Universidade de Aveiro
2015

Departamento de Biologia

CATARINA SILVA CARVALHO

ROLE OF CLIMATE ON BARN OWLS ROAD-KILL LIKELIHOOD AND THE EFFECT ON POPULATION VIABILITY IN FUTURE CLIMATE CHANGE

O PAPEL DO CLIMA NOS ATROPELAMENTOS DE CORUJA-DAS-TORRES E A SUA VIABILIDADE POPULACIONAL NO CONTEXTO DE ALTERAÇÕES CLIMÁTICAS

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia Aplicada, realizada sob a orientação científica do Doutor Carlos Manuel Martins Santos Fonseca, Professor associado com agregação do Departamento de Biologia da Universidade de Aveiro e coorientação da Doutora Clara Grilo, investigadora pelo CNPq e Professora no Programa de Pós-graduação de Ecologia Aplicada do Departamento de Biologia da Universidade Federal de Lavras (Brasil).

À minha família, pais e irmã.

o júri

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agradecimentos

Aos meus, orientador Professor Carlos Fonseca e co-orientadora Clara Grilo por todo o apoio à realização desta tese.

Ao Luís Borda-de-Água por toda a ajuda disponibilizada, especialmente na programação. A todos os que ajudaram na obtenção de dados quer pela disponibilização dos mesmos quer pela ajuda nos contactos.

Aos meus pais e á minha irmã por todo o apoio e entusiasmo.

À Ana Pereira, "Flor", pelas indicações em inglês e a todos os amigos e familiares por todo o apoio.

Aos funcionários da biblioteca municipal de Vidigueira pela simpatia.

Palavras-chave Mortalidade nas estradas, precipitação, seca, modelos populacionais, aves de rapina, análise temporal.

resumo

As estradas representam uma nova fonte de mortalidade para vida selvagem devido ao risco de colisão com veículos apresentando mais uma ameaça à viabilidade das suas populações. O risco de atropelamento de cada espécie depende das características das estradas e das características bio-ecológicas da espécie. Neste estudo pretendemos conhecer a importância dos parâmetros climáticos (temperatura e precipitação) em conjunto com tráfego e os períodos do ciclo de vida da espécie e perceber o papel da seca na viabilidade populacional de coruja-das-torres afetadas por mortalidade nas estradas em três cenários: mobilidade elevada, elevada densidade populacional e a combinação dos cenários anteriores (misto) (Manuscrito). Para o primeiro objetivo correlacionaram-se os vários parâmetros (clima, tráfego e períodos do ciclo de vida). Usaram-se as variáveis mais correlacionadas para construir um modelo misto preditivo (GLMM) da influência dos mesmos. Através de um modelo populacional avaliou-se a viabilidade populacional nos três cenários. O modelo revelou que a precipitação, tráfego e dispersão têm uma relação negativa com os atropelamentos, embora esta não seja significativa. Os resultados foram diferentes, o cenário de mobilidade elevada resultou numa maior diminuição da população e em maiores flutuações ao longo do tempo apresentando um maior risco de extinção do que os restantes cenários. O cenário de elevada densidade populacional resultou numa maior estabilidade das populações com menor risco de extinção e o cenário misto apresentou resultados semelhantes ao cenário de elevada mobilidade. A precipitação parece apresentar um papel mais indireto na influência dos atropelamentos, influenciando a presença de presas a qual pode determinar o sucesso reprodutivo e a atividade desta espécie. A menor densidade populacional representa um maior risco para a viabilidade populacional e resiliência a outros eventos estocásticos. Estudos futuros deverão ter em conta o clima e o modo como este influencia os períodos de atividade das espécies e a incidência de atropelamentos de modo a tomar as medidas de mitigação mais adequadas que poderão passar pelo melhoramento da qualidade do habitat das presas.

keywords

Road mortality,precipitation, drought, populacional models, birds of prey, temporal analysis.

abstract

Roads represent a new source of mortality due to animal-vehicle risk of collision threatening log-term populations' viability. Risk of road-kill depends on species sensitivity to roads and their specific life-history traits. The risk of road mortality for each species depends on the characteristics of roads and bio-ecological characteristics of the species. In this study we intend to know the importance of climatic parameters (temperature and precipitation) together with traffic and life history traits and understand the role of drought in barn owl population viability, also affected by road mortality in three scenarios: high mobility, high population density and the combination of previous scenarios (mixed) (Manuscript). For the first objective we correlated the several parameters (climate, traffic and life history traits). We used the most correlated variables to build a predictive mixed model (GLMM) the influence of the same. Using a population model we evaluated barn owl population viability in all three scenarios. Model revealed precipitation, traffic and dispersal have negative relationship with road-kills, although the relationship was not significant. Scenarios showed different results, high mobility scenario showed greater population depletion, more fluctuations over time and greater risk of extinction. High population density scenario showed a more stable population with lower risk of extinction and mixed scenario showed similar results as first scenario. Climate seems to play an indirect role on barn owl road-kills, it may influence prey availability which influences barn owl reproductive success and activity. Also, high mobility scenario showed a greater negative impact on viability of populations which may affect their ability and resilience to other stochastic events. Future research should take in account climate and how it may influence species life cycles and activity periods for a more complete approach of road-kills. Also it is important to make the best mitigation decisions which might include improving prey quality habitat.

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Chapter I

Introduction

1. Introduction
1.1. Background

Road ecology has been a studied field in scientific research since the late 90s due to the rapid road expansion and exponential growth of the traffic (Forman & Alexander, 1998; Epps et al., 2005; Fahrig & Rytwinski, 2009). Roads can disrupt ecological processes (e.g. groundwater flow, foraging) and patterns of landscapes which can lead to changes on population dynamics (Forman & Alexander, 1998). Likewise, climate influences natural processes and change species habitat quality (Fronzek & Carter, 2007) which can also threat wildlife persistence in a long-term (Parmesan et al., 2013). Throughout the earth history, climate changes has led to habitat transformation and species become extinct (Parmesan, 2006; Carey, 2009). In the 21st century, several scientists estimate that climate change will force species to adapt faster to new environmental conditions (Carey, 2009; Bestion et al., 2015).

1.2. Road Mortality

A study on road ecology summed up the relevant questions that raise concern (Roedenbeck et al., 2007): how much does a road affect population persistence? By which mechanism does it affect that? Is it relevant? Can road effect be mitigated? In fact, roads create a barrier, preventing both dispersal movements and reproductive encounters, and also decreasing forage areas (Fahrig, 1997; Epps et al., 2005; Jaeger et al., 2005; Barrientos & Bolonio, 2008; Barthelmess & Brooks, 2010; Benítez-López et al., 2010; Barthelmess, 2014). Despite these effects, roads can add a new source of mortality within animal populations (Baker et al., 2004) which can threaten long-term population viability (Ramsden, 2003; Epps et al., 2005; Corlatti et al., 2009).

In England, road-kills are one of the main causes of mortality for populations of barn owls (*Tyto alba*) and European common toads (*Bufo bufo*), whereas in Spain, one of the main causes of Iberian lynx (*Lynx pardinus*) mortality is due to road traffic (Ramsden, 2003; Beebee, 2013; Barthelmess, 2014). However, the effects of road mortality are species-specific (Bissonette & Adair, 2008; Bissonette & Cramer, 2008; Cook & Blumstein, 2013) depending on how species perceive the risk and on their life-history traits (Barthelmess & Brooks, 2010; Gunson et al., 2011; Boves & Belthoff, 2012; Barthelmess, 2014). Species attracted to roads or with low road avoidance are apparently more vulnerable to roads and consequently more likely to be hit by vehicles (Fahrig & Rytwinski, 2009). Larger species with high mobility as well high density populations have a higher probability of encountering roads and collide with a vehicle (Alexander et al., 2005; Barthelmess & Brooks, 2010).

Traffic flow has great influence on the likelihood of vehicle-collisions (Baker et al., 2004; Benítez-López et al., 2010). While, high traffic intensities impede or discourage animals to cross, due to avoidance (Forman & Alexander, 1998; McGregor et al., 2007; Barrientos & Bolonio, 2008; DeVault et al., 2014), roads with low/intermediate traffic volume represent a higher risk of collision (e.g. Grilo et al. 2015). Flow variance does not allow animals to create cross habits and perceive the risk (Seiler, 2004; Thurfjell et al., 2015). This is true for wild boar (*Sus scrofa*)-vehicle collision in Southern Sweden, where most of the collisions occur with intermediate traffic because traffic is usually low when they are active (i.e. night and early morning) (Thurfjell et al., 2015). Likewise, roads included in high conserved landscapes with low traffic creates a sense of landscape connectivity which does not let individuals to notice the risk of traffic (Grilo et al., 2009; Gunson et al., 2011; Santos et al., 2013). Availability of prey on road verges which are mainly dominated by herbaceous vegetation also contribute to road mortality risk (Forman & Alexander, 1998). High plant species richness in the road verges can increase the number of prey near roads which may function as corridors for herbivores and carnivores (Forman & Alexander, 1998). Thus, the probability of collision with vehicles is higher as animals circulate near roads. For example European polecat (*Mustela putorius*) road-kills were highly related with the high prey abundance near roads (Barrientos & Bolonio, 2008).

