al.*, 2007). Os animais podem sentir-se atraídos para as bermas por variadas razões, mas principalmente devido ao habitat (e.g. para abrigos; espaço livre), facilidade de movimento ou disponibilidade de alimento (Forman *et al.*, 2003). Numa revisão realizada por Fharig & Rytwinski (2009) sobre os efeitos das estradas na fauna, as autoras consideraram que não há razões para o efeito negativo das estradas nos micromamíferos. Fharig & Rytwinski (2009) prevêem que podem existir populações viáveis em áreas adjacentes a estradas desde que as espécies evitem atravessamentos, não sejam perturbadas pelo tráfego e simultaneamente tenham pequenos movimentos e pequenos territórios.

Poucos estudos sobre ecologia de estradas foram levados a cabo com micromamíferos, principalmente com roedores (Rico *et al.*, 2007). Esta é provavelmente a principal razão da controvérsia sobre o efeito das estradas em micromamíferos. Acredita-se que os micromamíferos não são significativamente afectados pela presença das estradas, que as populações que vivem perto destas infraestruturas são grandes o suficiente para sobreviverem e que os indivíduos têm muitas possibilidades para atravessar as estradas (Rico *et al.*, 2007).

Apesar da espécie-alvo deste estudo ser generalista (facilmente adaptável a variadas condições ambientais), as estradas afectam esta espécie da mesma forma, porque os animais generalistas são mais propícios a aventurarem-se em ambientes estranhos, como as estradas, tornando-os mais vulneráveis à mortalidade por atropelamento (Tattersall *et al.*, 2002).

### *O rato-do-campo (Apodemus sylvaticus)*

Embora vários roedores sejam conhecidos por provocar danos em culturas, os danos provocados pelo rato-do-campo são esporádicos. Richards (1989) verificou danos provocados pelo *Apodemus sylvaticus* na beterraba sacarina (*Beta vulgaris* L.), mas só quando não há disponibilidade de alimento, o que pode ser evitado providenciando outras alternativas relativamente à disponibilidade de alimento. Os danos podem diminuir providenciando uma alternativa na disponibilidade de alimento. Os micromamíferos são animais com elevado valor ecológico uma vez que são importantes como presas (Halle, 1988; Carvalho & Gomes, 2001; Rosalino & Santos-Reis, 2002; Torre & Díaz, 2004; Mestre *et al.*, 2007), e como dispersores de sementes e esporos (Manson & Stiles, 1998; Hulme & Hunt, 1999; Wenny, 2000; Muñoz & Bonal, 2007; Pons & Pausas, 2007; Arosa *et al.*, 2010). A predação é primordial para regular as densidades de roedores evitando uma peste (Singleton & Petch 1994). O rato-do-campo é predado pelas seguintes espécies: corujas-do-mato (*Strix aluco*) (Kirk, 1992), genetas (Rosalino & Santos-Reis, 2002), raposas (*Vulpes vulpes*) (Carvalho & Gomes 2001), fuinhas (*Martes foina*) (Posłuszny *et al.*, 2007), gatos (*Felis catus*) (Baker *et* al., 2005), cobra-rateira (*Malpolon monspessulanus*) e cobra-de-escada (*Rhinechis scalaris)* (Pleguezuelos, 2003; Pleguezuelos, 2006).

*Apodemus sylvaticus* é um dos roedores mais abundantes nas florestas portuguesas (Gomes, 1986) e é facilmente capturado através de armadilhagem o que nos fornece dados robustos para análise. Esta espécie prefere sítios com arbustos altos (e.g. *Rubus sp.*) e aglomerados de troncos caídos sob cobertura arbórea densa (Gomes, 1986). Contudo, uma grande cobertura do substrato não é favorável para esta espécie (Gomes, 1986), pois dificulta o seu deslocamento. O rato-do-campo é um roedor muito adaptável, capaz de viver em todas as florestas com arbustos, campos de cultivo, áreas pastoreadas, dunas e orlas (Watts, 1969; Purroy & Varela, 2005). É predominantemente nocturna, mas apresenta um padrão bifásico durante as noites longas de inverno com picos de duas a quatro horas depois do pôr-do-sol e antes de nascer o sol (Montgomery & Gurnel, 1985). Purroy & Varela (2005) também registaram actividade diurna no verão para as fêmeas. A reprodução é dependente de vários factores, principalmente na disponibilidade de alimento e condições climatéricas (Jubete, 2007) mas para os matos mediterrânicos a actividade reprodutora está relatada entre Agosto e Abril (Moreno & Kufner, 1988; Pita, 2001; Rosário & Mathias, 2004). A dieta do rato-do-campo é principalmente granívora, mas também pode incluir plantas e artrópodes (Khammes & Aulagnier, 2007). *Apodemus sylvaticus* escava galerias ou usa cavidades naturais, como fendas em rochas ou cavidades de árvores para abrigo (Jubete, 2007). Os seus abrigos podem ser encontrados debaixo da vegetação, folhada, musgo e palha (Jubete, 2007) mas também dentro de árvores (Tattersall & Whitbread, 1994; Buesching et al., 2008). O rato-do-campo é classificado como "Least concern" em Portugal (Cabral *et al.*, 2006) e no mundo (UICN, 2010).

## ***Objectivos***

Os principais objectivos deste estudo são:

i) quantificar o efeito da estrada nos parâmetros populacionais do rato-do-campo;

ii) descrever como as estradas influenciam o padrão espacial da espécie a uma escala local baseado no número de capturas e recapturas em cada ponto de amostragem.

Para atingir estes objectivos, comparámos duas populações de rato-do-campo (fig.1) num sistema de montado: uma numa área atravessada por uma estrada nacional e outra por uma área sem estrada que funciona como área de controlo (fig.2).

