Universidade de Évora - Escola de Ciências e Tecnologia
Universidade de Lisboa - Instituto Superior de Agronomia

Mestrado em Gestão e Conservação de Recursos Naturais

Dissertação

Spatiotemporal patterns of culvert use by terrestrial Mediterranean mammals

Catarina Feliciano Mouta

Orientador(es) | António Paulo Pereira Mira
Sara Maria Lopes Santos

Évora 2020

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A dissertação foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor da Escola de Ciências e Tecnologia:

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Évora 2020

We owe it to ourselves and to the next generation to conserve the environment so that we can bequeath our children a sustainable world that benefits all.

Wangari Maathai, environmental activist (1940 – 2011)

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First, I must thank my beautiful partner in crime João Craveiro, for everything he did during this dissertation. Helping me climb fences, paying attention to all details, motivating me when I was feeling down and overall putting up with me and my antics.

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ABSTRACT

“Spatial and temporal patterns of culvert use by terrestrial Mediterranean mammals”

Culvert flooding jeopardizes their use as safe crossing locations for animals, especially in locations with significative precipitation. The installation of elevated dry ledges inside culverts has been studied as a solution, although it is still not certain how effective they are. In order to tackle this problem, we tried to understand the under-road crossing patterns of mammals in culverts with and without ledges. We got enough data for six species, which showed carnivores had distinct preferences regarding culvert design and that culvert use was also dependent on environmental features surrounding it. Structure openness, distance to the nearest passage, water inside the culvert and season were the variables that most influenced crossing probabilities. Responses to these variables varied among species, highlighting the need for different type of structures that can fulfil each species’ necessities.

RESUMO

"Padrões espaciotemporais de uso de passagens hidráulicas por mamíferos mediterrânicos terrestres"

A inundação das passagens hidráulicas põe em risco o seu uso como locais de atravessamento seguro para os animais, especialmente em locais onde a precipitação é significativa. A instalação de passadiços elevados tem sido usada como solução, no entanto ainda não é conhecida com rigor a sua eficiência. Para tentar resolver este problema, estudámos os padrões de atravessamento por mamíferos em passagens com e sem passadiços. Apesar de só terem sido reunidos dados suficientes para seis espécies, determinámos que estes carnívoros têm preferências distintas quanto à estrutura da passagem e que o ambiente circundante também é um factor relevante no seu uso. A abertura das passagens, a distância entre elas, a quantidade de água e a estação foram as variáveis que mais influenciaram o uso. As respostas variaram entre espécies, mostrando a urgência de estruturas polivalentes que colmatem as necessidades de cada uma.

SCIENTIFIC ARTICLE

Spatiotemporal patterns of culvert use by terrestrial Mediterranean mammals

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Abstract

Culvert installation and adaptation are increasingly becoming a cost-effective alternative in road mitigation, allowing animals to cross roads and minimizing their barrier effects. However, there is still uncertainty as to which design most species prefer. Furthermore, since their original purpose is to allow the flow of water from streams, some culverts are flooded during part or throughout the year. This poses a problem in some places as it refrains animals from using the culverts. Therefore, our purpose with this study is to understand if the implementation of elevated dry ledges inside the culverts would decrease the animals' distrust and promote their crossings when culverts are flooded. More specifically, our hypotheses are (1) During the wet season (i.e., when culverts are flooded), mammals will use more culverts with ledges, compared to dry season, (2) culvert flooding will affect species differently, (3) crossings will be different according to season and species' behaviors and (4) land cover around culverts should affect crossing probability. We analyzed 16 culverts – 6 of which with elevated ledge – during a whole year in the Evora district with photo and video surveillance along three national roads. We recorded 15 species of mammals. However only 6 mammal species – all carnivores – had enough data to be modelled, with 0.70 crossings per culvert per day. Carnivores' crossing probability varied with the presence of water inside the culvert, distance to the nearest passage, slope between the road and the culvert, culvert openness and season. Two of our hypotheses were confirmed, with water cover having a positive influence on crossings by Eurasian otter and a negative one on Red fox. Seasonality of crossing was also established, for both Eurasian otter and Egyptian mongoose (wet and dry season, respectively) related with both species' reproductive patterns. Both landscape and ledge influence need further research in order to be better understood in the study area.

Keywords: road ecology, culvert crossing, mammals, culvert flooding, seasonality

1. Introduction

Roads have many negative effects on wildlife (Mata et al., 2008; Serronha et al., 2013), including habitat destruction (Mata et al., 2008; Delgado et al., 2018), landscape fragmentation (Ascensão & Mira, 2007) and barrier effect (Forman & Alexander, 1998; Delgado et al., 2018; Ree et al., 2007; Villalva et al., 2013). This last one refers to the reluctance of some species to cross roads (Ascensão & Mira, 2007), that may lead to the decrease of population connectivity, reduced gene flow and increased probability of local extinctions (Grilo et al., 2009; Serronha et al., 2013; Villalva et al., 2013).

Additionally, roads are the main anthropogenic cause of terrestrial vertebrate mortality (Forman & Alexander, 1998). A previous study in southern Portugal found an average of 47 carnivores road-killed per 100 km per year (Grilo et al., 2009), with the highest peak in late spring, coinciding with breeding and dispersal of juveniles. Roadkill hotspots tend to occur in road sections of high habitat quality and diversity (Malo et al., 2004; Carvalho & Mira, 2011; Lesbarrères & Fahrig, 2012). Common and abundant species are more likely to be killed (D'Amico et al., 2015), which matches these species' tolerance to human activity and settlements (Červinka et al., 2015).

Currently, the two main goals in road ecology are to increase the permeability of roads and decrease the number of roadkills (Malo et al., 2004; Ascensão & Mira, 2007; Grilo et al., 2009). For this last goal, fencing has been implemented in roads with high levels of traffic (Mata et al., 2005). However, while fencing protects both wildlife and humans from collisions, it increases the barrier effect (Mata et al., 2005). Therefore, additional mitigation measures are needed to make roads more permeable to animal movement, while preventing roadkills. Crossing structures are one of the most common mitigation measures for wildlife (Cramer, 2013; Glista et al., 2009) that, combined with fencing, allow animals to cross roads safely (Mata et al., 2005; Mata et al., 2008). Some of these passages are built specifically for wildlife, such as the overpasses and underpasses present in countries like Canada (Clevenger & Waltho, 2000), United States of America (Bellis et al., 2007) and Spain (Mata et al., 2008). Nevertheless, most countries don't have specific wildlife structures (Ascensão and Mira, 2007; Grilo et al., 2008; Serronha et al., 2013; Villalva et al., 2013; Delgado et al., 2018) as their implementation along road corridors is considered too expensive by road agencies (Glista et al., 2009).

The use of drainage culverts as adapted wildlife passages has been increasing as an alternative for road barrier mitigation (Yanes et al., 1995; Clevenger et al., 2001; Taylor and Goldingay, 2003; Ascensão and Mira, 2007; Grilo et al., 2008), given their high availability under roads (Villalva et al., 2013) and their low cost for wildlife adaptation (Mata et al., 2008). Culverts are originally built to allow stream flow across the landscape and prevent flooding

(Liu and Zhao, 2003), taking into consideration the estimated return period of maximum discharge based on the local climatic conditions (Schall et al.,2012).

