Towards effective culvert design: monitoring seasonal use and behavior by Mediterranean mesocarnivores

Ana Marta Serronha · Ana Rita Amaro Mateus · Finn Eaton · Margarida Santos-Reis · Clara Grilo

Abstract Drainage culverts are known to be used by a diverse number of species. To date, most studies looking at culvert usage have been restricted to the dry season. This seasonal bias has limited our understanding of how different species respond to culverts and, consequently, our ability to find effective ways to promote the use of culverts as aids to species movement. The main goal of this study was to examine the role of highway culverts for mesocarnivores throughout the year. We addressed (1) the seasonality of culvert use, (2) the relative importance of culvert structure, highway features, and surrounding landscape on culvert use, (3) the influence of the water depth and cover on culvert use, and (4) the effect of culvert structure on individual behavior. Fifteen culverts were monitored along 2 highways in southern Portugal using video-surveillance cameras and marble dust for 10 consecutive days *per* season. We used generalized linear mixed models to determine which factors most affected the culvert use and behavior by mesocarnivores. Our results highlight the effect of seasonality and water on culvert use. Culvert use was positively related with species activity throughout the year. All species (except otters (*Lutra lutra*)) were less likely to use culverts that contained water more than 3 cm deep or covering more than 70 % of the culvert

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base. Based on our results, future surveys and culvert retrofit design should address (1) the importance of seasonality in the interpretation of results and (2) the complementarity of culvert-specific features (water, ledges, and naturalization).

Keywords Carnivore conservation · Road mitigation measures · Crossing structures · Video-surveillance

Introduction

Road networks have grown over the last few decades in response to increasing human demands (Forman et al. 2003) and have been described as one of the largest threats to biodiversity (e.g., Fahrig and Rytwinski 2009; van der Ree et al. 2011). They can act as barriers to animal movement, either through direct mortality due to vehicle strike or by the promotion of avoidance behaviors (Jaeger et al. 2005; Grilo et al. 2009). In the long term, roads may lead to irreversible ecological consequences, such as reduced gene flow between fragmented populations (e.g., Epps et al. 2005) which is known to contribute to the decrease in genetic variability and increase the risk of local extinction by stochastic effects (Riley et al. 2006).

In order to mitigate such effects, solutions have been sought to allow animals to cross roads safely. One solution has been the use of drainage culverts as aids to animal movement (e.g., Taylor and Goldlingay 2009; van der Ree et al. 2009). These structures pass perpendicularly under roads and are widespread throughout the road network. Their main function is to allow water to drain from the surrounding area to prevent flooding and maintain the natural flow of local streams (Rossell and Velasco 2001).

It is generally agreed that drainage culverts are regularly used by mesocarnivores (Yanes et al. 1995; Rodriguez et al. 1996; Clevenger et al. 2001; Cain et al. 2003; Ng et al. 2004). Previous research indicates that the shape of culverts (Mata et al. 2005, 2008), as well the availability of cover near culvert entrances (Rodriguez et al. 1996; Ascensão and Mira 2006; Grilo et al. 2008), plays an important role in how culverts are used. As the most widely used survey technique is marble dust, or other similar tracking substrates that are washed away with rain, previous studies were generally restricted to the dry season or were interrupted during rainy periods (e.g., Yanes et al. 1995; Rodriguez et al. 1996; Mata et al. 2005, 2009; Ascensão and Mira 2006; Grilo et al. 2008). This has limited our knowledge on how to design culverts so that they can best promote animal movement. To date, there have been no documented studies that have focused on how carnivores use culverts throughout the year or on how the presence of water within culverts may affect animal behavior and culvert usage.

One method that allows for the evaluation of how water affects the extent culverts are used by carnivores to cross roads is video-surveillance (Stewart et al. 1997; Mateus et al. 2011). This method also has the advantage of being able to record an animal's behavior towards the culvert itself (see Hardy et al. 2003; Dodd et al. 2007), which can yield valuable insights regarding culvert design as a road mitigation measure.