Species life-history traits may make species particularly vulnerable to traffic in some periods of the year (e.g. Barthelmess, 2014; Grilo et al., 2014; Bright et al., 2015). One of the clearest facts is that road-kill rates is higher when populations reach higher densities or when individuals increase their activity or enlarge their territory, increasing the chances to find a road and hit by vehicles. For example a seven year study in Bristol revealed a positive relationship between red fox (*Vulpes vulpes*) density and the number of foxes' road casualties (Baker et al., 2004). High mortality of red fox in late spring and early summer corresponded to the period of feeding the young and Eurasian badgers' mortality is higher when dispersal and breeding time occur (Clevenger et al., 2003; Grilo et al., 2009). Mule deer (*Odocoileus hemionus*) migrations in winter, in western USA, increase the likelihood to cross more roads (Olson et al., 2015). Likewise, lack of prey in winter may lead barn owls to increase their territory and increase the likelihood of those individuals crossing a road (Grilo et al., 2014).

1.3. Climate Change

Climate change poses a major threat to wildlife mainly because it affects the species survival and habitat quality (Pearson et al., 2014). Climate change has implications on species' life cycles and distribution and may accelerate the extinction risk globally (Urban, 2015). Predictions show that climate change may increase in 6% the extinction risk of European biodiversity (Urban, 2015). Estimates on climate change include the rising of global temperatures between 1.4 and 5.8°C, low precipitation levels for low latitudes and more frequent and variable extreme weather events (i.e. intense rainfalls and droughts) (Intergovernmental Panel on Climate Change, 2002; Butt et al., 2015). In Europe, climate change may lead to weather shifts, depending on latitude, influencing the seasons (Morellet et al., 2013). Until now, temperatures have risen and precipitation has been decreasing in the South and increasing in the North of Europe (Harrison et al., 2006). This fact, leads to direct or indirect changes in the biophysical environment (e.g. habitat quality, timing of seasons, resource availability, land use) and consequently threat the survival of individuals and populations persistence (e.g. low body condition and reduction on reproduction time) (Travis et al., 2013; Thornton et al., 2014; van Dijk et al., 2015). For example, changes in land use due to a shift of soil conditions has led to a 30% loss of core areas of Dutch meadow birds (van Dijk et al., 2015). However, each species respond to these shifts differently according to the interactions between specific life-traits and spatial characteristics (Pearson et al., 2014). Their adaptation also varies in accordance with occupied area, population size, generation length, thermal niche, dispersal ability and connectivity (Pearson et al., 2014). Species that are capable of adjusting their climate ranges (e.g. different temperature range) and able to vary in terms of food availability have more chances to persist (Morellet et al., 2013; Parmesan et al., 2013; Travis et al., 2013; McCain & King, 2014).

In the near future, it is expected that extreme weather events become more frequent (Morellet et al., 2013). These extreme events are rare, severe and unseasonal at a specific place and time and may extend in time (Thornton et al., 2014; Butt et al., 2015). Individuals are not prepared to face extreme weather events which cause immediate mortality (Altwegg et al., 2006; Parmesan et al., 2013), or affect fitness of different ages inside the same population (Benton et al., 1995; Altwegg et al., 2006). Variable weather and environmental degradation may affect foraging ability of adults, physiological maturation of juveniles, quality of breeding sites, and offspring survival (Martin, 1995) which may influence and jeopardize future generations (Martin, 1995).

1.4. Barn owl

Barn owl has a broad distribution range around the world and it is resident in Europe (BirdLife International, 2015). The IUCN conservation status is Least Concern (LC), which indicates the presence of a stable populations (BirdLife International, 2012). However, in some areas their populations have declined due to a decrease of prey availability as a consequence of habitat loss (Boves & Belthoff, 2012). Barn owl lives near human infrastructures and in open agricultural landscape (BirdLife International, 2015; Buscà, 2015) and their main prey are small mammals (BirdLife International, 2015). The reproduction cycle of barn owls comprise five stages: pre-breeding phase, breeding phase, birth, feeding the young and dispersal (Martinez & Lopez, 1999; Buscà, 2015). Clutches size varies from 4 to 7 eggs in the Iberian Peninsula (Martinez & Lopez, 1999; Buscà, 2015).

It has been observed that climate parameters such as precipitation, temperature and snow cover influence barn owl life cycle, namely the breeding season. In temperate zones like Portugal, reproduction is positively associated with moderate temperatures and increased food availability (Zuberogoitia, 2000; Carey, 2009). In western Switzerland, harsh winters have great impacts on barn owls population due to low survival of adults and juveniles (Altwegg et al., 2006). The lack of prey has been the main reason behind those effects (Altwegg et al., 2006). In contrast, egg laying occurs earlier during hot springs (Chausson et al., 2013) which can allow them to have an earlier second posture (Martinez & Lopez, 1999). The probability of a second brood has a latitudinal distribution in Europe, and it is greater at higher latitudes (Martinez & Lopez, 1999). At northern areas, in order to compensate high mortality in harsh winters, the probability of a second clutch is higher and the breeding season is compressed in the few months without snow shortening phases' duration. At lower latitudes, the probability and the number of eggs of a second clutch are lower because winters are softer and mortality is lower (Martinez & Lopez, 1999).

Barn owl is one of the species with higher number of road-kill records in Portugal with estimates for southern Portugal population of 0.49 owls/km/year (Gomes et al., 2008). In other countries of Europe there are estimates between 0.25 owls/km/year (France) and 0.64 owls/km/year (Great Britain) (Boves & Belthoff, 2012) which as lead to a decrease of populations, mainly in Spain and Great Britain (Fajardo, 2001; Boves & Belthoff, 2012). In winter, barn owl mortality seems to be related with the higher prey availability in the road verges than in the vicinity of roads (Gomes et al., 2008; Boves & Belthoff, 2012). In Devon (UK) during a survey in 1996, more barn owls were likely to be found near roads than in control areas (Ramsden, 2003) due to low altitude and suitable foraging areas (i.e. rough grassland) in the vicinity of the roads (Clevenger et al., 2003; Ramsden, 2003).

Species specific life-traits are also important to road mortality risk. In general birth period and juveniles' dispersal period correspond to higher risk of being hit by vehicles (Boves & Belthoff, 2012). Juveniles have to disperse in their first year of life from their birth area to random distances which may increase encounters with new areas and roads (Ramsden, 2003; Gomes et al., 2008; Boves & Belthoff, 2012; Grilo et al., 2014). The high mortality in the breeding seasons due to high hunt activity and expansion of their territory to feed the yearlings (Boves & Belthoff, 2012). Mortality in birth period due to adults have to hunt while eggs are being incubated which means more movements for one of the partners both partners increase their movements to feed the yearlings in feeding the young period (Boves & Belthoff, 2012).

To our knowledge studies only relate road mortality with road characteristics and life trait parameters (e.g. Barthelmess, 2014; Grilo et al., 2014; Bright et al., 2015) and no research has related the road mortality with climate. Role of climate on road mortality is not yet well understood and, also, for a better understanding of road-kills in a climate change context is needed to evaluate the impact of extreme weather events on the barn owls populations. As the adaptation of species to climate change may encompass adjusting to climate ranges (e.g. different temperature range) and to food availability variance (Morellet et al., 2013; Parmesan et al., 2013; McCain & King, 2014) this may have consequences on species vulnerability to road traffic and shift temporal variation of road-kills.

1.5. Main goals and structure of the thesis

In this study, we address:

1) the relative importance of climate parameters (temperature and precipitation) together with traffic volume and species life history traits on barn owl road mortality and

2) the role of drought on barn owl population viability at the long term regarding road mortality through three scenarios: high mobility, high population density and the combination of the previous scenarios (mixed).

Here, we suggest three hypotheses to run the three scenarios to explain the increasing of road casualties in drought years because these events are expected to be intensified in near future in south Europe. First hypotheses: road mortality increases due to higher animals' mobility due to lack of prey. Barn owls increase their activity in searching for food which increases the likelihood to encounter and/or cross a road (high mobility scenario). Second hypotheses: road mortality increases due to higher population density. Drought years stimulate barn owl breeding which may increase the number of individuals crossing roads, and increase the road-kill rates (high population density scenario). Third scenario is the combination of previous scenarios, high mobility and high recruitment in drought years (mixed scenario).

The availability of daily road-kill data of barn owls between 2005 and 2009 on 956 km of highways managed by BRISA (Auto-Estradas de Portugal, S.A.) in Portugal, as well the monthly traffic and climate data on these years, gave us the opportunity to analyze the role of climate on road mortality and develop forecast scenarios regarding climate predictions. Besides traffic and barn owls life periods explaining the temporal patterns of barn owl road mortality, we expect that climate may have a role in explaining the risk of mortality. High precipitation levels along with low temperatures may reduce prey availability and increase the risk of mortality for barn owls but the opposite may induce prey activity and increasing barn owl movements and road casualities. In the context of extreme weather events presence, we expect high mobility scenario to present greater risk of extinction of barn owl populations reducing populations' size and consequently increasing vulnerability to stochastic events. On other side, we expect high population density scenario to show less impact of drought on populations' size; here populations may show more stability through time with lower extinction risk.