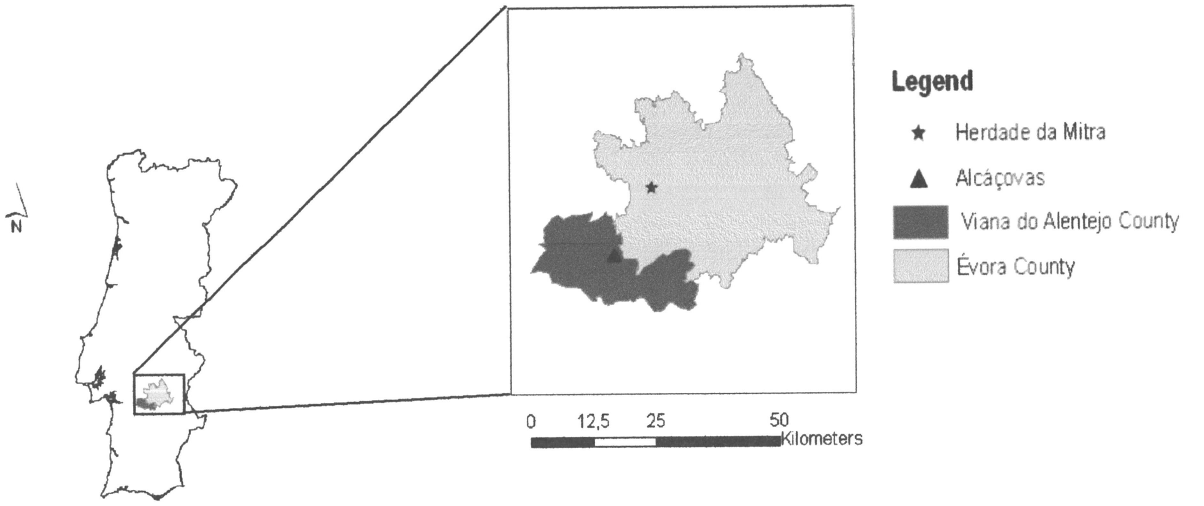


**Fig.1** – Localização da área de estudo

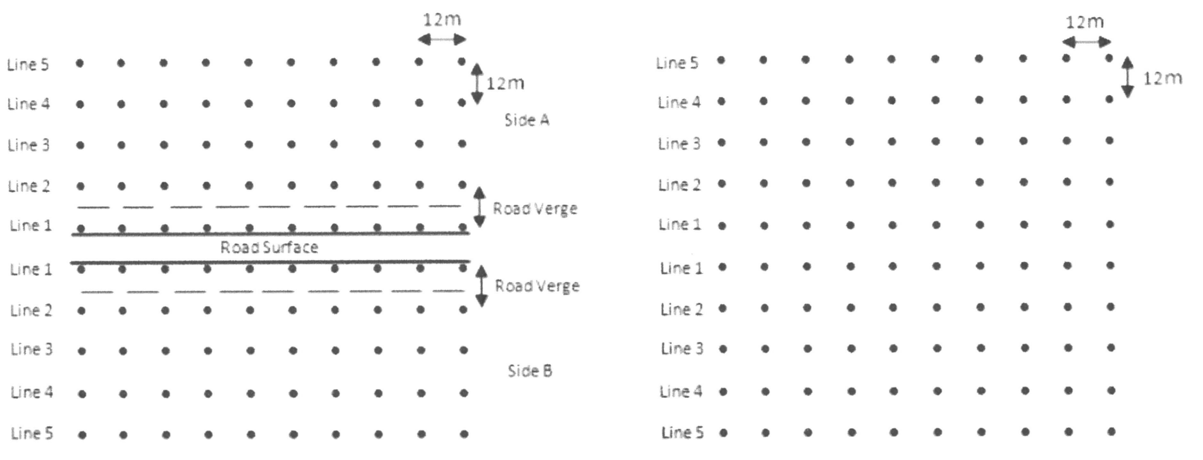


**Fig.2**- Esquema das grelhas de armadilhagem em cada local de amostragem (Local com Estrada, Alcáçovas -esquerda; local sem estrada, Herdade da Mitra-direita). Os pontos representam as armadilhas, o tracejado representa as cercas e as linhas cheias significam os limites da área de estrada pavimentada no local com estrada.

# Artigo Científico

## Effects of roads on population parameters and space use of the wood mouse (*Apodemus sylvaticus*)

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**Abstract:** Few studies of road ecology were carried out with small mammals, because there is a belief that small mammals are usually not significantly affected by the presence of roads, that populations living close to them are large enough for long term survival and small mammals have many possibilities to cross the roads. However, roads may provide negative, neutral or positive effects on small mammals. The goals of our study are: i) describe, for the first time, the effect of roads in the wood mouse (*Apodemus sylvaticus*) population parameters and ii) evaluate how roads and its surroundings affect the intensity of the wood mouse use of space, based on the numbers of captures and recaptures at each sampling location.

The wood mouse was live-trapped on two sites: (1) a section of the national road 257 (EN257) near Alcáçovas and its surroundings and (2) a similar area at Herdade da Mitra - Field Station of University of Évora, between March and August 2009. We used Pollock's robust design to access population size, survival and other population parameters at each sampling site. Generalized linear mixed models were used to evaluate the microhabitat effect on captures and recaptures of mice. Results show that populations at the roadside area have a lower survival, emigration and size than at the roadless area. At the road sampling site, the number of captures and recaptures of mice decreased with greater distances to the paved line and increased with higher values of herbaceous height, shrubs height and vegetation vertical density. At the roadless area, captures and recaptures of wood mouse were positively related with rock cover and shrub height while leaf litter and shrub cover were negatively related with these parameters. In conclusion, our results suggest that the presence of the road negatively affects population parameters of wood mouse. However, in the presence of the road, road verges seem to be more suitable for the species than roadless areas.

**Keywords:** road effect, population parameters, intensity of space use, small mammals, *Apodemus sylvaticus*, Pollock's robust design, GLMM

## Introduction

Roads are important lines for communication and are established wherever humans have settled. These infrastructures are physical manifestations of the social connections, and the economic and political decisions that lead to land use change (Coffin, 2007). Roads are essential for economic development by providing a safe and efficient mobility to commodities and people (Forman *et al.*, 2003). Economists attribute a strong correlation between infrastructure and productivity in some countries (Rosser, 2005). However, roads are also a global concern in wildlife conservation despite their overwhelming economic and social benefits (Oxley *et al.*, 1974; Mader, 1984; Jaeger *et al.*, 2005; Ramp *et al.*, 2006; Coffin, 2007; Mcgregor *et al.*, 2008; Bissonette & Rosa, 2009; Fahrig & Rytwinski 2009). In Portugal, approximately 25% of the country is under the effect of roads (Mira *et al.*, 2005) meaning not only the paved road itself but all the surrounding effect on the environment. The area affected by roads tends to grow significantly in Portugal and around the world.

During the last three decades, road collisions probably over headed hunting as the major human cause of vertebrate mortality on land (Forman & Alexander, 1998). Road-kill rates are apparently significant for a few species listed as threatened in various nations (Forman & Alexander, 1998). This is the case of *Lynx pardinus* that is classified as "Critically in Endangered" (Cabral *et al.*, 2006; IUCN, 2010). Road-kills are affecting significantly the Doñana population (Delibes *et al.*, 2000). Although medium and large mammals (e.g. boars (*Sus scrofa*), foxes (*Vulpes vulpes*), weasels (*Mustela nivalis*) and genets (*Genetta genetta*)) are more noticeable when killed on roads, a great biomass of small animals is road-killed. In a study carried out in Portugal by Carvalho & Mira (2010) amphibians and passerines were the most killed groups.

Nevertheless, road-kills are not the only negative effect of roads on wildlife. Roads, adjacent structures (pedestrian accesses, bridges, verges cobblestone, buildings, etc) and traffic affect these animals by many ways: loss and decrease habitat quality, prevent access to resources, subdivide animal populations into smaller fractions which are more vulnerable to stochastic negative effects (Jaeger *et al.* 2005) and impede animal movements (Forman *et al.*, 2003). These smaller populations typically have a greater potential of genetic problems (e.g. loss of genetic diversity) (Hale *et al.*, 2001; Keller & Largiadèr, 2003; Dixon *et al.*, 2006) and an increased chance of local extinction (Forman *et al.*, 2003).

Animals may avoid roads because of the noise provided from vehicles, road pavement or traffic volume (Jaeger *et al.*, 2005). Noise avoidance of animals from vehicles results from the noise, light and pollutants provided from vehicles; the road pavement avoidance occurs when animals avoid roads because of road inhospitable conditions; the avoidance of traffic volume prevents animals from approaching or crossing roads, decreasing traffic mortality, but increasing resource inaccessibility (Jaeger *et al.*, 2005). In the case of small mammals, they may avoid road surface because roads provide inhospitable conditions, such as: lack of shelter, artificial non-permeable pavement, different microclimate conditions and changes in vegetation at the edge between roads and adjacent habitat (Jaeger *et al.*, 2005).