Mammals have a high variability in both habitat requirements and ecological traits (Santos et al., 2006; Sabino-Marques & Mira, 2011; Červinka et al., 2015; Curveira-Santos et al., 2017). Carnivores are one of the most vulnerable groups (Grilo et al., 2015), due to their large home ranges, high dispersal needs and low reproductive rates (Grilo et al., 2015; Ceia-Hasse et al., 2017). Besides that, the more generalist carnivores might include roads in their home ranges due to the increased foraging opportunities such as carrion and rodent abundance on road verges; which in turn increases the probability of road mortality (Meek & Saunders, 2000; Little et al., 2002; Silva et al. 2019). Meanwhile, rodents are assumed to actively avoid roads (McGregor et al., 2008), since these are open areas with no protection from predation, frequently using them as boundaries for their home ranges (Grilo et al., 2018). However, rodents may show a similar pattern to larger animals, with habitat generalists using roads more than specialists, which can result also in high roadkill (D'Amico et al., 2015).

There are several landscape and culvert characteristics that can contribute to increase road crossing rates through culverts by mammals, namely the habitat type (Malo et al., 2004; Peris & Morales, 2004; Matos et al., 2009; Červinka et al., 2015), proximity to humanized areas (Malo et al., 2004; Glista et al., 2009; Grilo et al., 2009; Barrueto et al., 2014), the presence of vegetation near the culvert entrances (Bohman & Foresman, 2001; Ascensão and Mira, 2007; Grilo et al., 2008; Villalva et al., 2013; Craveiro et al., 2019), culvert structure (Clevenger & Waltho, 1999; Mata et al., 2005; Mata et al., 2008) and presence of water (Serronha et al., 2013; Villalva et al., 2013; Craveiro et al., 2019).

The presence of water inside culverts is a particularly important factor, especially due to the torrential or semi-torrential regime of streams in the Mediterranean (Feio & Ferreira, 2019), which increases the risk of culverts flooding (Grilo et al., 2010; Craveiro et al., 2019). Several studies have reported that culvert use can be limited by the presence of water inside the structure (Liu & Zhao, 2003; Mata et al., 2009; Grilo et al., 2010; Serronha et al., 2013; Villalva et al., 2013; Craveiro et al., 2019). Therefore, seasonality due to climate may also be a source of variation in crossing patterns (Mata et al., 2009; Serronha et al., 2013; D'Amico et al., 2015). Due to the hesitation from mammals towards water, a dry path is necessary in most cases to facilitate culvert crossing by many animals. One solution can be the installation of an elevated ledge inside culverts to allow both wildlife crossing and water runoff (Villalva et al., 2013; Niemi et al., 2014). Still, it is not certain which design each mammal species prefers; how these ledges will influence their movements across road corridors (Bohman& Foresman, 2001; Villalva et al., 2013) and if its intensity of use is dependent on species life cycle (Mata et al., 2009; Červinka et al., 2015).

In this study, we analysed the crossing probability by terrestrial mammals in a Mediterranean landscape, with a focus on the effects of seasonal flooding, in culverts with and without dry ledges. Along four intermediate-level traffic roads in Évora district, Portugal, we installed cameras inside culverts to evaluate mammal road crossing rates. Specifically, we aimed to (1) determine the factors that influence culvert crossing by mammals and (2) compare culvert efficiency – with and without ledge – for the different species of mammals. We hypothesized that (1) During the wet season (i.e., when culverts are flooded), mammals will use more culverts with ledges, compared to dry season, (2) culvert flooding will affect species differently, (3) crossings will be different according to season and (4) land cover around culverts should affect crossing probability.

2. Methods

a. Study area

The study took place between 1 April 2018 and 31 March 2019, in the Alentejo region, southern Portugal (Fig. 1). The local climate is characterized by a Mediterranean climate, with hot, dry summers and cool, wet winters – mean annual precipitation in the Evora district during the study period was 38.6 mm (IPMA, 2018, 2019).

The landscape is dominated by a traditional agro-silvo-pastoral system – *Montado*, with highly heterogenous landscapes, comprised of cork oak (*Quercus suber*) and holm oak (*Quercus rotundifolia*) woodlands intercalated with shrublands, pastures, croplands, olive groves and vineyards (Carvalho & Mira, 2011; Santos et al., 2011a). Population density in the area is 20.7 inhabitants / km^2 (INE, 2018).

According to the Atlas of Portuguese Mammals (Bencatel et al., 2019), the following mammal species can be found in the study area: West European hedgehog (*Erinaceus europaeus*), red fox (*Vulpes Vulpes*), least weasel (*Mustela nivalis*), European polecat (*Mustela putorius*), stone marten (*Martes foina*), European badger (*Meles meles*), Eurasian otter (*Lutra lutra*), Egyptian mongoose (*Herpestes ichneumon*), common genet (*Genetta genetta*), wild boar (*Sus scrofa*), Iberian hare (*Lepus granatensis*) and European rabbit (*Oryctolagus cuniculus*). Small rodents of the Cricetidae (*Microtus sp.*) and Muridae (*Apodemus sylvaticus*, *Rattus sp.* and *Mus sp.*) also occur in the study area (Bencatel et al. 2019) and may also occasionally use culverts.

Moreover, the area has a high mammal richness, associated with the spatial and structural complexity of the traditional Montado system that helps maintain a variety of habitats (Curveira-Santos et al., 2017), although the recent intensification in agriculture production can lead to the loss of these habitats and affect biodiversity (Grilo et al., 2008; Curveira-Santos et al., 2017). This high biodiversity can be due to the presence of two Natura 2000 sites in the vicinity – Monfurado and Cabrela (Grilo et al., 2008; Craveiro et al., 2019).

We surveyed 16 culverts (including six with an elevated ledge) along three national roads (EN114, EN4 and EN18) and one main road (IP2), with traffic ranging from 3000 to 10000 vehicles/day (Craveiro et al., 2019), and 6950 vehicles/day, respectively (EP, 2005) (Fig. 1). All these roads have high levels of vertebrate mortality (Santos et al., 2011b).