This thesis is structured in three chapters:

- **Chapter I** state of art in order to understand the goals of this thesis. This chapter provides a theoretical review about road-kills (risk and impacts), climate change (predictions and impacts) and barn owl biology and road-kill patterns. Also, it outlines thesis main goals and structure.
- **Chapter II (Manuscript)** identifies the role of climate on barn owl road-kills and assesses the impact of increasing road mortality rates in drought years' on the barn owl population viability. We set three different scenarios, high mobility and high population density, which results show different impacts on populations. High mobility scenario shows a greater negative impact on barn owl populations.

- **Chapter III** highlights the main conclusions of the thesis, as well future research perspectives and general mitigation measures.

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Chapter II

The role of climate on barn owls road-kill likelihood and the effect on population viability in future climate change

Manuscript

Chapter II – Manuscript

Carvalho C, Borda-de-Água L, Fonseca C, Clara G. (Submitted in *Biological Conservation*) The role of climate on barn owls road-kill likelihood and the effect on population viability in future climate change.

2. The role of climate on barn owls road-kill likelihood and the effect on population viability in future climate change

2.1. Abstract

In several species road mortality have a major negative impact on the long-term persistence. However, species respond differently to roads according to road characteristics and species-specific life traits. Although previous studies show the influence of traffic and life traits on road-kill likelihood, the influence of climate on road mortality is still poorly understood and the effect of climate change is unknown on species with high road-kill rates. Thus, the aim of this study is to evaluate: 1) the relative importance of climate parameters together with traffic volume and species life history traits on barn owl road mortality and 2) the role of drought on barn owl population viability regarding road mortality through three scenarios: high mobility, high population density and the combination of the previous scenarios (mixed). We run general linear mixed models to evaluate the relative role of climate on barn owl road-kill occurrence and we used an age-structured base model to evaluate the impact of future climate change on the barn owl population viability. Our findings show that precipitation has a negative association with road-kill occurrence likelihood as well as traffic and dispersal period. High mobility scenario represents a higher risk of extinction for barn owl populations and higher populations' depletion than high population density or mixed scenarios. The decrease of population densities makes barn owls more vulnerable toward stochastic events or the increase of road mortality, which may threaten the viability of population at a long-term. Because precipitation might play an indirect role on prey availability, mitigation measures should take into account the creation of suitable areas for small mammals.

Keywords: road mortality, precipitation, drought, age-structured models, birds of prey, temporal analysis

2.2. Introduction

Wildlife-vehicle collision is the most visible impact of roads and the one which cause more concerning because it results in direct mortality (Baker et al., 2004; Barrientos & Bolonio, 2008; Barthelmess, 2014). The implications of this effect on population dynamics are the decline and isolation by limiting dispersal, reproductive or dispersal movements threatening long-term population viability (Epps et al., 2005; Barrientos & Bolonio, 2008). The extension and magnitude of these implications depend on the species behavior towards roads and to their life history traits (e.g. body size, diet, habitat preference, mobility) (Fahrig & Rytwinski, 2009; Grilo et al., 2010; Cook & Blumstein, 2013).

Several studies have examined the road-kills temporal patterns with traffic volume and/or species life traits (e.g. Barrientos & Bolonio, 2008; Barthelmess, 2014; Grilo et al., 2014; Bright et al., 2015). High variance of traffic volume increases the risk of collision (Seiler, 2004; Thurfjell et al., 2015) because it does not allow individuals to create road crossing habits or perceive the risk (Seiler, 2004). Also, the incidence of road-kills in some species is related to periods of high activity when looking for a mate (breeding), finding a place to settle (dispersal) or searching for food (Baker et al., 2004; Barrientos & Bolonio, 2008; Grilo et al., 2009; Barthelmess & Brooks, 2010; Cook & Blumstein, 2013). In addition, the high availability of resources in the road verges can attract predators which increase the risk of mortality (Barrientos & Bolonio, 2008; Cook & Blumstein, 2013). Road verges may constitute a refuge and a corridor for small mammals mainly due to landscape conversion to extensive or intensive agriculture (Ascensão et al., 2012; Ruiz-Capillas et al., 2013). For instance, fenced roads maintain high density of native vegetation which promote higher abundance of small mammals than the surrounding areas (Ascensão et al., 2012). Because small mammal population dynamics interact with climate (Torre et al., 2002), the mortality risk of predators can be indirectly affected (Olson et al., 2015). Climate influences the biophysical environment (e.g. habitat quality, timing of seasons and resource availability) which can affect negatively prey populations (distribution range, phenology, physiology and abundance) (Brook et al., 2009; Travis et al., 2013) and consequently increase the predators mobility and the likelihood of road encounters.

Forecasts of climate change comprise an increase of temperature and weather extreme events, such as, intense rainfall and droughts (Intergovernmental Panel on Climate Change, 2002; Altwegg et al., 2006; Bestion et al., 2015). In Southern Europe, in particular, it is expected to suffer an increase in meteorological droughts frequency (Intergovernmental Panel on Climate Change, 2002). This may lead some species to shift their distributions to adjust the availability of food with their occurrence (Morellet et al., 2013; Parmesan et al., 2013; McCain & King, 2014).

A theoretical long term viability study showed the negative effect of road mortality on barn owl (*Tyto alba*) populations (Borda-de-Água et al., 2014). Road mortality is responsible for the reduction of barn owl populations around 50% when the road mortality is included in the analysis, even at low road-kill rates (Borda-de-Água et al., 2014). This fact may lead to unstable populations in the long term, jeopardizing population ability to survive extreme stochastic events (e.g. droughts) (Borda-de-Água et al., 2014). Several studies show that drought years are positively related with an increase of barn owl road-kills (Ramsden, 2003; Met Office, 2013). For example, in south England, between 1995 and 1997 there was a drought which increased the number of barn owl road casualties (Ramsden, 2003; Met Office, 2013). A similar relationship between droughts and high road-kill rates occurred in 2005 in Portugal and Idaho (USA) (García-Herrera et al., 2007; Borda-de-Água et al., 2014). On the other hand, in Devon (UK) researchers noticed that the number of barn owl breeding pairs was higher in drought years than in regular years (Toms et al., 2001; Met Office, 2013). Thus, there are at least two possible explanations to increase the number of road-kills in drought years: 1) those years correspond to lack of prey and thus increase barn owl activity near roads searching for food (Barthelmess & Brooks, 2010; Cook & Blumstein, 2013) or 2) those years may increase the likelihood of reproduction success, and consequently the population density increase likewise the number of road-kills (Clevenger et al., 2003; Bright et al., 2015).

The availability of daily road-kill data on barn owls during the period between 2005 and 2009 in 956 km of highways managed by BRISA (Auto-Estradas de Portugal, S.A.) in Portugal, as well monthly traffic and climate data on these years, give us the opportunity to analyze the relative role of climate on road mortality and develop scenarios regarding climate change. Thus, the aim of this study is to evaluate: 1) the relative importance of climate parameters together with traffic volume and species life history traits on barn owl road mortality and 2) the role of drought on barn owl population viability at the long term regarding road mortality through three scenarios: high mobility, high population density and the combination of the previous scenarios (mixed).

We expect that climate explains significantly the road mortality trends together with traffic and life-history traits. We predict that years with low temperatures and low precipitation may increase the risk of mortality of barn owls due to lack of prey. In a future scenario of climate change we expect a high risk of barn owls extinction when road mortality increases due to higher mobility in searching for prey.

2.3. Methods

2.3.1. Study area

We conducted this study in BRISA highways in Portugal (Figure 1). BRISA manage 11 highways comprising 79 segments distributed from north to south of Portugal, mostly located in littoral areas. Only one highway is located in the interior of the country. Median traffic volume is 25 352 vehicles/year/segment with a maximum of 137 282 vehicles and a minimum of 361. Highways are fenced and the traffic speed limit is 120 km h^{-1}. Landscape is diverse characterized in the north by mountains with forest, agriculture and urban areas and in the south is characterized by the mainly presence of wide plains mainly with an agro-silvo-pastoralism system. Atlantic climate influences littoral and northern regions with a high rainfall in the winter and suave summer. Center and south of Portugal are influenced by Mediterranean climate that corresponds to rainfall in winters and dry hot summers (IPMA, 2015a).