However, other authors had described several benefits of roads on wildlife, specially the benefits of road verges on some species of small mammals (Bellamy *et al.* 2000; Forman *et al.*, 2003; Santos *et al.*, 2007). Animals can be attracted to road verges for a variety of reasons, but mainly because of habitat (nesting, living space), facility of movement, or food resources (Forman *et al.*, 2003). In a review made by Fharig & Rytwinski (2009) about road effects on wildlife, they have considered that there are no reasons for negative effects of roads on small mammals. They predict that viable populations can exist within areas bounded by roads when species avoid going onto roads but are not disturbed by road traffic, and simultaneously have smaller movement ranges and smaller territories.

Few studies of road ecology were carried out with small mammals, particularly with rodents (Rico *et al.*, 2007). This is probably the main reason for the controversy about the effects of roads on small mammals. There is a belief that small mammals are usually not significantly affected by the presence of roads and highways, that populations living close to them are large enough for long term survival and that small mammals have many possibilities to cross the roads (Rico *et al.*, 2007). Even though the subject of our study (*Apodemus sylvaticus*) is a generalist species (easily adapted for several environmental conditions), roads

## 2. Methods

### *2.1. Study area*

The study was carried out in two areas of southern Portugal: (1) a section of the national road 257 (EN257) near Alcáçovas ($38^0$24'09''N, $8^0$06'52''W) and its surroundings and (2) a similar area at Herdade da Mitra - Field Station of University of Évora ($38^0$31'24''N, $8^0$01'11''W) (fig.1). Sites 1 and 2 are 16 km apart and the distance between site 2 to the nearest paved road is 1km (fig. 1).

The study areas have the typical Mediterranean climate pattern of wet winters and dry summers. In 2009, the mean rainfall was 1,4mm, and the mean annual minimum and maximum temperatures were 8,4ºC and 22,2ºC, respectively (CGE, 2009).

As our goal was to evaluate the effects of roads on small mammals, mainly wood mouse (*Apodemus* sylvaticus), we aimed to select two sites as similar as possible in terms of vegetation structure and composition and agricultural activities. The main differences between the two study sites should be the presence/absence of the road. However, our selection had to be constrained to the available landscape and the authorization of the landowners.

Both sites are embedded in a montado landscape, a traditional Mediterranean agro-silvo-pastoral system of evergreen tree stands of cork (*Quercus suber*) and/or holm (*Q.rotundifolia*) oaks with herbaceous and shrub strata. In the studied areas both tree species exist along with several shrub species including the sage-leaved rockrose (*Cistus salvifolius*), the crispus rockrose (*Cistus crispus*), the rosemary (*Rosmarinus officinalis*), the broom (*Genista triacanthos*) and the spurge flax (*Daphne gnidium*). The killamey strawberry tree (*Arbutus unedo*) and *kermes oak* (*Quercus coccifera*) are also present as shrubs and/or small trees. Nevertheless, the proportion of area covered by shrubs is slightly greater in roadless area. Roadside area is crossed by a national road (fig.2) with an average traffic volume of 4879 vehicles per day (Estradas de Portugal, 2005). This site is composed of two fenced private properties, one on each side of the road, what allows for the establishment of a slightly different vegetation structure on each road verge. Shrub cover is higher on side A, and

**herbaceous cover is higher on side B. Additionally, cattle was present at Side A eight days between April and May (3 animals per hectare).**

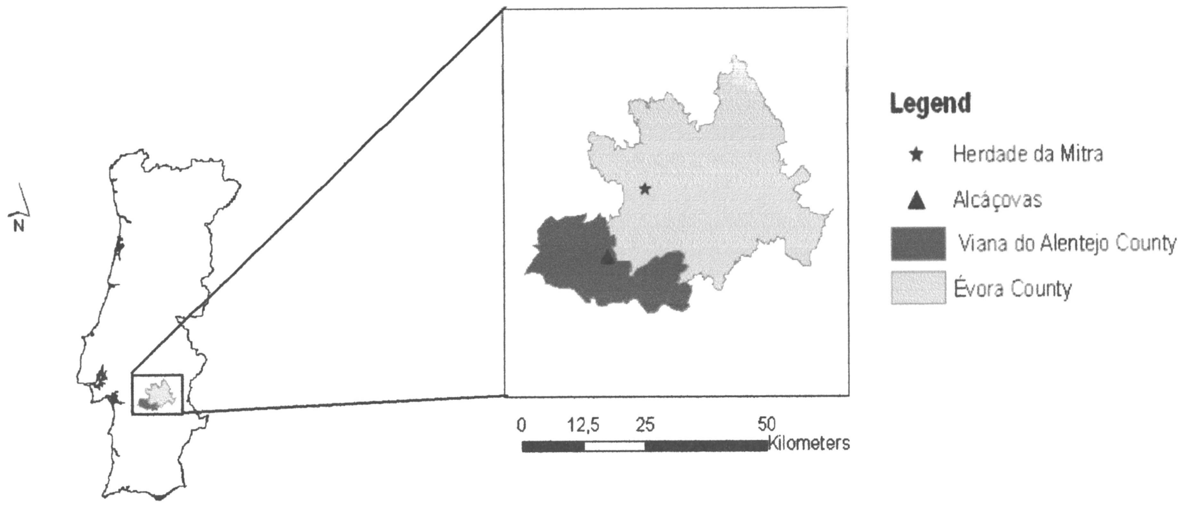


**Fig.1** –Location of study area

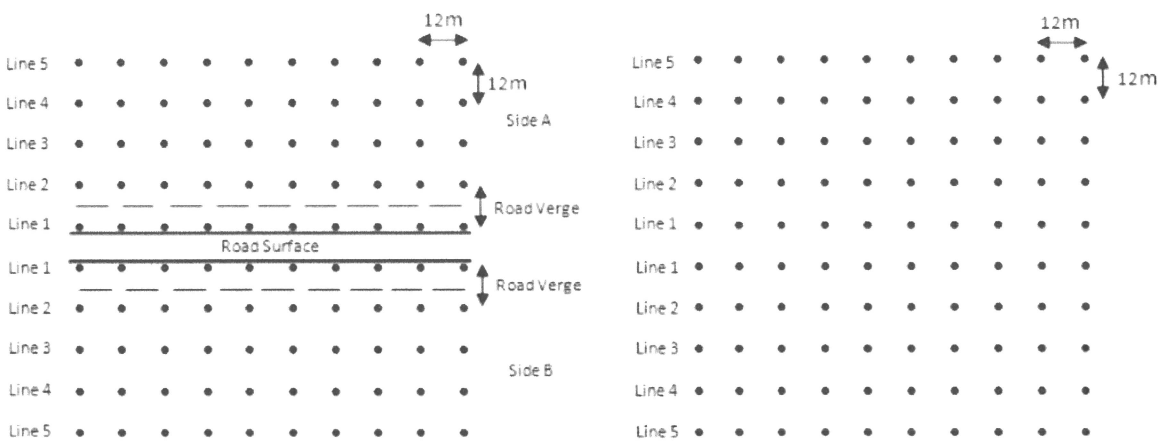


**Fig.2-Live trapping grid at each study site (roadside-left; roadless-right). Points represent the traps and the dashed lines represent the road fence and solid lines represent the limits of the paved road at roadside.**

### *2.2. Trapping and marking of individuals*

**Small mammals were sampled at the two study sites every four weeks between March and August of 2009. In each trapping site a square grid of 100 (10 x 10) Sherman traps (8x9x23 cm) were placed at about 12 m apart from each other. Trapping grids are one of the most**

suitable methods to study population size/density (Gurnell & Flowerdew, 2006) which is one of our main purposes. On the first trapping occasion we registered each trap location by GPS and marked it with strip to keep the trapping design as accurate as possible along the entire study.