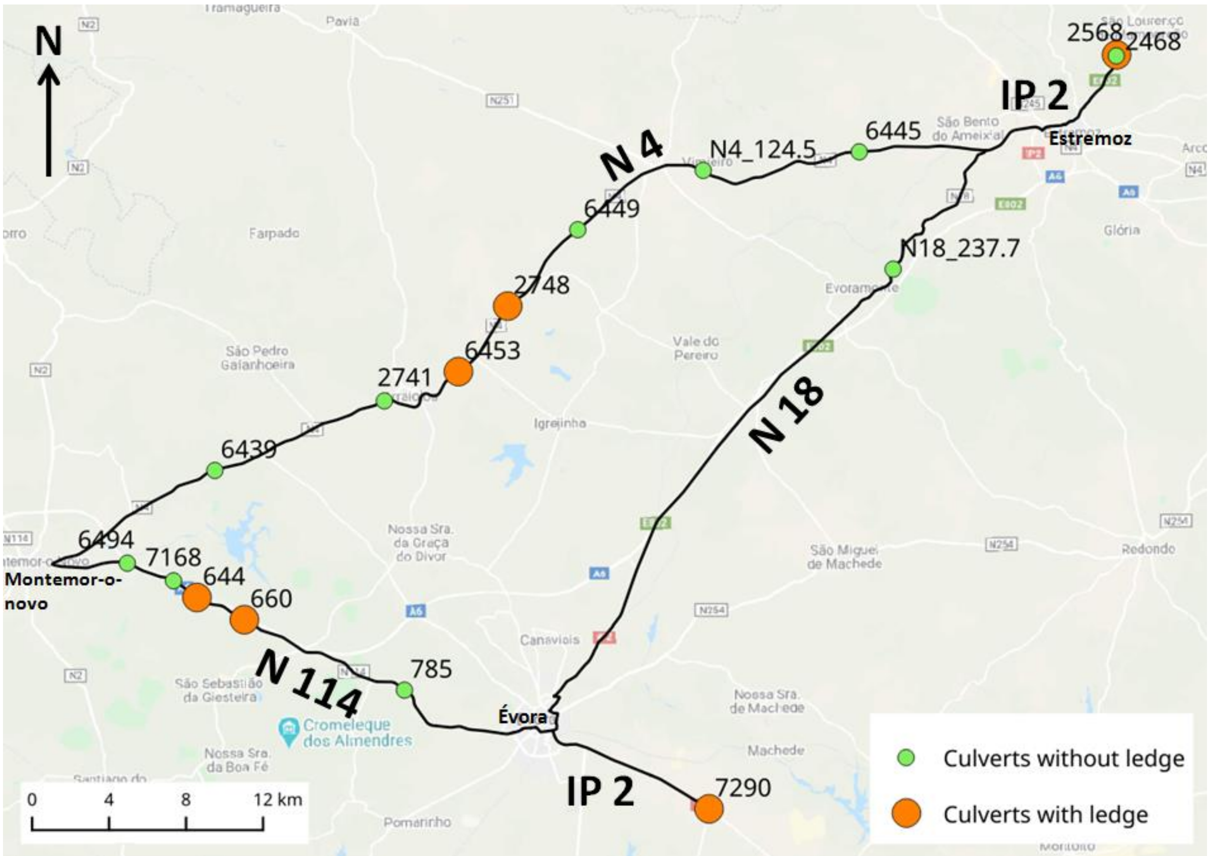

Figure 1: drainage culverts sampled in the study area

b. Sampling method

We used camera trapping and video surveillance to assess crossing probability by mammals. Sixteen Bushnell® Trophy HD Aggressor (Kansas City, MO, USA) cameras (one in each culvert) were used, which recorded two pictures with a two second interval and a thirty second video per trigger. Cameras were checked every week to replace SD memory cards, and batteries if necessary. Given the several sources of variation described above that could influence crossing probability, a full year sampling is important to get accurate results on seasonal variation (Serronha et al., 2013). Therefore, cameras were left in the field during a whole year. Photo and video-surveillance can be used all year, as opposed to marble dust (track-pads) which cannot be used in winter when culverts are flooded (Mateus et al., 2011). Furthermore, it makes detection easier, allows the record of complete crossings and gives the time of the event, which in turn can indicate why an animal is using a culvert (Mateus et al., 2011; Serronha et al., 2013).

In this study, we evaluated complete crossings only, discarding exploring visits (see Martinig & Bélanger-Smith, 2016). We considered that a mammal only visited the culvert when (1) an animal crossed towards the camera and came back within ten minutes afterwards (Martinig & Bélanger-Smith, 2016), as the lack of visibility on the far end of the camera side did not allow to make sure that the animal exited the culvert (Fig. 2d) and (2) an animal entered the culvert but did not reach the opposite end and turned back (Fig. 2e). These two situations were not considered a crossing. We considered a complete crossing to most of the other directions' combinations (Fig. 2a, 2b, 2c).

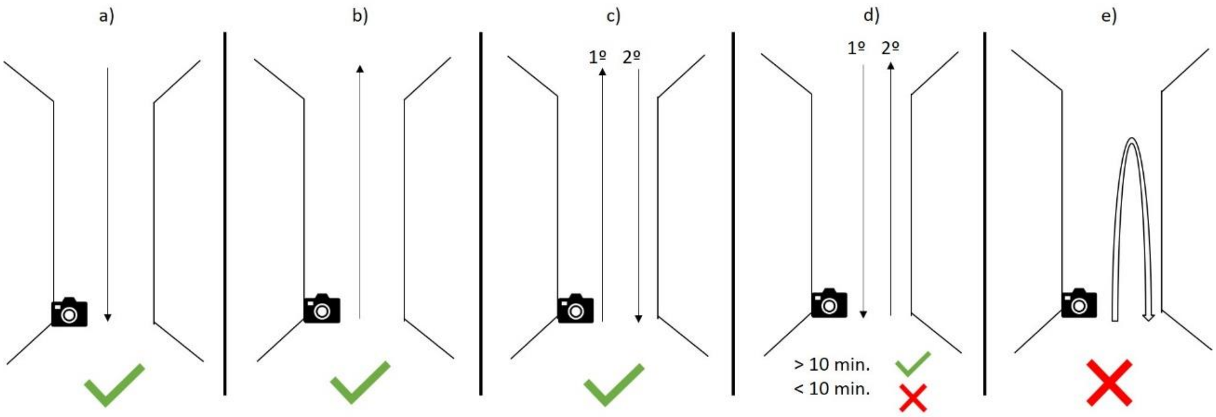

Figure 2: schematics used to assess visits and complete crossings by mammals. a) and b) - one crossing; c) – two crossings; d) – two crossings if more than 10 minutes, one visit if less than 10 minutes; e) – one visit

c. Collection of explanatory variables

According to previous studies in the area regarding culvert flooding and crossing patterns (Serronha et al., 2013; Villalva et al., 2013; Craveiro et al., 2019), we considered thirteen explanatory variables that intended to be used to explain culvert crossings evaluated by camera trapping (Table 1).

Structural variables related to the culvert or the road were also collected in the field.

- Ledge: presence or absence of an elevated ledge inside the culvert.
- Openness (m): calculated by dividing the culvert's cross section area (CCS) by its length (CL) (Ascensão & Mira, 2007), and subtracting ledge area (LA) when present (CO = CCS/CL - LA).
- Guiding fence: absence/presence of a fence perpendicular to the culvert's entrances, which guides individuals to the passage.

– Guardrail: presence/absence of a guardrail, considering three classes: absence, single and double guardrail (Fig. 3)

Figure 3: example of a single (left) and double (right) guardrails in the study area

– Stream: presence/absence of a stream running inside the culvert.
– Slope (%): average of the two slopes between the asphalt and the culvert entrances, measured in percentage as the ratio of vertical drop per horizontal distance. Horizontality was assessed with a 1 m Carpenter's level and distances were measured with a meter tape (Craveiro et al., 2019).
– Tree cover (%): visually estimated percentage of arboreal vegetation in a 10-meter radius around each culvert.

Flooding variables were measured in the field once a week, as described below:

– Water width (%): average of three water transverse widths inside the culvert as measured at both entrances and at the midpoint of the culvert tunnel having the widest water transverse width.
– Water depth (cm): average of the water depth measured at three points inside the culvert (both entrances and the middle).
– Floor water cover (%): visually estimated percentage of the culvert's ground covered with water.

In order to study the effects of the Mediterranean wet season, we considered a seasonal variable. The sampling period was divided in two seasons – wet and dry – according to meteorological reports for the district (IPMA, 2018, 2019). The decision was made according with the average temperature for each month in the Évora district and the percentage of water present in the soil, as shown on the graphic below (Fig. 4):

– Season: the two seasons of the year, as defined above. In the dry season were included the three months of summer (June, July and August), and September and October (5 months), given the large difference between the temperature and the amount of water available in the soil. Accordingly, the wet season corresponded to the period between November and May (7 months).