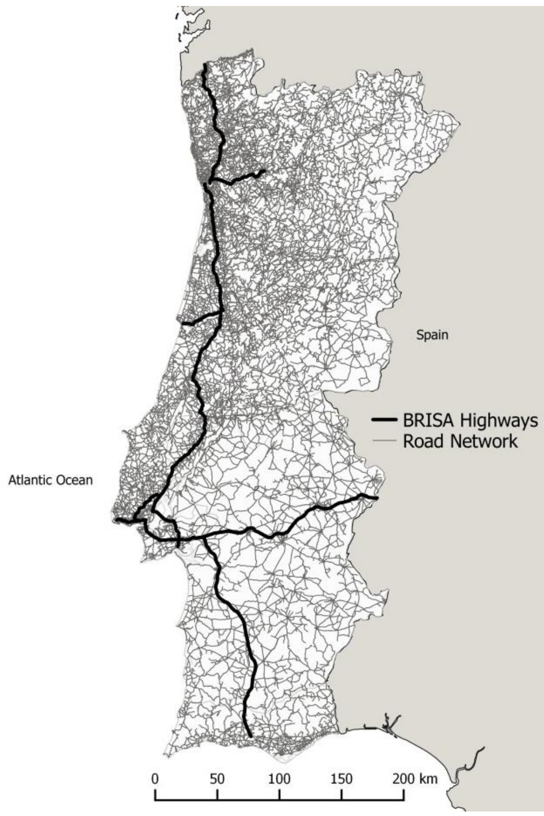

Figure 1 - Location of highways managed by BRISA, in Portugal. Adapted BRISA Auto-estradas de Portugal and IgeoE.

2.3.2. Data collection

BRISA employees collected road-kill data daily between January 2005 and December 2009. Average daily per month traffic volume was collected from Instituto da Mobilidade e Transportes, I.P. (IMT, I.P.) for the same period and climate data (monthly, maximum and minimum temperature and precipitation) were obtained from Instituto Português do Mar e Atmosfera (IPMA). We obtained life-history traits through literature (e.g. Martinez & Lopez, 1999; Grilo et al., 2014; Buscà, 2015) and assigned for each month. Because highways comprise 79 segments, we obtained information by month for road-kill records, traffic volume and climate for a total of 4860 segments (79 segments*12months*5years).

2.3.3. Data analysis

2.3.3.1. The importance of climate on barn owl road mortality likelihood

To evaluate the role of climate on barn owl road-kill occurrence, we run general linear mixed models (GLMM) (Bolker et al., 2009; Zuur et al., 2009). We included traffic volume and barn owl life history traits (pre-breeding, egg-laying, feeding the young and dispersal) as explanatory variables. We used presence/absence of road-kills in each highway segment as the response variable. To assure the same number of presences and absences, we randomly selected the same number of segments with presence and absence of road-kills. To avoid include correlated variables among explanatory variables we test multicollinearity using the Fisher exact test between presence/absence variables and GLM models in the binomial family to binomial and continuous variables (Burnham & Anderson, 2002) between traffic, climate and life-history traits. Among the pairs of the most correlated variables, we selected the one with the highest correlation with road-kill occurrence. Then, we defined a group of seven candidate models for barn owls road-kills regarding the following five hypotheses that may explain the barn owls road mortality temporal patterns: 1) only one type of variable (traffic, climate or life-history trait) explain road-kills occurrence; 2) traffic and climate affect road-kills occurrence; 3) traffic and life-history trait influence road-kills occurrence; 4) climate and life-history trait promote road-kills likelihood; or 5) all variables play a role on the road-kills likelihood. Road segments and year were used as random effects to avoid confounding by the sampling variance (Bolker et al., 2009). We ranked each model according to AIC (Akaike Information Criterion). We used averaging when we found similar good models ($\Delta AIC<2$) (Burnham & Anderson, 2002). We estimated the area under curve (AUC) to validate the best model (Hosmer & Lemeshow, 2000).

All statistics analysis were performed using the R statistics software V. 3.1.2 (R Core Team, 2014). We used lme4 (Bates et al., 2015) and pROC (Robin et al., 2011) R packages to run the GLMM and AUC, respectively. Model averaging was performed using R package MuMIn (Barton, 2015).

2.3.3.2. Role of climate change on barn owl population viability at long term

We used an age-structured base model developed by Borda-de-Água et al. (2014) to evaluate the impact of future climate change on the barn owl population viability. This model assumes that barn owl population is controlled by mortality which includes road mortality, age of the first breed, clutch sizes, recruitment, survival rates for different ages, and proportion of breeding as yearling (Borda-de-Água et al., 2014). The number of recruits was modeled according to the number of eggs based on the Beverton-Holt relationship, $R = \frac{aE}{b+E}$ (Beverton & Holt, 1957; Borda-de-Água et al., 2014). In this relationship, in order to ensure that the number of eggs (*E*) is always larger than the number of recruits (*R*), we used $a = b$ (Beverton & Holt, 1957; Borda-de-Água et al., 2014). Life-history parameters included in this model were based on a barn owl population of Switzerland (Altwegg et al. 2003, 2007). We used barn owl road-kill data proportion in regular years in southern Portugal which correspond to 10% (f=0.1) with median size populations between 400 (0.05 ind./km^2) and 2300 individuals (0.27 ind./km^2) in an area of 8589 km^2. We also used recruitment values in regular years from northern hemisphere temperate region (Martinez & Lopez 1999, Altwegg et al., 2007; Borda-de-Água et al., 2014) which correspond to 80% of producing the first clutch and 22% of producing a second clutch in the same year.

We developed three scenarios (high mobility, high population density and the combination of both scenarios - mixed) considering the effect of drought years on barn owls population dynamics. In the high mobility scenario, we assume a severe road-kill proportion of 20% (double of road kill proportion estimated in southern Portugal). Several studies show that road mortality doubles in dry years (Ramsden, 2003; Borda-de-Água et al., 2014). In fact, individuals may be forced to spend more time and reach new areas when searching for food, thus increasing the risk of collisions with vehicles. In the high population density scenario, we assume that the increment in the number of road-kills is due to a higher population density. To increase the number of breeding pairs (see Toms et al., 2001), we used a higher probability of a second recruitment in the same year (100% of producing first clutch and 50% of producing the second clutch in the same year). Therefore, we will have the same proportion of the population killed on roads in drought years with higher population density. In the mixed scenario, we undertake both two models' assumptions: higher road mortality and recruitment success in drought years. Road kill proportion is 20% and an increment of probability of a second recruitment in the same year (100% of producing first clutch and 50% of producing the second clutch in the same year).

Due to lack of precise data on how much drought frequency will increase in near future, we estimated the risk of extinction for each scenario using diverse road-killed proportions and drought occurrence probability. The risk of extinction varies between 0 and 1 and time to extinction has a minimum of nine years. We ran the three scenarios for an increasing drought per year probability occurrence (from 0 to 0.9 with increments of 0.05) with different road-killed proportions (between 10% - 40% - *f*=0.1 to *f*=0.4 with increments of 0.1). To run the high mobility scenario we multiply fixed road mortality proportion (*f*) by a factor (d parameter) for drought years until population is totally road-killed (i.e. d parameter * *f* < 1), but we kept the recruitment success estimates as in typical climate years (80% of producing the first clutch and 22% of producing a second clutch in the same year). For the high population density scenario, we increased the recruitment success percentage in drought years - 100% of producing first clutch and we multiplied the percentage of producing the second clutch in the same year by a factor (s parameter) populations until reach a 70% of success of producing second clutch in same year. In this scenario we used fixed road mortality (i.e. f=0.1 to f=0.4) for drought and non-drought years. In the mixed scenario, we multiplied the road mortality proportion by *d parameter* in drought years and included a higher recruitment success, 100% of producing first clutch and 50% of producing the second clutch in the same year.

We run the model with an initial population of 200 individuals in each age class. All scenarios assumed a simulation time of 320 years with three regimes. The first regime (*transient* 1 <120 years) does not include road mortality data; further, and to ensure this transient did not interfere with the results of the simulations, we ran a burn out period of 20 years. In the second regime (*transient* 2 – between 120 and 170 years) we included the road-kill proportion of the total population observed in June (first recruitment month); the road-kills are distributed throughout the year and per age class. The third regime (*transient 3* between 170 and 320 years) we added drought regime variability to the presence of road mortality.

The simulation codes were developed and the analyses were performed using the R software package (R Core Team, 2014).

2.4. Results

The Brisa database comprises 352 barn owl road-kills over 956km between 2005 and 2009. We obtained 224 highway segments with barn owl records of each month over five years and we randomly selected 224 segments with absence of barn owl road-kill records.

The year with the highest number of road-kills was 2005 (n=93) followed by 2007 and 2009 with, 76 and 84, respectively (Figure 2). The years 2006 and 2008 were the ones with the lowest number of records, 26 and 56, respectively. Months with the highest records of barn owl road mortality vary between years. In 2005 and 2009 high road morality occurred in summer months, August and July respectively. All other years had higher road mortality rates in winter months, January (2006), February (2008) and December (2007).