At each site we conducted six trapping sessions of four trapping nights leading to a total trapping effort of 2400 trap-nights (6x4x100). Traps were baited with oats and sardines, using cotton for bedding and were checked once a day at sunrise (e.g. Mira, 1990). Bait was replaced at the middle of the trapping session or whenever needed (e.g. dry, presence of ants).

We have used the capture-mark-recapture (CMR) methodologies to evaluate population parameters and space use. At each trapping day all unmarked animals caught were marked and released back into the population. With recaptured animals we had the entire history for every animal at the end of the study (Pollock *et al.*, 1990).

Captured small mammals were identified to the species level, sexed, measured and weighted. For body measures we used a rule (1mm precision) and a 60g scale (Pesola®, 0,5 g precision) was used to weight animals. Additionally, each individual was marked subcutaneously with an individual PIT (Passive Integrated Transponder) tag that is composed of an electromagnetic coil, tuning capacitor, and microchip sealed in a tubular glass enclosure (McCormick & Smith 2004). The tag is *passive* because it is dormant until activated by a hand-held reader with which the researcher scans an animal. If a PIT tag is present, the reader generates a close-range, electromagnetic field that immediately activates the tag, which transmits its number (Gibbons & Andrews, 2004). We used TX148511B PIT tags (8.5mm X 2.12mm, 0.067g; Biomark, USA) and the petSCAN RT100 V5 reader (Real Trace, France).

### *2.3. Microhabitat characteristics*

In order to access the influence of microhabitat characteristics in the space use of the wood mouse, on each trapping session we measured 10 microhabitat variables (table 1) at each trapping point using a wood square (1x1m) centred at each trap.

To soften measurement errors associated with visual estimations, all the proportion values were classified into four classes: class 1[0%-25%], class 2 [26%-50%], class 3(51%-75%)

and class 4(76%-100%). We assessed ***Herbaceous Mean Height***, ***Shrubs Mean Height*** and ***Trees Mean Height*** by measuring the maximum height of each stratum at the four vertices and at the centre of the square. The vertical density of vegetation was measured at the centre of the square using a vertical scored ruler of 150cm long. We previously attributed a score for each 10 cm interval decreasing from top to bottom - to obtain a weighted vertical density considering that vegetation cover close to the ground would be more important for small mammals due to their anti-predatory behaviour and resource availability. We registered the proportion occupied by the vegetation at each 10cm, multiplied it by the weighting factor and added these values to obtained a vertical density of vegetation.

### *2.4. Data analysis*

#### ***2.4.1. Estimation of population parameters***

We used the Robust Design capture-recapture model (Pollock *et al.* 1990) in Program MARK 6.0 (White & Burnham, 1999) to estimate population parameters. The robust design consists of two levels of sampling periods. The primary sampling occasions are separated by a relatively long period of time over which the population is assumed to have gains (births and immigration) and losses (death and emigration). At each primary sampling occasion there are several secondary sampling occasions. Secondary sampling occasions occur over a very short time interval. The population is assumed to be closed between secondary sampling occasions, although generalizations to this exist. With PIT tags as an individual identification we may construct a capture history for each animal, in which **1** means a capture at a specific sampling occasion and **0** means that the animal was not captured at that occasion (Cooch & White, 2009). The design can be used to estimate the population size for each of the primary sampling periods (*N*) assuming that the population is constant over the secondary sampling periods within each primary period. We also can estimate survival rates (*S*), numbers of temporary emigration ($\gamma''$) and return rate of temporary emigrants ($1-\gamma'$) trough this method (Pollock *et al.*, 1990; Kendall *et al.*, 1997; Cooch & White, 2009). We opt to refer the return rate of temporary emigrants to as "immigrants". The robust design in Mark 6.0, also calculates capture (*p*) and recapture (*c*) probabilities.

We developed four different models with the logit link function (Lebreton *et al.*, 1992) differing in the assumptions concerning sources of variation in capture probability: the null model M0 (no variation between individuals or over time); the heterogeneity model Mh (individual heterogeneity due to age, sex, etc.); the time variation model Mt (capture probabilities can change along the time) and the behaviour model Mb (animals have different responses to capture and recaptures) (Amstrup *et al.*, 2005). A fifth model (M1) was constructed assuming survival (S), emigration ($\gamma''$) and "immigration" ($1-\gamma'$) constant and the other parameters (*p, c* and *N*) changing along the time. Finally we selected the "best" model, for each study site, from this set of models on the basis of Akaike Weights (Wi) using the Akaike's information criterion corrected for small samples (AICc) (Burnham & Anderson, 2002).

### 2.4.2. Modelling space use

We accessed the microhabitat effect on *Apodemus sylvaticus* captures with generalized linear mixed effects models (GLMM), with poison distribution error, (Zuur *et al.*, 2009) using the total number of animals caught (sum of captures and recaptures) at each trap, at each monthly sampling occasion as the response variable and 10 microhabitat explanatory variables (Table 1).

Additionally, to the 10 vegetation related variables we also used the distance from the central line of the grid to account for the possible road or edge effects and the month of trapping session (Table 1). The distance from the central line was coded in five classes (1 to 5) corresponding to the trapping lines increasingly distant from the centre of the grid (see figure 2 for details). Two different models were developed, one for each trapping site.

Previously to statistical analyses, we applied the logarithmic transformation to explanatory continuous variables that had a skewed distribution to approach normality and soften the effects of extreme values (Zar, 1999). Collinearity between each pair of explanatory variables was evaluated on SPSS 18.0 (Spss Inc, 2009) with the Spearman correlation coefficient. Only the most biologically meaningful variable from each pair of highly correlated variables ($r > 0{,}7$) was selected for further analysis (Tabanick & Fidell, 2001).

At a first step, the effect of each explanatory variable on captures of *Apodemus sylvaticus* was evaluated trough a univariate GLMM. Subsequently, all the variables considered significant ($p<0,05$) at the previous stage were used to the development of a multivariate GLMM (Zuur *et al.*, 2007). Best multivariate model, for each site, was chosen on the basis of AIC (Burnham & Anderson, 2002).

Mixed-effects models include a fixed and a random component (Zuur *et al.*, 2009) and they are appropriate for representing clustered data – for example when data are gathered over time on the same individuals, as in our case (Fox, 2002). We used GLMM to remove the effect of the month (random component) between trapping sessions. Modelling was done on R 2.10.1 (R Development Core Team, 2009).