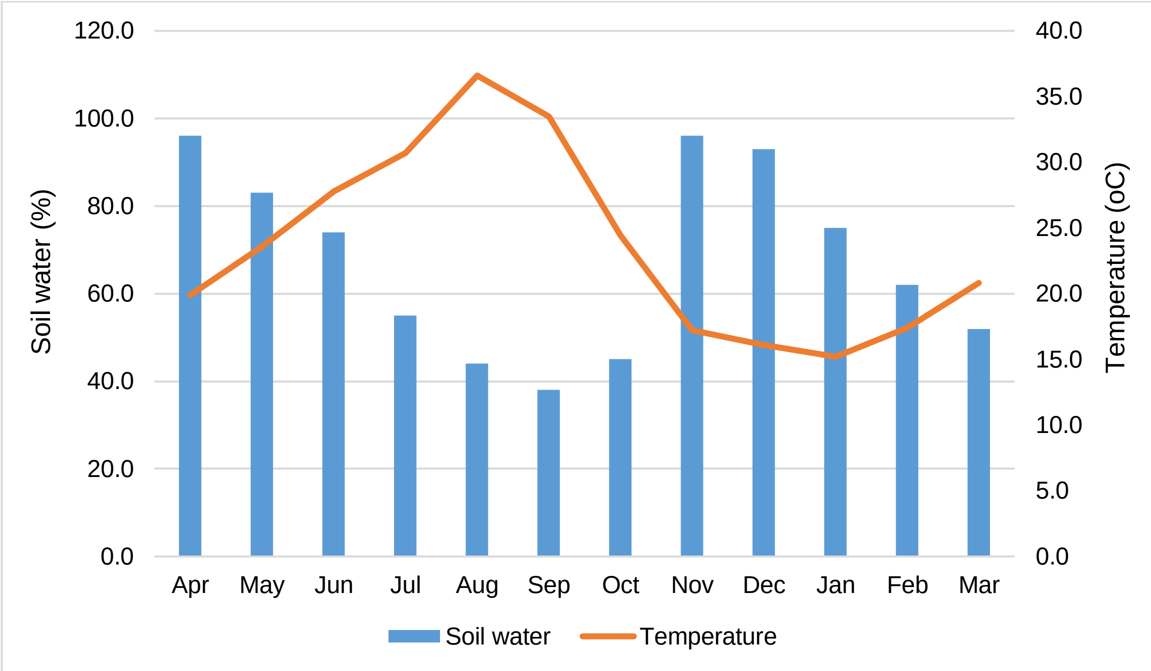

Figure 4: graphic representing average temperature and water in the soil for the Evora district during the duration of the dissertation (April 2018 – March 2019)

The remaining explanatory variables were landscape descriptors and, as so, were acquired using Geographical Information Systems (QGIS software):

– Land use: dominant land cover within a 1000 m surrounding the culvert. From the eight possible land cover classes, only the two dominant in the study area (pasture and *montado*) were used.

– Distance to nearest culvert (km): distance along the road to the nearest culvert, out of all existing culverts along the road.

Table 1: summary of the explanatory variables analyzed, including their description and range

Variable	Description	Range
Structural descriptors		
Ledge	Presence or absence of an elevated ledge	0; 1
Openness (m)	Culvert cross-section/culvert length	0.05 – 2.69
Guiding fence	Presence of a fence: 0 = absence; 1 = guiding fence; 2 = other fences	0; 1; 2
Guardrail	Presence of guardrail: 0 = no rail; 1 = single rail; 2 = double rail	0; 1; 2
Stream	Presence/absence of a stream inside the culvert	0; 1
Slope (%)	Average of the two roadside slopes between asphalt and the culvert entrances	0 - 100
Tree cover (%)	Arboreal cover in a 10-meter radius around the culvert	0 - 100
Flooding descriptors		
Water width (%)	Average of three water transverse widths inside the culvert	0 – 100
Water depth (cm)	Average of the water depth measured at three points inside the culvert	0 – 51
Floor water cover (%)	Percentage of the culvert's ground covered with water	0 - 100
Season descriptors		
Season	Two seasons of the year, defined as described above: 1 = dry season; 2 = wet season	1; 2
Landscape descriptors		
Lands use	Dominant land cover surrounding the culvert: 1 = pasture; 2 = *montado*	1; 2
Distance to nearest culvert (km)	Distance along the road to the driest culvert	0.03 – 0.59

d. Statistical analyses

After estimating the culvert crossings using the data from the cameras, this information was added to a spreadsheet of crossings per day by each species, along with the values from the explanatory variables.

Given the nature of the data, the matrix had an excess of zeros, which created a very large disparity between the crossing events and the absence of them. In order to counteract this effect, the crossings' data was transformed into binary values (presence/absence).

However, even with this transformation, the crossing data still had many zeros, so the daily matrix was condensed into weekly periods, considering crossing events per week by each species, and associated explanatory variables, using R packages "plyr" (Wickham, 2011) and "dplyr" (Wickham et al., 2019).

Due to the asymmetrical value distribution some covariates had to be transformed: continuous ones such as openness and floor depth were logarithmically transformed. The arcsine transformation was applied to covariates presented as percentages (tree cover, slope and floor cover).

Despite the initial objective of modelling crossings for all mammals, not all species had enough data to do so. Therefore, only wild species with more than 100 crossings were selected for further analysis.

After selecting which species had enough data for modelling, the matrix was separated in species-specific data sets, with associated covariates.

In order to make sure they all had the same weight over the models, continuous covariates were standardized due to their differing range of values (Zuur et al., 2007). Afterwards, we tested for collinearity between the covariates using Pearson correlation (Zuur et al., 2007). Floor water cover had a high association (> 0.5) with water width (0.96) and water depth (0.61). In turn, water depth was correlated with water width (0.56) and tree cover (0.52). Since floor water cover better describes the available dry portion for crossing the culvert, both water depth and water width were removed from the analyses to avoid multicollinearity problems in multivariate models.

To determine which variables had more effect on crossing probability, one full model (GLMM) was built for each species using R package "lme4" (Bates et al., 2015), with the culvert ID as the random factor so that each one was treated independently.

To check which combinations of covariates better explain each species's crossing probability, a set of models was generated from each of the six full models mentioned above (Barton, 2019). The Alkaike Information Criteria (AIC) was used to compare models within the same species (Bolker et al., 2009). Models displaying ΔAIC smaller than four, relative to the best model, were considered all as good as the best model (Burnham & Anderson, 2002). Thus, whenever no single model was superior, coefficients and related parameters were calculated for average models (ΔAIC < 4). The significance of covariates in the average models was assessed using the coefficients' confidence intervals (a significant covariate has confidence intervals not including the zero).

To understand if these average models show good fit to data, we compared the worst AIC from the group of averaged models to the null model's one – a model built only with the response variable and the intercept, not including any explanatory variable. If the AIC of average models are lower than the AIC of null models (ΔAIC < 4), the average model is considered significant. The fit of models was also assessed through the analysis of residual plots.

For each species, we also tested the interaction between the presence of a ledge and season (Ledge x Season) in the best previously selected models. If the AIC improvement was lower than 2 (or no improvement), the interaction was considered non-significant and was discarded from final results.