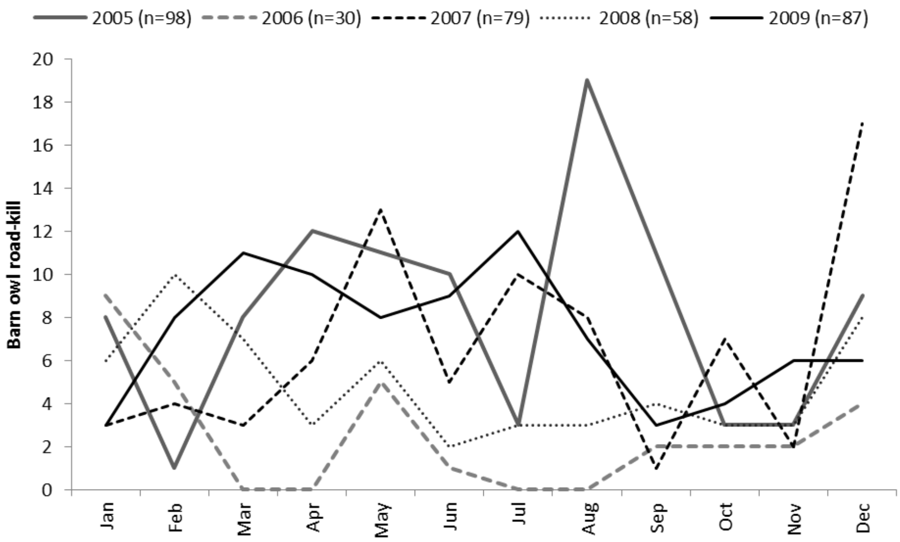

Figure 2 - Barn owl annual road-kill record in BRISA highways between 2005 and 2009 period. n between parenthesis is the total number of barn owl road-kills per year.

The average road–kill rate was 0.5 owls/year/100km. Although peaks varied between years, we observed three peaks: one in the spring (0.8 owls/year/100km), one in late summer (0.7 owls/year/100km) and one another in late autumn (0.9 owls/year/100km) (Figure 3a). Climate variation followed the typical Mediterranean pattern: warmer temperatures and low precipitation in the summer months and high precipitation in the winter months (IPMA, 2015a) (Figure 3b). Traffic also varied along the year with a peak in summer months between July and August (Figure 3c). The first peak of road-kills (May) correspond to feeding the young period; the second peak (August) is coincident with dispersal movements and finally the third peak is highly related with the pre-breeding period (see Figure 3a and 3d).

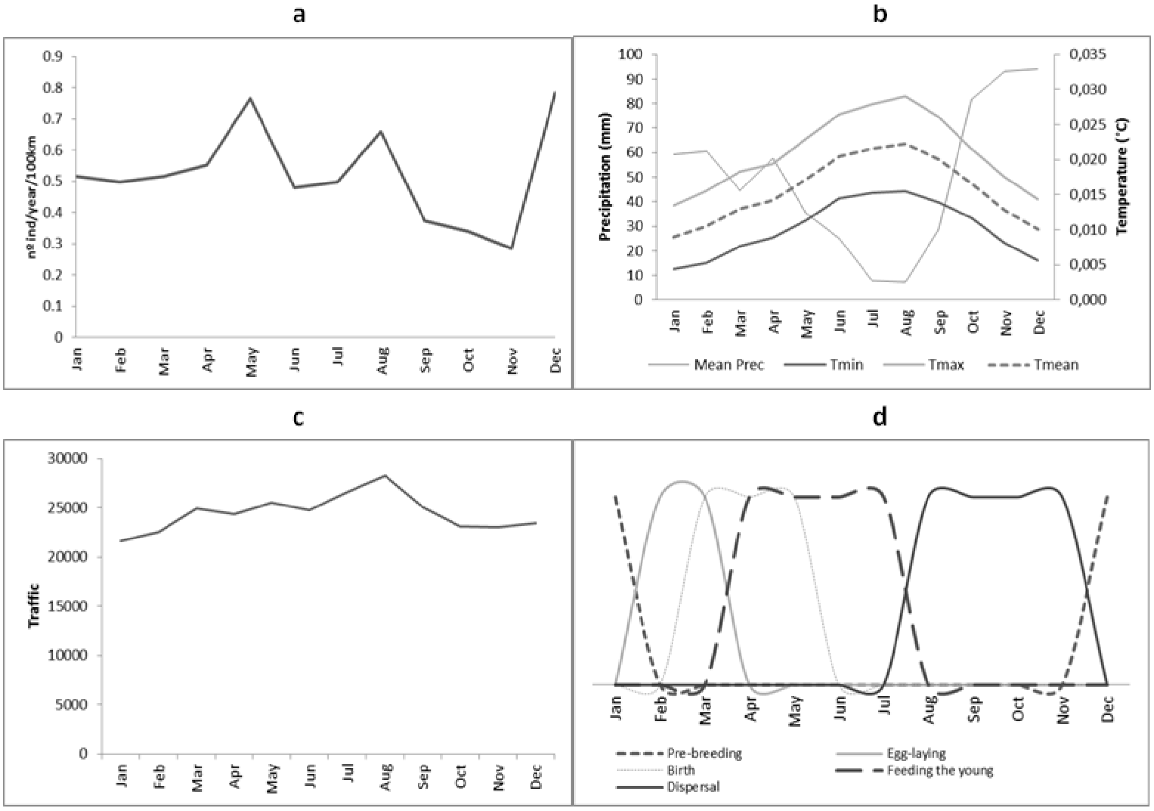

Figure 3 - Annual variation of barn owl road-kills, climate, traffic and life history traits a – Barn owl road-kills rate (owls/year/100km); b – Temperature (Maximum, minimum and mean) and mean precipitation variation in Continental Portugal; c – monthly daily mean Traffic volume; d – Barn owl life cycle in Portugal, a second egg-laying period may occur between late July and September (Buscà, 2015; Grilo et al., 2014; Martinez & Lopez, 1999).

2.4.1. The importance of climate on barn owl road mortality likelihood

Temperature and precipitation were highly correlated (R= - 0.303, p<0.001) and also were correlated with barn owl the life history periods. While temperature was correlated with all four life history periods, precipitation was only correlated with pre-breeding and feeding the young. Traffic did not show correlation with any of life history traits and climate parameters. Thus, precipitation, traffic and dispersal period were used as explanatory variables to run the GLMM. Our results show that all models are good except the precipitation model which ΔAIC is higher than 2.

Table 1 - Barn owls road-kill candidate models (GLMM) with AIC, ΔAIC ($AIC_I - AIC_{MIN}$) and AIC_{wi} ($\frac{exp(-\frac{1}{2}\Delta AIC)}{\sum_{r=1}^{R} exp(-\frac{1}{2}\Delta r)}$) (Burnham & Anderson, 2002).

Variables	AIC	ΔAIC	AICwi
Null	250.2	1.9	0.079
Traffic	249.4	1.1	0.118
Precipitation	250.8	2.5	0.059
Dispersal	248.5	0.2	0.186
Traffic + Precipitation	249.7	1.4	0.102
Traffic + Dispersal	248.3	0	0.205
Dispersal + Precipitation	249.5	1.2	0.113
Traffic + Dispersal + Precipitation	249.1	0.8	0.138

Barn owl best model is an averaged model and it has a good discrimination (Hosmer & Lemeshow, 2000) (Table 2). Although no significant, all parameters have a negative association with the road-kill likelihood. Traffic has the strongest association with road-kills likelihood while precipitation has the weakest association with barn owl road mortality (Table 2).

Table 2 - Best model explaining barn owl road-kills. This is an averaged model of the similar good model (ΔAIC<2). Parameters are represented (estimate, standard error, z value, significance (Pr(>|z|)) and model accuracy (AUC).

Variables	Estimate	Std. Error	z value	Pr(>|z|)	AUC
Intercept	2.873	4.088	0.701	0.484	0.961
Dispersal	-0.838	0.474	1.758	0.079	
Traffic	-1.401	0.908	1.535	0.125	
Precipitation	-0.0051	0.0046	1.116	0.264	

Role of climate change on barn owl population viability at long term

With an initial population of 200 individuals in each of the nine age classes the pre-road mortality mean population reached to near 1700 individuals (0.19 individuals/km^2) (Figure 4). After road mortality was included in the model at year 120 all scenarios showed a depletion in population size to around 670-680 individuals (0.07 individuals/km^2). When we added drought years, all scenarios showed populations fluctuations but different population sizes.

The high mobility scenario shows that the increase of road mortality in drought years leads to large fluctuations on the number of barn owls (Figure 4a). Road mortality reduced the barn owls population size around 60%. When the drought was included, the mean population size reduced to approximately 196 individuals (SD=40, 0.02 individuals/km^2) reaching a minimum population size of 134 individuals. As expected when there were consecutive droughts we observed even larger population depletion; two followed drought years deplete population from 326 to 273 individuals in the year after the drought. In long term, the population size does not exceed 250 individuals (Figure 4a).

In the higher population density scenario, drought years benefit barn owls population (Figure 4b). Although road mortality is present (proportion of 10%), it seems to have a low influence on barn owl population because recruitment may compensate barn owl mortality. In drought years road mortality decrease the average population density to 0.04 individuals/km^2, which correspond to average of 370 barn owl individuals (SD=37, 0.04 individuals/km^2) and a minimum of 286 individuals. Consecutive drought years led to little change in population size over time. For example, the occurrence of four consecutive drought years increases the population from 308 to 320 individuals. Population size is maintained above 250 through time.