**Table 1**- Response and explanatory variables. *Trees Mean Height* was clustered into classes to reduce probable measurement errors.

| Variable set | Acronyms | Description | Type(Unit) | Transformation |
|---|---|---|---|---|
| Response variable | ApCR | Number of captures and recaptures of *Apodemus sylvaticus* at each trapping point, per month | Ordinal (n) | ------- |
| Explanatory variables | LIN | Line of trap point concerning its distance to the central line of the grid (see fig. 2) | Categorical(1/2/3/4/5) | ------- |
| | MON | Month of the trapping session | Categorical(1/2/3/4/5/6) | ------- |
| | LL | Class of proportion of litter leaf cover | Categorical(1/2/3/4) | ------- |
| | ROC | Class of proportion of rock cover | Categorical(1/2/3/4) | ------- |
| | BS | Class of proportion of bare soil | Categorical(1/2/3/4) | ------- |
| | HER | Class of proportion of herbaceous cover | Categorical(1/2/3/4) | ------- |
| | SHR | Class of proportion of shrub cover | Categorical(1/2/3/4) | ------- |
| | TRE | Class of proportion of tree cover | Categorical(1/2/3/4) | ------- |
| | MHER | Herbaceous Mean Height | Continuous (cm) | Log(x+1) |
| | MSHR | Shrub Mean Height | Continuous (cm) | Log(x+1) |
| | MTRE | Tree Mean Height | Categorical(1/2/3) | ------- |
| | STIC | Vegetation vertical density | Continuous(cm) | Log(x+1) |

## 3.Results

### *3.1. Total number of animals captured (captures and recaptures)*

During the 4800 trap nights we captured a total of 119 individuals. In roadside we recorded 259 captures of 52 different individuals, 39 of which were recaptured at least once. In roadless area we obtained 280 captures of 67 different individuals, 44 of which were recaptured at least once. We may observe the monthly captures and recaptures at figures 3 and 4.


**Fig.3**- Number of mice caught (C- captures; R - recaptures) at each trapping session at the roadside area. The recaptures refer to different animals and not to multiple recaptures of the same individual.

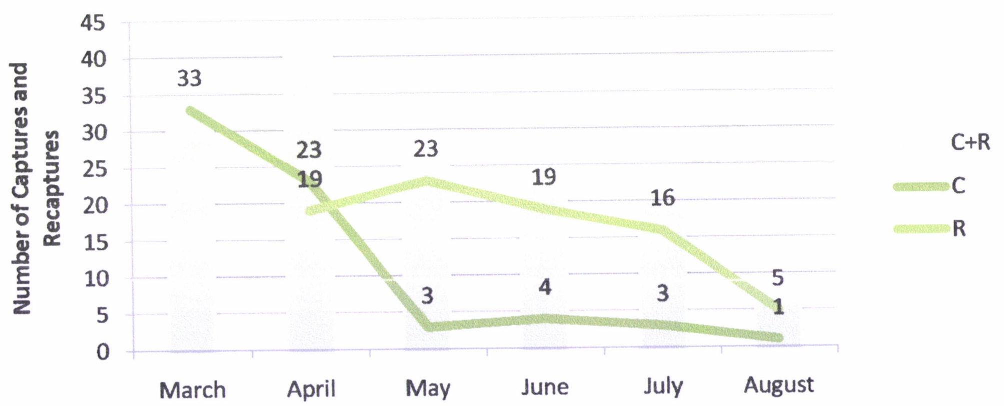


**Fig.4**- Number of mice caught (C- captures; R - recaptures) at each trapping session at the roadless area. The recaptures refer to different animals and not to multiple recaptures of the same individual

### *3.2.Estimation of population parameters*

The estimation of population parameters was conducted only with data obtained on March, April, May and June because the low number of captures in July and August drawn into poor estimations of the parameters if this data were included in the analysis. The top-ranked model for both sites was model M1 that considered survival, emigration and immigration as constants during trapping sessions (roadside: AICc=193,94; roadless: AICc=135,36; table 2). According to this model, survival rate is higher at the roadless site (*S*=98%; S.E.=0,0) than at the roadside (*S*=63%; S.E.=0,06) (table 3). The same tendency was observed for temporary emigration (roadless: 37%, S.E.=0,00; roadside: 20%, S.E. = 0,08) and "immigration" (roadless: 0%, S.E.= 0,00; roadside= 100%; S.E.=0,00). Although the low SE might indicates caution on the interpretation of these results[1]. On both places population size increased from March to April and decrease until June. The size estimated for the population is higher at roadless.

**Table 2**- Models used for estimation of population parameters at roadside and roadless areas. Models were evaluated using Akaike's Information Criteria adjusted for small sample size. The numbers in bold identify the best model (with the lower AICc).The number of parameters ***K*** (number of parameters estimated) and deviance (-2[log-likelihood]) are also given for each model.

| Roadside | | | | Roadless | | | |
|---|---|---|---|---|---|---|---|
| Model | AICc | K | Deviance | Model | AICc | K | Deviance |
| M1 | **193,94** | 25 | 170,04 | M1 | **135,36** | 25 | 244,43 |
| Mb | 202,88 | 13 | 209,36 | Mb | 142,00 | 30 | 238,11 |
| M0 | 204,18 | 10 | 217,56 | M0 | 149,51 | 24 | 261,10 |
| Mh | 210,83 | 33 | 163,85 | Mh | 172,01 | 14 | 307,48 |
| Mt | 220,42 | 25 | 196,52 | Mt | 187,65 | 10 | 332,06 |

1 When our real parameter estimates are 0,999 or 1,0 and standard error is 0 or 1 (or real close), maybe our estimates are on a boundary and we have got one of two situations: 1) parameter really is 0 or 1, or (2) you do not have enough data to estimate the parameter.

**Table 3**- Population parameters according model M1 for populations at roadside and roadless areas. Survival (S), emigration (γ''), return rate of temporary emigrants (1-γ') and population size (N).

| Roadside | | | Roadless | | |
|---|---|---|---|---|---|
| Parameter | Estimate | S.E. | Parameter | Estimate | S.E. |
| S | 0,63 | 0,06 | S | 0,98 | 0,00 |
| γ'' | 0,20 | 0,08 | γ'' | 0,37 | 0,00 |
| 1-γ' | 1,00 | 0,00 | 1-γ' | 0,00 | 0,00 |
| N March | 21,00 | 0,00 | N March | 33,00 | 0,00 |
| N April | 29,00 | 0,00 | N April | 41,00 | 0,00 |
| N May | 23,00 | 0,00 | N May | 30,22 | 4,17 |
| N June | 18,00 | 0,00 | N June | 23,00 | 0,00 |

*3.3.Microhabitat influence on captures/recaptures*

To study the influence of microhabitat on the captures and recaptures of wood mouse we used all trapping occasions (between March and August).