3. Results

In total, we recorded 4568 mammal crossings in our 16 culverts (0.78 ± 0.12 crossings / culvert / day), from which 89.75% were wild carnivores – 68.67% (n=3137) Egyptian mongoose, 6.92% (n=316) Common genet, 4.44% (n=203) Stone marten, 3.70% (n=169) Red fox, 3.09% (n=141) European Badger, 2.91% (n=133) Eurasian otter and 0.02% (n=1) Least weasel.

From the remaining species, 4.62% (n=211) were domestic carnivores, 0.5% (n=23) were hedgehogs, 0.33% (n=15) were rodents, 0.18% (n=8) were lagomorphs, 0.15% (n=7) were wild boars, and 4.47% (n=204) were unidentified mammals.

In total, we documented 15 mammal species. However, from these species, we only have data to statistically analyze 6: Common genet, Egyptian mongoose, Red fox, Stone marten, Eurasian otter and European badger.

In general, there was no discernible pattern in the use of the several culverts regarding ledge presence or absence (Fig. 5) (see also fig. 2 in supplementary material).

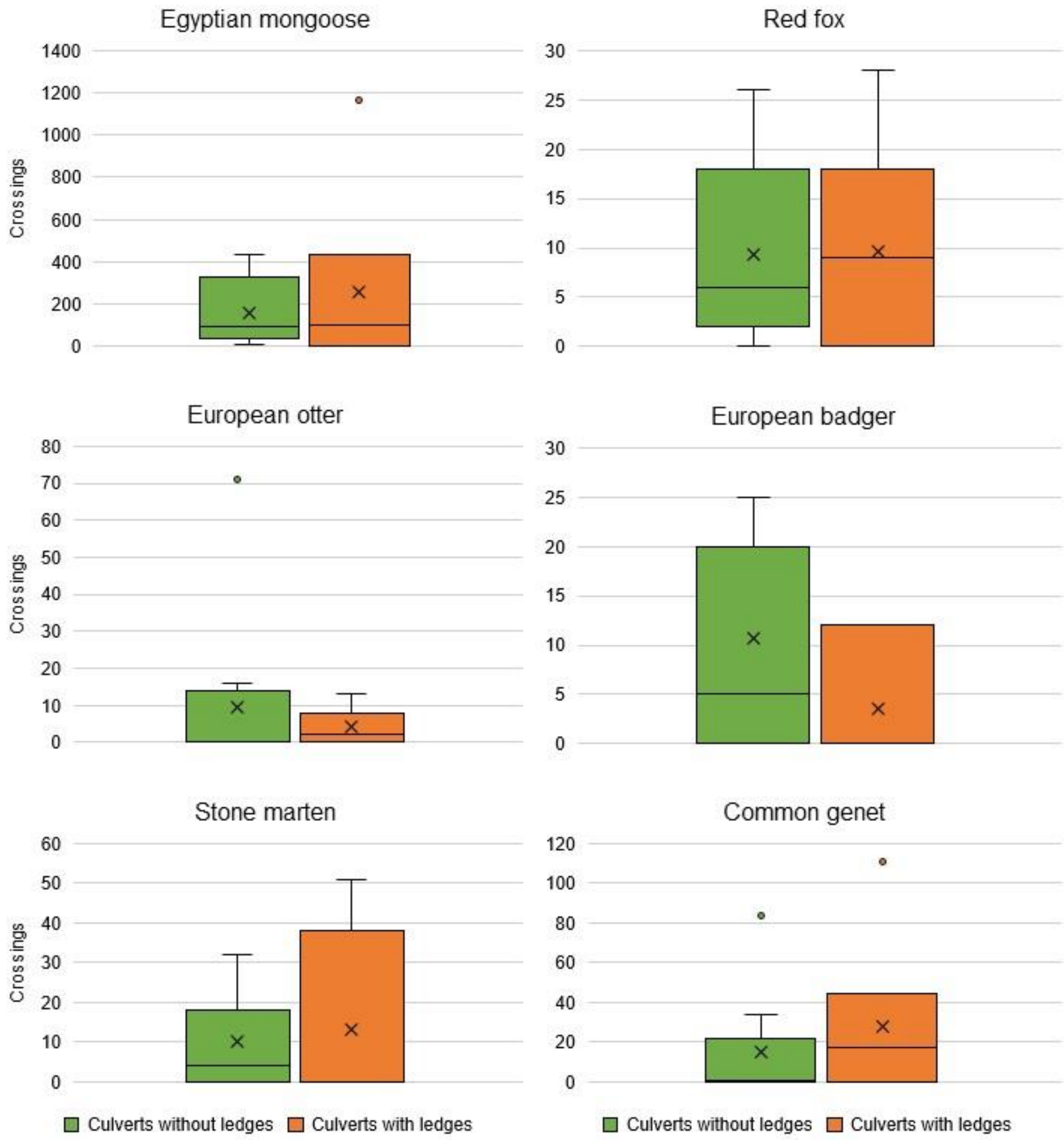

Figure 5: distribution of total of crossings (y axis) per culvert type (x axis) for each species (x: average; box: 50% percentile; black line: median value)

Although spatially we could not find any apparent patterns, there were some seasonal patterns mostly related with stages of more activity for each species (see fig. 1 in supplementary material).

Except for genet and red fox, all average models were significant, with the AIC of the worst component of the average model being lower than the AIC of the null model (Table 2). However, while the result for the genet's average model was very poor, the red fox model was very close of being significant (ΔAIC = 3.74).

None of the interactions (Ledge x Season) improved any model (see fig. 1 in supplementary material).

Table 2: comparison between AICs: null models and average models for each species (* from the worst component of the average model)

Species	AIC (null model)	AIC (average model) *	ΔAIC
Egyptian mongoose	528.2	516.42	11.78
Red fox	538.4	534.66	3.74
Eurasian otter	345.6	320.33	25.27
European badger	502.0	496.41	5.59
Stone marten	485.2	479.61	5.59
Common genet	488.8	492.47	-3.67

a. Egyptian mongoose

For the Egyptian mongoose, the probability of crossing significantly increased in the dry season and when the nearest passage was further away. None of the other variables proved to be significant or important for the probability of crossing by Egyptian mongoose (Table 3).

Table 3: average model predicting the significance and importance of the covariates influencing the crossing probability for the Egyptian mongoose (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.5%	97.5%	
(Intercept)	-	2.566	1.258	0.098	5.035	-
Season*	**27**	**-0.952**	**0.241**	**-1.425**	**-0.478**	**1.00**
Distance*	**10**	**1.153**	**0.530**	**0.113**	**2.193**	**0.56**
Stream	8	1.961	1.306	-0.603	4.525	0.30
Slope	7	0.877	0.585	-0.271	2.025	0.29
Water cover	4	-0.104	0.194	-0.484	0.277	0.10
Openness	4	-0.212	0.497	-1.186	0.763	0.10
Ledge	4	-0.337	1.392	-3.070	2.396	0.10
Landcover	3	-0.035	1.335	-2.654	2.585	0.08
Tree cover	3	-0.305	0.508	-1.302	0.692	0.08
Guardrail (simple)	1	1.943	1.662	-1.321	5.208	0.04
Guardrail (double)		2.243	1.599	-0.896	5.382	
Fence (guiding)	1	-0.311	1.628	-3.507	2.885	0.02
Fence (others)		-0.605	1.801	-4.142	2.932	

b. Red fox

For Red fox, probability of crossing significantly decreased with floor water cover, which means that this species preferred drier culverts. Moreover, the probability of crossing seems to increase when the nearest passage was further away. None of the other variables proved to be significant or important for the probability of crossing by Red Fox (Table 4).