In the mixed scenario (higher mobility combined with population density scenario), barn owls populations do not have a high population reduction in drought years (Figure 4c). Although road mortality is higher in drought years (20%), the recruitment seems to compensate barn owl mortality. Road mortality reduced the mean population density to 0.07 individuals/km^2 and with drought years presence, the mean size population is 226 individuals (SD=41, 0.02 individuals/km^2) with a minimum of 138 individuals. Consecutive drought years led to small changes on population size. For example, the occurrence of three consecutive drought years alters the population in four individuals, the number of individuals decrease from 218 to 214 individuals. Population size is maintained near 250 over time.

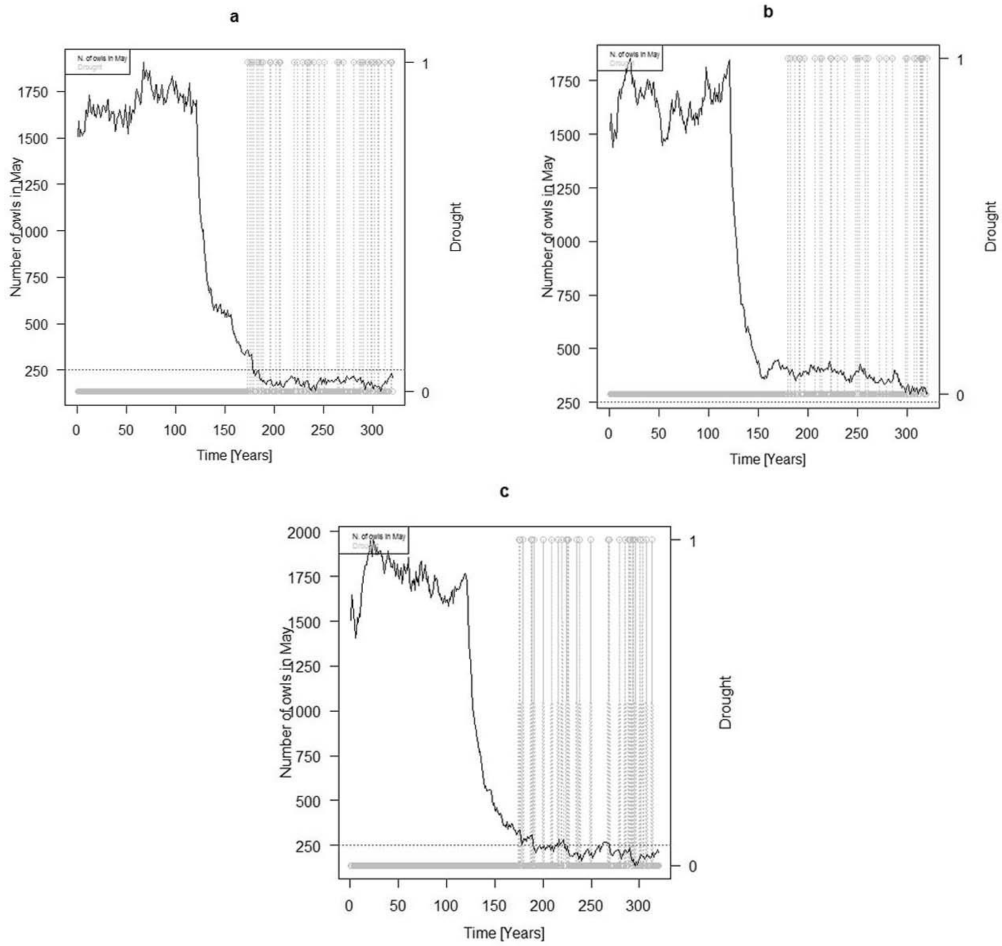

Figure 4 - Three scenarios for barn owl population viability in 320 years: a – high mobility scenario; b –high population density scenario); c – represent the mixed scenario, high mobility combined with high population density scenario. Years with drought are represented by dashed grey lines and the grey round symbol at 1, regular precipitation years are represented by 0. Dashed horizontal line represent: number of owls in May=250.

We found different results when using different scenarios to evaluate the barn owls population viability at different road-kill proportions. In the high mobility scenario, the probability of extinction increases and time to extinction gets lower with the increasing of road-killed population proportion (f) (Figure 5). The frequency of drought periods increases barn owl populations' probability of extinction and decrease time to extinction.

Barn owl populations with a road-kill proportion of below 20% (f<0.2) have probability of extinction of 0 in the absence of a drought period (Figura 5a and b). When barn owl proportion of road-kills is 40% (f=0.4), barn owls probability of extinction is 1 even when there is no drought periods (Figure 5d).

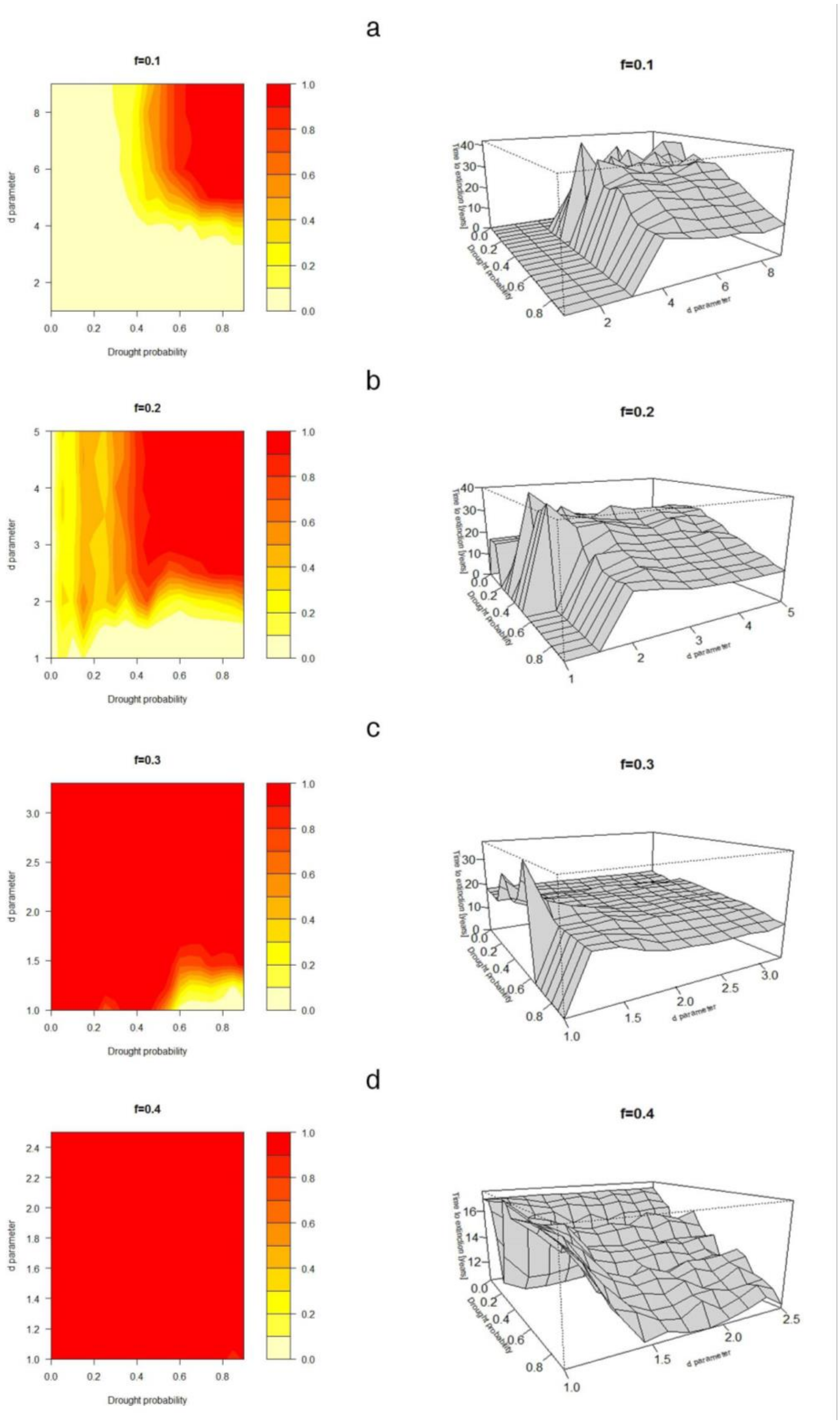

Figure 5 - High mobility scenario. Probability of extinction (left side) and time to extinction (right side) for increasing fixed road mortality. Probability of extinction - x axis: drought probability; y axis: d parameter. Time to extinction – x axis: drought probability; y axis: d parameter; z axis: time to extinction [years].

In high a population density scenario, with a road-kill proportion of 10% the barn owl population has a zero extinction risk (Figure 6a). Extinction probability is different from zero when the proportion of population road-killed is higher than 20% (Figure 6b). With road-kill proportions of 30 and 40%, higher drought frequencies represent low extinction probability for barn owl populations (Figure 6c and d). Probability extinction is 1 or near 1 for any *s parameter* or drought frequency when the road kill proportion is 40% (Figure 6d). Time to extinction is higher as the drought probability and the *s parameter* increase for populations with a road-kill proportion of 40% (Figure 6d).