Tree cover and tree height were correlated (roadside: *Rs* =0,81; roadless: *Rs* =0, 79) so, we discarded tree height from further analysis because it is more prone to measurement errors. GLMM univariate models with month as random effect revealed that at roadside captures of wood mouse were higher in lines adjacent to the road when compared with other lines (see table 4)[2]. Five of the microhabitat variables were positively related with captures and recaptures of *Apodemus sylvaticus* at this sampling site: herbaceous cover, shrub cover, herbaceous height, shrub height and vegetation vertical density. The only significantly negative univariate variable was the bare soil cover (see table 4). When the significant variables were considered all together the best model showed that the distance from the road was negatively related with number of captures (LN 2: $\beta$=-0,902; *p*= 0,001; LN 3: $\beta$=-0,782; *p*=0,002; LN 4: $\beta$=-0,441; *p*=0,053; LN 5: $\beta$=-0,003; *p*= 0,98) and

[2] For categorical variables program R always compares higher level categories with the lowest level category of the variable. Categorical variables are considered as significant (*p*<0,05) when they had at least one level of the variable considered to be significant.

three microhabitat variables were positively related with the captures of *Apodemus sylvaticus:* herbaceous height ($\beta$=0,357; *p*=0,042), shrub height ($\beta$=0,759; *p*=0,000) and vegetation vertical density ($\beta$=0,385; *p*=0,141). The model explained 14% of the deviance for *A. sylvaticus* number of captures and recaptures at roadside.

At the roadless sampling site, univariate GLMM models, with month as the random effect, revealed that three of the microhabitat variables were positively related with the number of captures and recaptures of wood mouse: proportion of rocks, bare soil and shrub height (see table 5). On the other hand, other two microhabitat descriptors were negatively related with wood mouse presences: shrub and tree cover (table 5). Mice were also less captured in areas of highest leaf litter cover (LL2: $\beta$=0,337; *p*=0,115; LL3: $\beta$= -0,038; *p*=0,864; LL4: $\beta$= -0,508; *p*=0,014). In this site, the distance to the center of the grid (LIN) has different directions of association with captures and recaptures of the wood mouse (table 5). The best multivariate model showed that *Apodemus sylvaticus* was more captured in areas with higher cover of rocks (ROC2: $\beta$=0,627, *p*=5,42e-04; ROC3: $\beta$=0,923; *p*=2,84e-04; ROC4: $\beta$=0,826; *p*=0,008),shrub height ($\beta$=0,479; *p*=0,016) and at the border of the grid (LIN5:$\beta$=0,386; *p*=0,077). On the other hand the species was significantly less captured in areas with higher litter cover (LL2: $\beta$=0,058; *p*=0,792; LL3: $\beta$=-0,361; *p*=0,121; LL4: $\beta$=-0,680; *p*=0,002). Multivariate model (obtained on the basis of $AIC_C$ value) also considered the variable of shrub cover, but it was only significant at univariate level (see table 5). The deviance explained by the final model for the roadless area was 16%.

**Table 4** - Significant variables for GLMM univariate model at roadside area. Variables in bold were selected in the multivariate model.

| | *β* | *p* |
|---|---|---|
| **LIN2** | **-1,360** | **0.000** |
| **LIN3** | **-1,213** | **0.000** |
| **LIN4** | **-0,870** | **0.000** |
| **LIN5** | **-0,227** | **0.195** |
| BS2 | -1,057 | 0.002 |
| BS3 | -0,410 | 0.367 |
| BS4 | -0,296 | 0.769 |
| HER2 | 0,466 | 0.008 |
| HER3 | 0,151 | 0.485 |
| HER4 | 0,439 | 0.027 |
| SHR2 | 0,743 | 0.002 |
| SHR3 | 0,783 | 0.002 |
| SHR4 | 1,213 | 0.000 |
| **MHER** | **0,758** | **0.000** |
| **MSHR** | **1,201** | **0.000** |
| **STIC** | **1,289** | **0.000** |

**Table 5** - Significant variables for GLMM univariate model at roadless area. Variables in bold were selected in the multivariate model.

| | *β* | *p* |
|---|---|---|
| **LIN2** | **-0,187** | **0.420** |
| **LIN3** | **-0,495** | **0.051** |
| **LIN4** | **0,445** | **0.026** |
| **LIN5** | **0,430** | **0.032** |
| **LL2** | **0,337** | **0.115** |
| **LL3** | **-0,038** | **0.870** |
| **LL4** | **-0,051** | **0.014** |
| SN2 | 1,15 | 0,46 |
| SN3 | 0,87 | 0,03 |
| **ROC2** | **1.031** | **1.32e-10** |
| **ROC3** | **1.133** | **6.86e-07** |
| **ROC4** | **0,984** | **0.001** |
| **SHR2** | **-0,706** | **0.002** |
| **SHR3** | **-0,734** | **0.001** |
| **SHR4** | **-0,180** | **0.407** |
| TRE2 | -0,115 | 0.614 |
| TRE3 | -0,288 | 0.331 |
| TRE4 | -0,371 | 0.014 |
| MHER | -0,504 | 0.060 |
| **MARB** | **0,763** | **2.98e-05** |

## 4. Discussion

Taken all together, our results suggest that the presence of the road affects population parameters and that roadless areas, as a whole, are more suitable for wood mice when compared with road influenced areas. However, in the presence of the road, areas nearest to the road (e.g. road verges) seem to be more suitable for the species than off road areas.

Our results also revealed the importance of different microhabitat characteristics, for each population of wood mouse.

*Population parameters*

Although there are higher numbers of *Apodemus sylvaticus* in the roadless area, a seasonal pattern of abundance occurred on both sites which has already been reported for the Meditteranean region, at Herdade da Mitra (Pita *et al.*, 2003; Rosário & Mathias 2004) and other regions like France (Ouin *et al.*, 2000), Britain (Gurnel, 1978), Northern Ireland (Montgomery, 1989) and Iceland (Bengtson *et al.,* 1989). In fact, the population size of the wood mouse was higher in spring (March, April, May) than in summer (June, July, August – data up to June for population size estimation, but low numbers of captures on the other months also suggests very low numbers). In addition, Rosário & Mathias (2004) also observed a decrease of reproductive activity in late spring and summer, when precipitation ceased. Animals only became reproductively active again in September, when temperatures decline after the first rains. Our data gathered from March to August suggested the same reproductive activity pattern (data not shown). Butet *et al.* (2006) reported a dispersion of *A. sylvaticus* from hedges to crop fields (600/700m about) during summer and also registered a low abundance of individuals during the same season and high numbers of mice at autumn and winter. In our sampling sites surroundings (less than 1 km away) there are several small crop fields so, it is possible that the low number of animals caught during summer months may be partially explained by this kind of short distance migrations. Our results suggest that the presence of a road does not affect this seasonal pattern of *Apodemus sylvaticus*, but may alter other population parameters.

The population of Herdade da Mitra (roadless) has a higher survival rate than the population of the roadside. This difference may reflect the possible collisions with vehicles, contributing to mice mortality (Clevenger *et al.*, 2003) and a reduction in habitat quality and decreasing resource availability on the roadside (Forman *et al.*, 2003). Although we did not collect systematically data from road-kills we did not observe any carcasses when travelling along the road during the five consecutive days of each trapping period. Nevertheless, small-bodied animals like amphibians, passerines, or small mammals, remain fewer time (less than one day) on the traffic lane (Mira, unpublished data) what certainly has prevented the detection of road-kills between the 5-day trapping periods. This must have lowered the probability of detecting a dead tagged animal.