Table 4: average model predicting the significance and importance of the covariates influencing the crossing probability for the Red fox (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.5%	97.5%	
(Intercept)		-1.981	0.796	-3.542	-0.421	
Water cover*	**17**	**-0.409**	**0.162**	**-0.726**	**-0.091**	**0.91**
Distance*	**11**	**0.592**	**0.288**	**0.027**	**1.158**	**0.66**
Guardrail (simple)	10	-0.276	0.653	-1.558	1.006	0.47
Guardrail (double)		0.946	0.612	-0.256	2.149	
Openness	3	-0.517	0.313	-1.132	0.098	0.21
Season	2	0.443	0.268	-0.082	0.969	0.16
Landcover	3	-0.750	0.495	-1.721	0.221	0.16
Stream	3	-0.737	0.506	-1.731	0.256	0.13
Tree cover	2	0.068	0.330	-0.580	0.716	0.06
Slope	2	0.189	0.221	-0.245	0.623	0.06
Ledge	2	-0.281	0.475	-1.214	0.652	0.05

c. Eurasian otter

For Eurasian otter, the probability of crossing significantly increased with floor water cover, which means that this species preferred culverts with a greater water cover. Also, the probability of crossing significantly increased in the wet season and with greater values of culvert openness, i.e., when the structures were wider. None of the other variables proved to be significant or important for the probability of crossing by Red Fox (Table 5).

Table 5: average model predicting the significance and importance of the covariates influencing the crossing probability for the Eurasian otter (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.5%	97.5%	
(Intercept)	-	-4.189	1.411	-6.957	-1.421	-
Openness*	**10**	**1.192**	**0.314**	**0.577**	**1.808**	**1.00**
Water cover*	**5**	**0.775**	**0.315**	**0.157**	**1.392**	**0.68**
Season*	**6**	**1.152**	**0.456**	**0.257**	**2.047**	**0.60**

Fence (guiding)	2	-0.466	0.899	-2.231	1.299	0.20
Fence (others)		1.266	1.138	-0.968	3.500	
Stream	1	-1.685	0.861	-3.375	0.005	0.14
Tree cover	1	0.423	0.282	-0.132	0.977	0.08
Slope	1	-0.380	0.252	-0.875	0.116	0.08
Landcover	1	0.608	0.590	-0.551	1.766	0.04
Ledge	1	-0.756	0.701	-2.133	0.620	0.04

d. European badger

For European badger, the probability of crossing significantly increased with lower culvert openness only. None of the other variables proved to be significant or important for the probability of crossing by European badger (Table 6).

Table 6: average model predicting the significance and importance of the covariates influencing the crossing probability for the European badger (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.5%	97.5%	
(Intercept)	-	-3.242	0.942	-5.091	-1.393	-
Openness*	**15**	**-1.824**	**0.922**	**-3.635**	**-0.013**	**1.00**
Slope	8	0.905	0.461	-0.001	1.811	0.68
Season	6	0.437	0.241	-0.036	0.910	0.47
Ledge	3	-0.958	1.084	-3.087	1.171	0.14
Stream	2	1.091	1.069	-1.007	3.189	0.12
Distance	2	0.412	0.561	-0.689	1.514	0.09
Tree cover	2	0.257	0.424	-0.576	1.089	0.08
Water cover	1	0.121	0.156	-0.184	0.426	0.06
Landcover	1	0.537	1.010	-1.447	2.521	0.05

e. Stone marten

For Stone marten, the probability of crossing significantly decreased with slope, i.e., in culverts at steeper locations. The presence of a fence surprisingly was not significant. None of the other variables proved also to be significant or important for the probability of crossing by Stone marten (Table 7).

Table 7: average model predicting the significance and importance of the covariates influencing the crossing probability for the Stone marten (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.5%	97.5%	

(Intercept)	-	-20.027	1183.249	-2343.569	2303.515	-
Fence (guiding)	10	17.424	1183.249	-2306.118	2340.966	1.00
Fence (others)		19.356	1183.250	-2304.187	2342.899	
Slope*	**10**	**-1.175**	**0.455**	**-2.067**	**-0.282**	**1.00**
Season	1	-0.452	0.238	-0.920	0.016	0.33
Ledge	1	-1.208	1.191	-3.547	1.131	0.10
Water cover	1	-0.147	0.168	-0.476	0.182	0.08
Distance	1	0.205	0.441	-0.661	1.072	0.06
Openness	1	0.131	0.453	-0.758	1.020	0.06
Stream	1	0.281	1.566	-2.793	3.355	0.06
Tree cover	1	-0.031	0.394	-0.804	0.742	0.06
Landcover	1	0.029	1.136	-2.202	2.260	0.06
Guardrail (simple)	1	-0.064	1.534	-3.076	2.947	0.05
Guardrail (double)		-1.224	1.685	-4.533	2.084	

f. Common genet

For Common genet, none of the variables studied significantly influenced the probability of crossing for this species. Additionally, no variables rated as important (> 0.5) (Table 8). This was expected since the average model for this species was not significant (see Table 2).

Table 8: average model predicting the significance and importance of the covariates influencing the crossing probability for the Common genet (* significant variables)

Variables	N	Estimate	Std. Error	Confidence intervals		Importance
				2.50%	97.50%	
(Intercept)	-	-3.456	2.015	-7.412	0.499	-
Openness	52	1.261	0.896	-0.498	3.020	0.45
Tree cover	43	1.189	0.980	-0.734	3.112	0.35
Water cover	34	0.210	0.172	-0.127	0.548	0.31
Slope	31	-0.944	0.867	-2.647	0.759	0.26
Ledge	28	1.282	1.819	-2.289	4.853	0.19
Season	24	-0.19	0.283	-0.744	0.365	0.17
Guardrail (simple)	18	3.428	2.836	-2.141	8.996	0.14
Guardrail (double)		0.709	3.454	-6.069	7.486	
Landcover	21	0.399	1.861	-3.255	4.053	0.13
Stream	21	-0.208	2.189	-4.505	4.089	0.13
Distance	20	-0.111	0.909	-1.894	1.673	0.13
Fence (guiding)	9	0.512	2.553	-4.5	5.524	0.06

Fence (others)		3.253	3.137	-2.906	9.411	

In conclusion, none of the models identified the presence of ledges inside culverts or the Ledge x Season interaction as a significant. Surprisingly, land cover was also not identified by the models as an important (or significant) covariate. This implies that hypotheses 1 and 4 were not supported by our results.

On the contrary, culvert flooding (Floor water cover) affected two species differently: the presence of water inside the culvert increased the crossing probability of otters but decreased the crossing probability of foxes. This clearly supports the hypothesis 2. On the other hand, there was also support for the hypothesis 3 as season influenced the crossing probability of two species: mongoose crossing was more likely to occur during the dry season, while otters crossing was more probable in the wet season.

4. Discussion

Understanding what factors influence the efficient use of drainage culverts allows road agencies to make intelligent choices when it comes to implement measures against road barrier effect and roadkill (van der Grift et al., 2013). A smart design allows for higher effectiveness, not only ecologically, but also financially (McCollister & van Manen, 2010; Karlson et al., 2017).