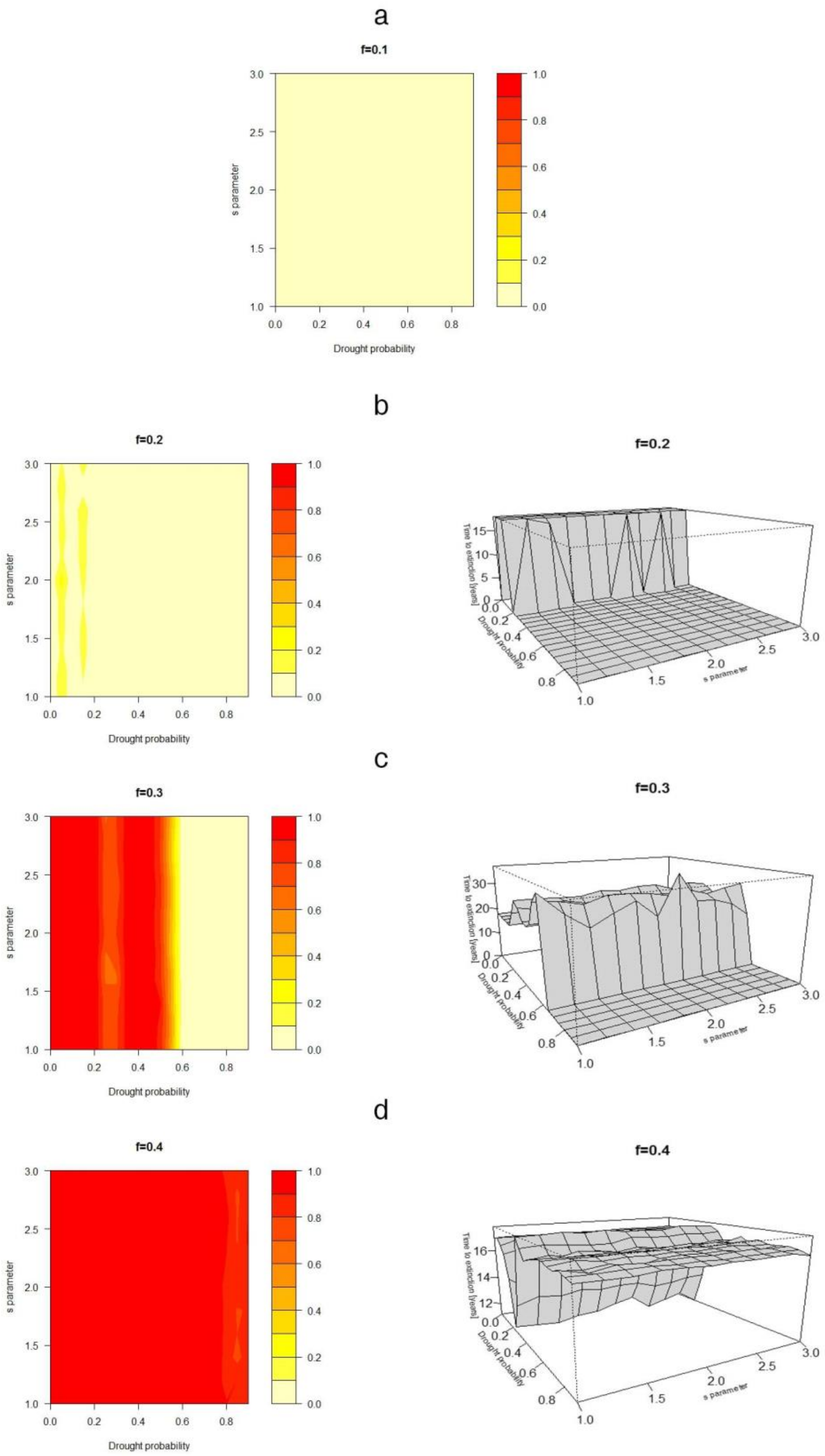

Figure 6 - High population density scenario. Probability of extinction (left side) and time to extinction (right side) for increasing fixed road mortality. Probability of extinction - x axis: drought probability; y axis: s parameter (Second clutch increasing probability). Time to extinction – x axis: drought probability; y axis: s parameter; z axis: time to extinction [years].

In the mixed scenario, road-kill proportions of 10% have a probability of extinction of 1 when d parameter and drought probability are high (Figure 7a). Extinction probability and consequently time to extinction is similar to high mobility scenario.

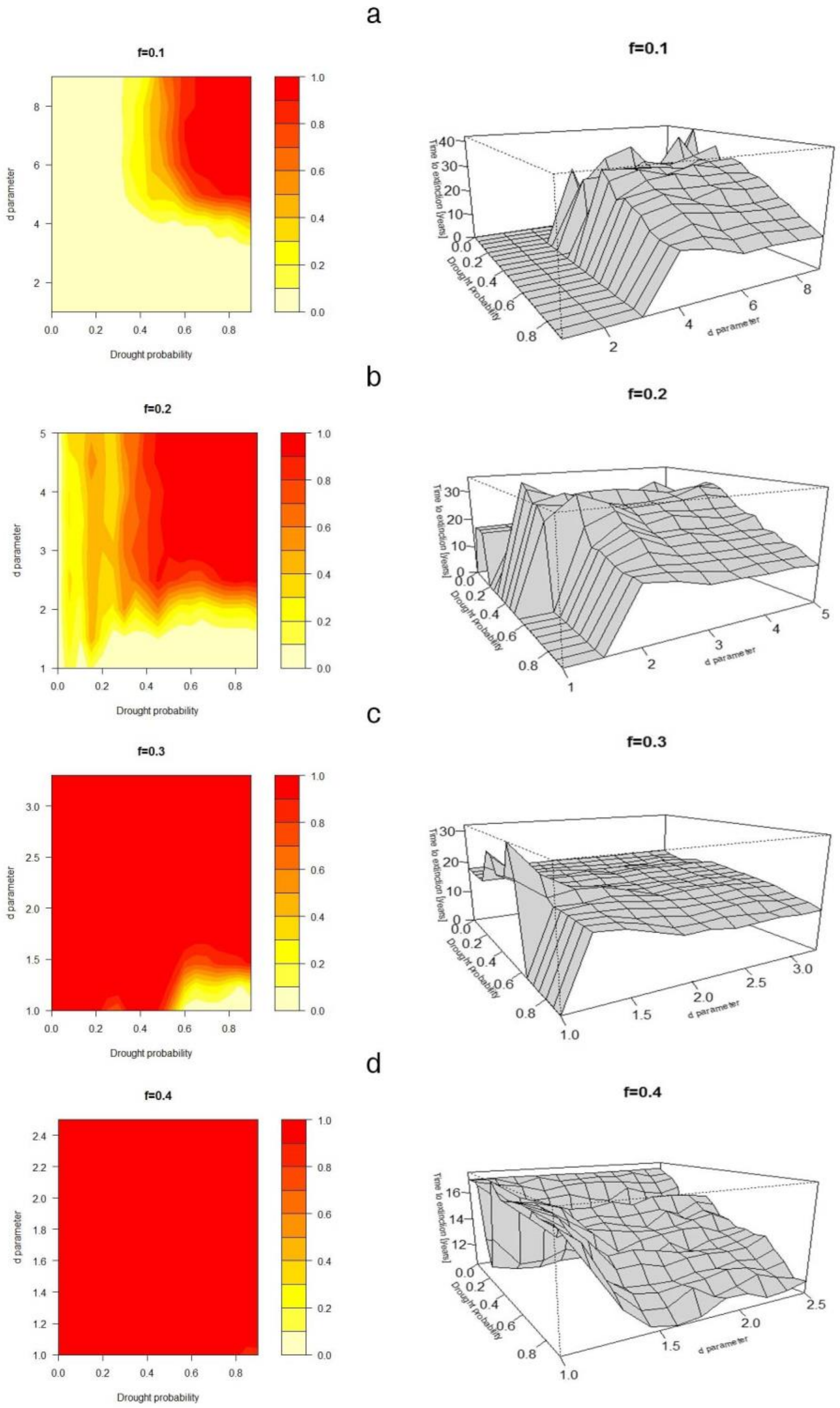

Figure 7 - Mixed scenario, high mobility and population density scenario. Probability of extinction (left side) and time to extinction (right side) for increasing fixed road mortality. Probability of extinction - x axis: drought probability; y axis: d parameter (factor of increasing road mortality). Time to extinction – x axis: drought probability; y axis: d parameter; z axis: time to extinction [years].

2.5. Discussion

This study reveals the importance of including climate to explain road-kills occurrence and in evaluating the effects on barn owl populations' viability over time. Because population dynamics are related with climate, including climate-related parameters in road-kill studies will help to understand the mechanisms underlying temporal patterns of road-kills in the present and in the future.