Even if our data is not robust enough to access a barrier effect of the road (Fahrig & Rytwinski, 2009) and animal movements were not analysed, we registered twice as much crossings between central lines at the roadless area than road crossings (data not shown) what may suggest a tendency of road avoidance by mice. The width of the road (Rico *et al.*, 2007) and the road surface itself (McGregor *et al.*, 2008) might also be factors influencing road avoidance behaviour. McGregor *et al.* (2008) predicted that if small mammals avoid the road surface, their densities should be higher near roads. This statement is in accordance with our results, because we captured more mice in line traps near roads, mainly on road verges. Although our results may be based on low numbers of events we did find some interesting trends on the space use of *Apodemus sylvaticus* in the roadside areas.

While interpreting the emigration and "immigration" results we have to bear in mind that parameters calculated through MARK relate both to temporary emigrants. Therefore, the "immigration" term relates to the return rate of temporary emigrants to the studied areas. Consequently, our data suggests that mice leave the roadless area at higher rates and do not return. This may mean that a less disturbed habitat - roadless - sustains a higher number of animals (N from March to June is always more than 1,2 fold higher in the roadless area) and that each animal has a greater chance of surviving longer (survival in the roadless area is 1,56 fold higher). The highest number and survival of animals in the roadless area may prevent a great proportion of animals from establishing territories in the area and therefore some are forced to leave and search for new territories. Indeed, *A. sylvaticus* are known to have a territorial behaviour (Randolph, 1977; Tew & Macdonald, 1994; Buesching *et al.*, 2008). On the roadside the number of individuals, their survival and emigration is lower while the return of emigrants is higher when compared to the roadless area. Probably the presence of the road diminishes the quality of the habitat, reducing the availability of resources (e.g. space, food, shelter, mates) forcing animals to have larger home ranges. Therefore, this area would sustain fewer animals forcing them to use more often (lower emigration and higher return rate of temporary emigrants) the available resources which may be better in the immediate vicinity of the road where we found significantly higher abundances of mice. Moreover, lower survival means higher chances of occupying empty territories that are available to be (re)colonized.

Another reason for the high captures and recaptures of mice in road verges is probably the fact that road verges may act as ecological corridors for mice dispersion (Bennett, 1990; Bellamy *et al.*, 2000).

*Microhabitat influence on total captures*

Our results support the idea of the high importance of vegetation cover for small mammals which are known to respond strongly to plant community structure (Bissonette & Rosa 2009).

At the roadside area, shrubs and herbaceous heights are strongly positively related with the number of captures and recaptures of the wood mouse. Shrubs are an important part of the microhabitat of wood mouse in Mediterranean landscapes, once they provide shelter from ungulates (Muñoz *et al.*, 2009) and predators (Muñoz & Bonal, 2007) and more accessibility to seeds (Khidas *et al.* 2002). Mice also may hide acorns from predators under shrubs (Muñoz & Bonal, 2007). In the mediterranean context, higher shrubs are associated to lesser livestock and human perturbation and also to a greater diversity of fruits (e.g. *Arbutus unedo* and *Pyrus bourgaeana*). In our study area, we found *Arbutus unedo* at edge lines in the roadless area and *Pyrus bourgeana* at road verges which enhances habitat suitability for the wood mouse. Pita *et al.* (2003) also registered a positive association between the abundance of *A. sylvaticus* and shrubs height for the same region 11 years earlier.

Our result for the positive relation between captures of wood mouse and herbaceous height is in accordance with Marsh & Harris (2000) that reported that *A. sylvaticus* was more abundant at higher height of the herbaceous stratum. Similar to shrubs height, tall herbaceous allow wood mouse to hide from predators. The vegetation vertical density is significant only in the univariate analysis. However, vertical density of vegetation is an important feature of the habitat for the anti-predatory strategy of the small-mammals particularly when mammal carnivores and birds of prey co-exist in the same habitat. In fact, in the roadless area we found tracks and faeces of genets (*Genetta genetta*) and red-foxes (*Vulpes vulpes*) and at least one common buzzard (*Buteo buteo*).

Wood mouse is the most eaten prey of genets in Portugal (Rosalino & Santos-Reis 2002). In the presence of terrestrial and aerial predators, the greater density of vegetation simultaneously at the ground level and above should decrease predation risk.

Although broadly roads affect negatively mice survival, in road environments small mammals mostly use the verges, i.e. the areas immediately adjacent to the road pavement, which seem to have more suitable microhabitat conditions (Bellamy *et al.*, 2000; Bissonette & Rosa, 2009). In fact, road verge vegetation usually presents a higher herbaceous and shrub cover when compared with the surrounding areas. These characteristics provide better availability of food (Fahrig & Rytwinski, 2009), lower disturbance due to grazing (Santos *et al.*, 2007), higher cover and allows connections between populations (Meunier *et al.*, 1999).

Our results showed that at the roadless area higher abundance of rock encroachments, taller shrub and traps located at lines in the border of the trapping area promote the captures and recaptures of the wood mouse.

Rocks allowed mice to find protection against predators by constructing burrows underneath them or simply sheltering in the rock fissures (Khidas *et al.*, 2002). Several times, we have observed wood mice hiding in fissures of rocks or entering the gaps beneath them after being released from handling. We also observed arboreality in wood mouse after release, especially in the areas close to the road. Arboreality may offer small rodents protection from ground predators (e.g. foxes *Vulpes vulpes*), cover from raptors and owls, and even though some predators (e.g. stoats, weasels and genets) are light and agile enough to climb, they may be isolated on different branches to those being used by rodents (Buesching *et al.*, 2008).

At the roadless area we registered a significantly greater number of captures at the extreme trap line (Line 5). This phenomenon has been reported as the edge effect in studies using trapping grids (Tanaka, 1972; Mendel & Vieira 2003). The traps on the edge of a trapping grid have higher probability to be visited by animals settling in the closer area outside de quadrant and by the animals that immigrate from other sites or whose home ranges sporadically encompass that area (Tanaka, 1972). We achieved some unexpected results in the final model for the roadless area namely negative correlations between captures of wood mouse and litter cover and shrub cover (the later only in the univariate analysis). Pita *et al.* (2003) reported a higher abundance of *Apodemus sylvaticus* in the presence of high levels of leaf litter cover in a nearby area, in a one year study. Our data corresponds only to six months but may be comparable to this study once Pita *et al.*

(2003) did not find significant seasonal differences in litter cover along the macchia communities (wet season= 56,45 ± 2,32; dry season= 60,35 ± 2,53). Wood mouse is basically a granivorous and a secondary insectivorous (Khammes & Aulagnier 2007). Higher leaf litter cover is often associated with higher abundances of insects, and positive associations between leaf litter and numbers of captures would be expected. In our study area, lower litter cover is associated with higher rock cover which is in turn significantly positively associated to higher abundances of the wood mice.

Therefore, probably cover from predators provided by rocks is more important than secondary prey availability enhanced by litter. Pita *et al.* (2001) gathered data from a fenced area with a much higher density of shrubs providing mice with a lower human and predator pressure. Concerning shrub height, our result is not in accordance for what is described for wood mouse (Boitani & Molinari, 1985; Khidas *et al.*, 2002; Pita *et al.*, 2003; Torre & Díaz 2004). Once again, this result may be explained by the regular presence of rocks that is strongly positively related with the captures and recaptures of mice. It is possible that due to the higher availability of rocks in the roadless area, these are acting as the most important refuges against predators, as suggested by Khidas *et al.* (2002), having a similar ecological role to the one attributed to the shrubs at the roadside.