Although our results regarding ledge effectiveness were not completely in line with previous studies, there are still some interesting conclusions to be taken from them. The variables with significance were openness, slope, distance to the nearest passage, floor water cover and season. Although only the last two will help explain our hypotheses, all of them are important to understand carnivore preference towards culvert design, as described below.

Culvert openness influenced both European badger and Eurasian otter. For badgers this was expected, since previous studies (Grilo et al., 2015) suggested carnivores that require more cover, such as badger, seem to prefer narrower culverts. For otter, little is known about their preference for culvert openness. However, Bekker (1998) refers that otter may avoid narrow culverts. Our study seems to be consistent with this, since otter showed a preference for culverts with higher values of openness.

Slope was only significant for Stone marten. We found no ecological reason for their preference for culverts located at a less steep road sides. In our study, the roads are mostly elevated related to level of the surrounding landscape, which means that slopes are higher than in narrow roads. Dickson et al. (2005) show that for cougars (*Puma concolor*) a riparian vegetation corridor should lie along routes with relatively gentle topographies. Maybe Stone marten shows a similar behaviour as cougars in culverts at less steep road sides. Another possible explanation could be individual's responses to the structures. In their study, Ascensão et al. (2014) found that resident Stone martens tended to repeatedly use the same passages, as they were more familiar with their locations. So, it could be the case that the preferred culverts were merely the ones Stone martens were more accustomed to using.

Distance to the nearest passage had a role in the crossing probability in some species. Both Egyptian mongoose and Red fox probability of crossing increased with distance to the nearest passage, meaning isolated culverts had a higher use probability (Clevenger & Waltho, 2005; Craveiro et al., 2019). This is an important result and suggest that in some road stretches culverts availability within the individuals' home range may be scarce, forcing them to travel larger distances to find safe road passages (Seiler & Olson, 2009; Delgado et al., 2018).

Surprisingly, the presence of a stream on culverts and their contiguity did not show any influence in crossing probabilities, not even for otter, a species highly associated with riparian galleries (Serronha et al., 2013). Many studies suggest the importance of riparian ecosystems for carnivores (Santos et al., 2011a), particularly during summer, when resources are harder to find (Matos et al., 2009; Grilo et al., 2016). Since only four of our culverts did not have an associated stream, this lack of data variability can be the cause of this unexpected result.

The remaining structural descriptors were not significant for any species, although we were expecting some degree of significance for the presence of a guiding fence. Both Ascensão et al. (2007) and Craveiro et al. (2019) have related the role of fences in directing the animals, thus making culverts easier to find.

a. Influence of ledges

Despite several technical recommendations advising the implementation of dry ledges in culverts (Trocmé et al., 2002; Reck et al., 2018), the information of their effectiveness for carnivore use is still scarce. In his study, Villalva et al. (2013) showed the importance of dry ledges for stone marten and genet. In our study, contrary to our expectations, ledge presence had no significant influence – or importance – in the carnivores' crossing probabilities, even during wet season. This may be because culverts without ledges are not flooded in a way that it hampers the crossing by carnivores, thus making the comparison between culverts with and without ledges more difficult. For example, Serronha et al., (2013) related that only a water cover superior to 70% would make carnivores less likely to cross. Other possible explanation could be the adjustment period that animals need to adapt to the new structures (Clevenger & Huijser, 2011; see Grilo et al., 2015). The ledges were installed in September 2017 and may have caused environmental disturbance (Clevenger & Waltho, 2000; Barrueto et al., 2014). It is thus, important to continue the monitoring of these modified culverts to obtain more long-term data.

b. Influence of culvert flooding

Floor water cover was the only flood-related factor that significantly influenced the crossing for some species. Red fox crossed more often in drier culverts, a preference already related by Villalva et al. (2013) and Serronha et al. (2013). Contrary to red fox, Eurasian otter preferred culverts with water inside, a result also related by Serronha et al. (2013), which is consistent with the species's aquatic habits requirements (Santos et al., 2011a; Grilo et al., 2016).

c. Influence of season

Not surprisingly, our study showed that season influenced the crossings of two different carnivore species in opposite ways. As expected, both seasonality patterns found were related with specific life-history moments of each species (Mata et al., 2009; Červinka et al., 2015). Egyptian mongoose crossed more during the dry season, when the females have their cubs and when juveniles disperse (Loureiro et al., 2012). We observed adult females crossing some culverts along with their cubs. For otter, seasonality of crossings was related not only with its affinity with aquatic environments, but also with reproduction, since most births in the Mediterranean area occur between December and February due to the larger availability of resources (Ruiz-Olmo et al., 2002).

d. Influence of surrounding landcover

As stated before, our study area is a human modified landscape with high heterogeneity (Carvalho & Mira, 2011; Santos et al., 2011a). The carnivore species present on this study have different landscape needs, where some being more arboreal (e.g., genet) and others more generalist (e.g. mongoose). So, and even with the recent intensification in livestock production in all study area (personal observation), we were expecting carnivore preference for areas of *montado* over areas of pasture.

While generalist carnivores such as Egyptian mongoose and red fox are more flexible and tolerant and may even benefit from farming activities (Červinka et al., 2015), genet and stone marten are more dependent on shrub and arboreal cover in their activity (Santos-Reis et al., 2004). However, this did not happen for any of our species, not even the more arboreal ones, such as genet and stone marten (Grilo et al., 2008). One possible explanation for these results is that many culverts in the study area are in the continuity of riparian corridors that cross pasture land, which are intensively used by the more arboreal species when moving in this more inhospitable areas turning easier to find and use the culverts.

5. Conclusion and future recommendations

Even though our study did not fully support the importance of dry ledges, culvert adaptation with elevated ledges is considered an effective measure to avoid crossing reluctance by individuals (Trocmé et al., 2002; Niemi et al., 2014; Reck et al., 2018; Craveiro et al., 2019). This means culverts with ledges in our study area require more monitoring and research concerning their location, design, and effectiveness.

Some of the covariates analysed in this study also require further examination, as is the case of fences, which should be improved in order to better guide animals towards the structures and therefore prevent access to the road.

This study helped consolidate some ideas that had already been proposed (Serronha et al., 2013; Polak et al., 2019), such as the need for polyvalent structures that can accommodate several species, since the crossings patterns we observed varied among them.

For the remaining species that could not be modelled, mainly smaller mammals like rodents and lagomorphs, a bigger remodelling of culverts probably needs to be done. According to McDonald & St. Clair (2004), these mammals prefer smaller passages with a thicker cover for protection.

The lack of long-term monitoring and culvert maintenance is pointed out as one of the causes for the information deficiency in this field (van der Grift et al., 2013). Therefore, in line with previous studies (Delgado et al., 2018), we emphasize the importance of monitorization both during and after culvert adaptation. Not only will this show the effectiveness of the measures but will also serve as a tool for future studies.