Our findings show that precipitation has a negative association with road-kill occurrence likelihood as well as traffic and dispersal period. In the context of a climate change as road-kill proportion increases the time to extinction decreases for all three scenarios. However, the high mobility scenario seems to represent a higher risk of extinction for barn owl populations even with low road-kill rates than in the high population density scenario.

In fact, high precipitation is largely responsible for food availability because it promotes the growth and diversity of vegetation which increases the abundance of small mammals (Zuberogoitia, 2000). In contrast, low precipitation for a long period of time, i.e. droughts, are associated to the degradation of habitat and consequently food scarcity (Thornton et al., 2014). However, the relationship between precipitation and life-history traits are complex and difficult to predict. Several studies show that the availability of prey influence the time and the length of some life cycle periods (Carey, 2009; Chausson et al., 2013). For example, bird postures can be postponed or delayed due to prey abundance that is affected by climate (Carey, 2009; Chausson et al., 2013). High precipitation levels few weeks before the postures promote the increase of clutches size due prey availability (Carey, 2009; Chausson et al., 2013) while high levels of precipitation just before the postures and birth periods have a negative impact on adults due to lack of prey (Altwegg et al., 2006). Low precipitation in the breeding period may favour early postures allowing the occurrence of a second or a third clutch along the year which benefits the population abundance (Martinez & Lopez, 1999). Thus, precipitation levels variation may change the period where they cross and also increase the number of individuals that cross the roads.

In line with a previous study, traffic has influence in road-kills affecting negatively the mortality likelihood (Grilo et al., 2015). We show that traffic play a stronger role than the other parameters. Surprisingly, we observed a negative association between dispersal and road-kill likelihood which is in contrast on what was previously found in national roads of southern Portugal (Grilo et al., 2014). This may occur due to high traffic volume and width of highways which may have an effect of road avoidance impeding juveniles to disperse (e.g. Ramsden, 2003; Seiler, 2004).

The above set scenarios for 10% road-kill proportion of population and 20% of drought probability show populations size variations. High mobility scenario seems to reduce the number of individuals and increase the populations' density fluctuations over time than in the high population density and mixed scenarios. In the high population density scenario the increasing on the number of recruits might compensate road mortality. Mixed scenario shows that an increasing recruitment success in drought years does not highly impact positively barn populations as expected; barn owl populations still have a higher depletion. In agreement with Borda-de-Água et al. (2014), populations in all scenarios decrease to less than 50%, from the original population taking only into account the proportion of road-kills. When we included the drought event, the barn owl population reduced between 79% and 88% in all scenarios. Low density populations have an increasing risk of extinction due to difficulties in recover from stochastic events such as other extreme weather events or unexpected lack of prey (Altwegg et al., 2006; González-Suárez & Revilla, 2013). Climate studies show an increase in the frequency of droughts in the 21st century, although to the best of our knowledge there is a lack of data on how much drought will increase in frequency. Last century, according to historic records of Portugal, England and Wales around 15 out of 100 years were drought years (Met Office, 2013; IPMA, 2015b). Here, we established 20% probabilities of a year become a drought year but it may not reflect the reality. The number of drought years' frequency may be higher than we assumed in the near future.

Regarding the lack of precise data on future drought frequency, a larger understanding of the implications on barn owl viability of drought presence were showed for populations affected by different road-kill proportions at different scenarios. High mobility scenario and mixed scenario show a greater risk of extinction to barn owl populations with similar results. Thus, high recruitment in drought years in mixed scenario does not compensate increasing road mortality. For instance, adults have to travel more often in order to find food or juveniles have to disperse to more distant suitable territories. Although, high population density scenario is more positive to barn owl populations in future climate predictions of more drought frequency, this might be an unrealistic scenario. It is generally well-known the consequences of drought years on individuals survival and fitness (i.e. direct or indirect mortality and diminished physical conditions) and on habitat degradation (i.e. reduced vegetation cover for prey availability) (Benton et al., 1995; Zuberogoitia, 2000; Torre et al., 2002; Altwegg et al., 2006; Chausson et al., 2013;

Parmesan et al., 2013). Thus, increasing the recruitment on drought years may only occur in first drought year and consecutive drought years may increase drastically the barn owl population extinction probability. Populations may show the same behaviour response as populations in the high mobility scenario. In fact, the improvement in the number of breeding pairs in drought years occurred only on the first year of drought (Toms et al., 2001; Met Office, 2013).

Our main conclusion is that climate may play an indirect role on barn owls population affecting the prey availability. Indeed, it has been observed that climatic conditions at regional level may affect food resources which has consequences on barn owl breeding success at local level (Marti 1994). Measures to minimize barn owls road-kills usually include road verges management to control the availability of small mammals and, therefore to reduce the attractiveness of roads to predators. However, reducing the prey availability in humanized landscape may also be harmful to barn owl populations. Our recommendation is increasing availability of prey far from the road verges by promoting the vegetation growth in the surroundings of the roads.

This study gives us the general picture of the possible effect of drought frequency increase on barn owl populations viability threaten already by road mortality, namely for southern Europe. We used general demographic parameters for Europe. For a better understanding of the effects of climate on road-kill rates, more accurate information is needed on the populations' demographic parameters at a local level.

Acknowledgments

We thank BRISA Autoestradas de Portugal for the providing barn owl road-kill records and to Instituto da Mobilidade e Transportes, I.P. (IMT, I.P.) for the traffic data.

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NOTA:

Carvalho C[1], Borda-de-Água L[2], Fonseca C[1], Clara G.[3] (Submitted in *Biological Conservation*) The role of climate on barn owls road-kill likelihood and the effect on population viability in future climate change.

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Chapter III

Conclusions and Perspectives

3. Conclusions and Perspectives

3.1. Main Conclusions

This study revealed an indirect influence of climate on barn owl road-kill likelihood. Thus, it is important to include climate parameters for a better understanding of road-kill temporal variation. Forecasted scenarios of our study showed mobility scenario puts barn owl populations in greater extinct risk if drought occurrence highly increases rather than other simulated scenarios. Possible effects of climate 21st century predictions in barn owl populations' viability might help to implement mitigation measures more effectively.
Although precipitation had little influence on barn owl road-kill likelihood, it has importance on the habitat quality for prey which in turn affect the life history periods of the species. Also, the species performance is determined by the interaction with other species, whether they are predators, competitors or preys, thus, the response to climate change will also be determined by the changes in those species which they interact.
All scenarios (high mobility, high population density and mixed) showed a similar and high impact of road-mortality on barn owl populations, population size depletion and fluctuations through time. However, high mobility scenario shows a higher extinction risk to barn owl populations. High mobility scenario led to a greater reduction of barn owl populations and larger fluctuations along time which might threat their ability to recover from other stochastic events or the increasing of road mortality.

3.2. Future perspectives

The danger of extreme weather events is that they are rare, severe and unseasonal at a specific place and time and may extend for long time. Extreme weather events might be critical to study in population viability studies in a climate change context because individuals are not used to it and in order to understand the real impacts of ecological changes on populations. Impacts of climate studied alone may underestimate the real impacts of future climate on populations (Brook et al., 2009); including climate in road mortality studies will help determining the best mitigation measures in order to reduce the effects of road mortality and climate change. Studying all these factors together (i.e. traffic, life-specific traits and climate) will give us a better understanding of possible road-kills patterns and it will be useful for mitigation and conservation plans. Also, road ecology has been relevant in species abundance studies and distribution, Fahrig & Rytwinski (2009) found 79 studies relating animal abundance and roads/traffic, thus, road-kills can help the study of animal populations due increase of road-kills with animal abundance across wider geographic regions. Likewise road-kills, each species might respond differently to climate change according to interactions between their species specific life traits and spatial characteristics (Pearson et al., 2014). Therefore, the use of these studies might help the study of the impact of climate change on abundance and distribution range of the mammals and birds populations. Due to lower carcasses road persistence of some animal groups (e.g. turtles, amphibians, small birds) this type of study needs a more effort on monitoring roads (Santos et al., 2011).

Mitigations measures to road-kills usually include fencing or vegetation control in the road verges (e.g. Bissonette & Cramer, 2008; Grilo, Bissonette et al., 2008; Glista et al., 2009). In drought scenarios these measures may not be enough to prevent barn owl populations from crossing the highways. Barn owls are already threatened by habitat loss and fragmentation (BirdLife International, 2012) which has led to prey availability depletion. Droughts might increase this depletion, so, the measures might need to be related with creating good conditions to increase prey populations' density and diminish habitat fragmentation in barn owls territories. A less suitable and fragmented landscape, it may difficult the ability of species to complete their dispersal movements by increasing the probability of crossing roads and therefore the risk to be hit by vehicles.

Here we show the big picture of the consequences of drought on barn owl populations also affected by road mortality. These were simulated effects of drought and road mortality presence on a barn owl population. In the future it will be needed a more profound study of the effects of other stochastic events (e.g. intense rainfall, lack of prey due to disease) which may reduce populations. Likewise, for a better road planning and mitigations measures, it will be needed a confirmation in field of the information provided by simulated scenarios.

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