In conclusion, relatively to population parameters, at roadside area, populations are smaller and have lower survival and emigration rates. The roadless area has a lower return rate of emigrants. Some of these differences may reflect the small differences concerning microhabitat conditions between both sites as it was not possible to found areas that were exactly equal. However, despite the lower densities found in the roadside area, the lower survival is consistent with the hypothesis of increased mortality due to car hits. Moreover, we have shown that microhabitat on the verges is more suitable that the one found in the immediate adjacent areas and that verges may act as a valuable habitat for the mice that tend to concentrate on these areas.

Our research was a pilot study that took place along six months only, and partially on summer. This season is usually a critical period for wood mouse (Gurnel, 1978; Bengtson *et al.*, 1989; Montgomery, 1989; Ouin *et al.*, 2000; Rosário & Mathias 2004) in the Mediterranean. Moreover, the summer of 2009 was very dry (rainfall below 0,048 mm) which may have contributed even more to lowering number of captures and thus turning population and habitat models weaker.

The poor explained deviance of the models (roadless= 17%, roadside=14%) shows that, besides sampling size, many other uncontrolled factors are influencing wood mouse captures/recaptures and further studies controlling for new descriptors (predation risk, food availability, habitat seasonal disturbance, etc.) and for longer periods are needed to properly describe the influence of roads on the wood mouse populations.

Despite being preliminary, our results have some implications for habitat management concerning small mammals in road dominated environments. In fact data suggest that to minimize the road effects on the wood mouse, adjacent landscapes have to be managed creating suitable habitats for them away from the road, e.g. the construction of stone clusters. The creation of underpasses is a measure often suggested to minimize the road-kill risk and road barrier effect for several species of terrestrial vertebrates (Forman & Alexander, 1998; Clevenger & Waltho, 2000; Aresco, 2003; Iuell *et al.*, 2003; Ascensão & Mira, 2007). The lower survival of the wood mouse at the roadside may also suggest that this passages may also be useful. However, their specific adequacy for small-bodied species and their efficacy must be previously tested before a generalized use of these structures is proposed. To increase the efficiency of underpasses for small mammals might be used patches of vegetation up to passages for animals guideless and some infrastructures or another vegetation management that can retract animals from the road before enter the underpasses.

Another mitigation measure that has been adopted in Switzerland and works pretty well for small mammals are "ecological compensation areas" that are "areas with specific guidelines of cultivation and a subsidy that include for example: low-intensity meadows, litter meadows, hedgerows, wild-flower strips and traditional orchards" (Aschwanden *et al.*, 2007).

Although these measures may prevent lower survival of animal populations the best solution are preventive measures. Before building linear infrastructures, engineers, architects and ecologists have to bear in mind not only the presence of species in the area, but also the landscape. They should achieve the perfect harmony between constructions and environment.

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# Conclusão

De um modo geral os resultados sugerem que a presença das estradas afecta negativamente os parâmetros populacionais de ***Apodemus sylvaticus*** e que as áreas sem o efeito de estradas são mais favoráveis para as populações desta espécie. Por outro lado, na presença da estrada as áreas adjacentes (bermas) são mais favoráveis a esta espécie do que as áreas mais afastadas do asfalto.

Relativamente aos parâmetros populacionais: (i) na área com estrada a população tem menor taxa de sobrevivência e emigração; (ii) na área sem estrada existe menor taxa de retorno dos emigrantes. Parte das diferenças encontradas podem reflectir as pequenas diferenças que existem nos dois locais de amostragem, dado que não foi possível encontrar áreas de estudo exactamente iguais.

De qualquer modo, embora as menores densidades tenham sido encontradas na área com estrada, a menor taxa de sobrevivência é consistente com a hipótese do aumento da mortalidade por atropelamentos. Os nossos resultados confirmam também que o microhabitat nas bermas é mais favorável que o microhabitat nas áreas adjacentes e que as bermas podem actuar como um habitat viável para os micromamíferos que tendem a concentrar-se nessas áreas.

O presente estudo é um estudo piloto de apenas seis meses incluindo o verão. Esta estação é o período mais crítico para o rato-do-campo (Gurnel, 1978; Bengston *et al.*, 1989; Montgomery, 1989; Quin *et al.*, 2000; Rosário & Mathias, 2004) no Mediterrâneo. Adicionalmente, o verão de 2009 foi bastante seco (média de precipitação abaixo dos 0,048mm) o que pode ter contribuído para o baixo número de capturas resultando na obtenção de modelos menos robustos.
Os baixos valores para a variância explicada dos modelos (área sem estrada= 17%, área com estrada=14%) sugerem que para além do tamanho da amostra, existirão outros factores que influenciam a taxa de capturas e recapturas do rato-do-campo. Sendo assim, serão necessários futuros estudos que controlem novas variáveis (risco de predação, disponibilidade de alimento, distúrbios sazonais do habitat, etc) durante períodos mais longos para explicitar a influência das estradas nas populações de rato-do-campo.

Apesar de preliminares, os resultados têm algumas implicações no que diz respeito à gestão do habitat dos micromamíferos em ambientes influenciados por estradas. De facto, os dados sugerem que para minimizar os efeitos da estrada no rato-do-campo, as paisagens adjacentes têm de ser geridas de maneira a criar habitats sustentáveis para que os animais possam permanecer longe da estrada. Em áreas adjacentes à estrada podem ser criados, por exemplo, aglomerados de pedra que permitem o refúgio dos animais. Todavia, a criação de passagens subterrâneas é uma das medidas mais sugeridas para minimizar o risco de morte por atropelamento e o efeito barreira que afecta várias espécies de vertebrados terrestres (Forman & Alexander, 1998; Clevenger & Waltho, 2000; Aresco, 2003; Iuell *et al.*, 2003; Ascensão & Mira, 2007). O facto das populações perto da estrada apresentarem valores mais baixos de sobrevivência sugere que passagens seguras poderão ser úteis para esta espécie. Contudo, a sua adequação específica para espécies com pequenas dimensões corporais e a sua eficácia deve ser testada previamente antes do uso generalizado das mesmas. De modo a aumentar a eficiência das passagens subterrâneas para os micromamíferos, podem ser criadas manchas de vegetação perto das passagens de modo a servirem de guia para os animais até às passagens, para que evitem a aproximação à estrada.

Outra medida de mitigação que pode ser bastante útil para micromamíferos e que foi adoptada na Suíça é a criação de "áreas ecológicas de compensação" que são áreas subsidiadas e com linhas de orientação muito restritas para o cultivo. Estas áreas podem incluir por exemplo: pequenos prados, prados pouco intensivos e faixas de plantas silvestres em volta de pomares (Aschwanden *et al.*, 2007).

Embora todas estas medidas possam ajudar a aumentar a taxa de sobrevivência dos animais a melhor solução será sempre usar medidas preventivas. Antes da construção de infra-estruturas lineares os engenheiros, arquitectos e ecologistas devem ter em mente não só a presença das espécies nas áreas, mas também toda a paisagem envolvente. O seu grande desafio deve passar por alcançar a harmonia perfeita entre as construções e o meio ambiente.

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