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7. Supplementary material

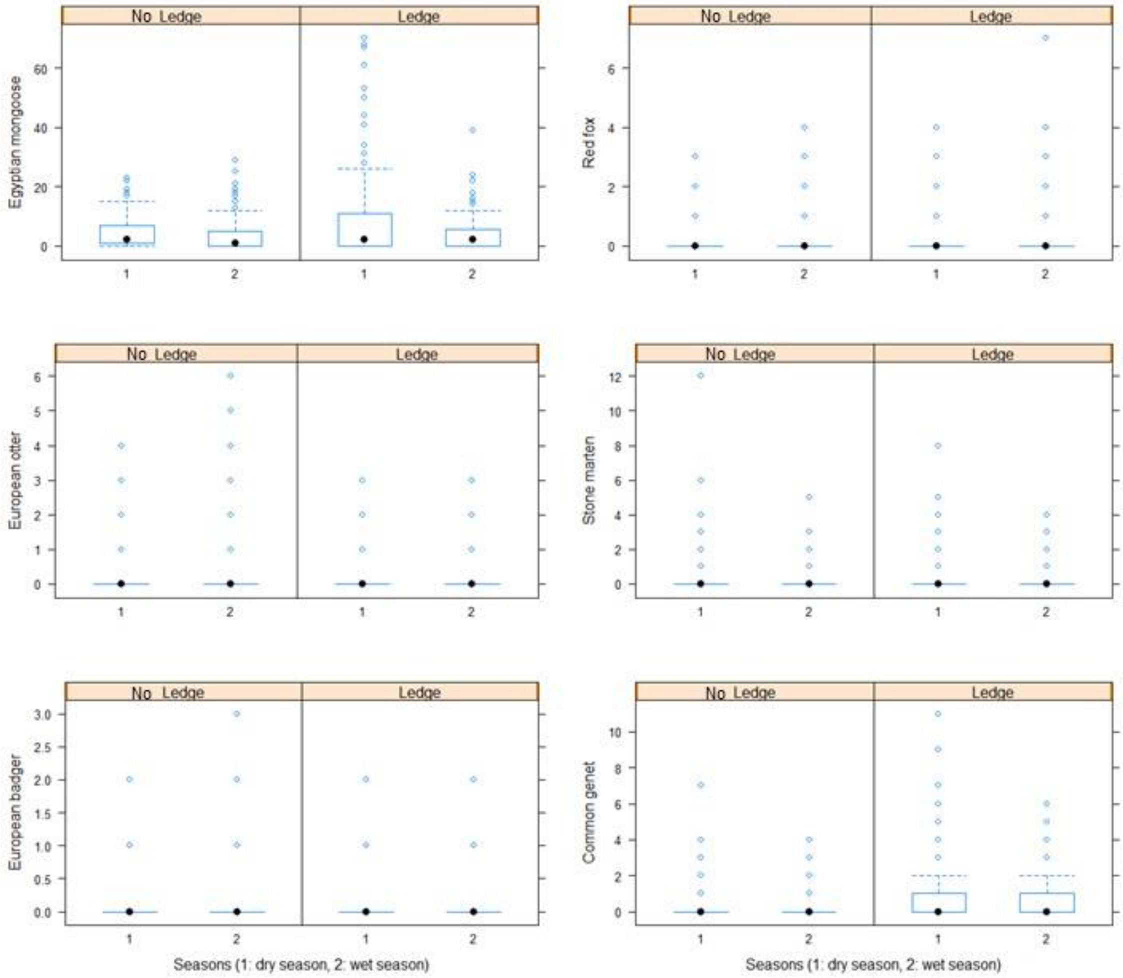

Figure 1: distribution of crossings rate (y axis) for each species during the seasons (x axis), with culverts without ledges on the left of the plot and culverts with ledges on the right. Points – median; Boxes – 50% percentile

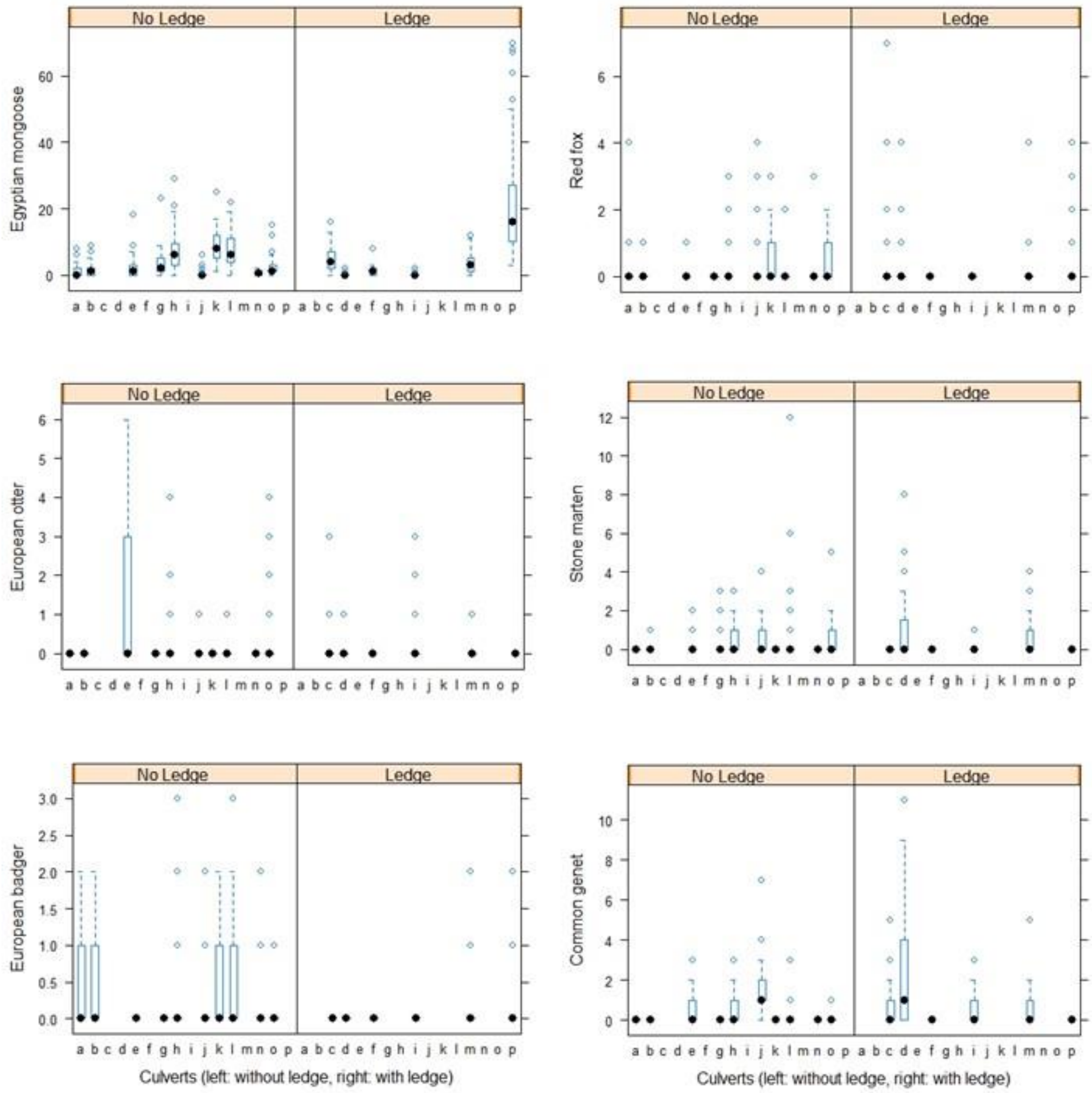

Figure 2: distribution of crossings rate (y axis) for each species during per culvert (x axis), with culverts without ledges on the left of the plot and culverts with ledges on the right. Points – median; Boxes – 50% percentile