In this study we wanted to address (1) the effect of season on culvert use; (2) the relative importance of culvert and highway features and of the surrounding landscape on culvert use, irrespective of season; (3) the influence of water depth and cover at culvert entrances on culvert use, and also (4) the effect of culvert structural features on individual behavior. We separated the analysis to clarify the role of each group of features on culvert use, taking into account the random variation in space (culverts surveyed) and/or time (season).

Methods

Data collection

Fifteen drainage culverts were surveyed along 2 highways (A2 and A6) in Alentejo, southern Portugal (Fig. 1). The average distance between culverts was 2 km to minimize the effects of spatial autocorrelation and assure independence of observations (Guisan and Zimmermann 2000). This value corresponds to the average diameter of medium-sized carnivore home range (Cavalini and Lovari 1994; Palomares and Delibes 1994; Rosalino et al. 2004; Ruiz-Olmo et al. 2001; Santos-Reis et al. 2004). The majority of culverts used in this study were located in cork oak (*Quercus suber*) woodlands, the dominant landscape in the region, and their choice was based on logistical

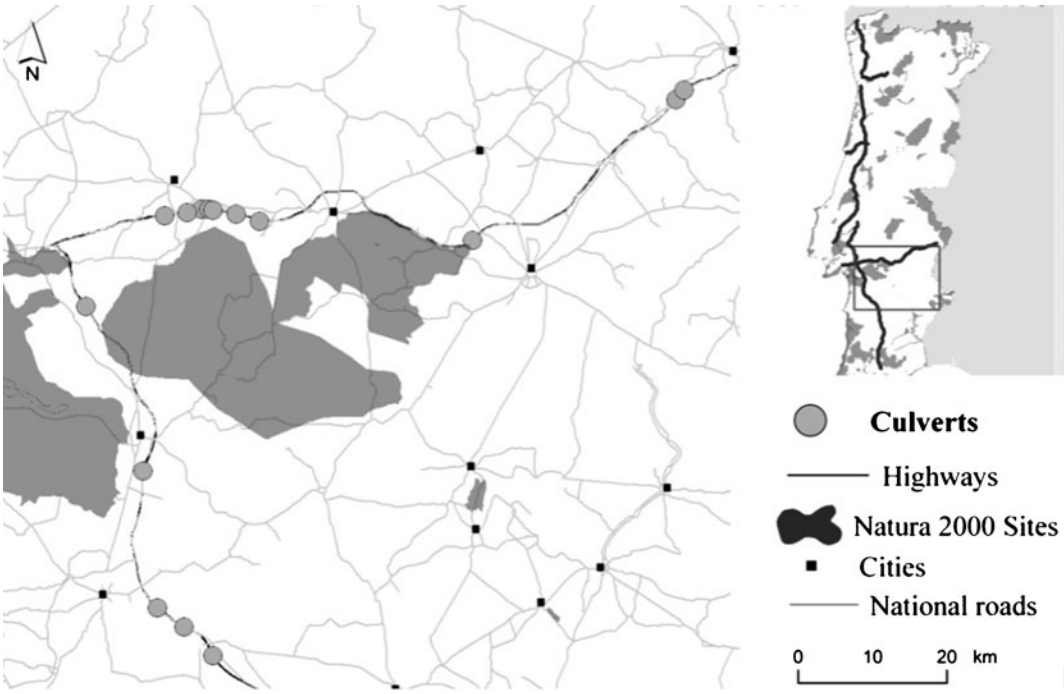

Fig. 1 Study area with the location of the culverts surveyed

criteria such as security and a low probability of vandalism.

Culverts were surveyed throughout 1 year (from the autumn of 2005 to the summer of 2006) using video-surveillance systems to visualize animals approaching/crossing and marble dust to record their tracks. Each culvert was surveyed for 10 consecutive days *per* season (autumn, winter, spring, and summer), resulting in a total of 40 days of surveillance. Video-surveillance provided a continuous record of the nighttime activity, from dusk till dawn, a total of 14 h of nighttime surveillance. This decision was based on the fact that, with the exception of the Egyptian mongoose *Herpestes ichneumon* (Palomares and Delibes 1992), Mediterranean carnivores exhibit nocturnal activity (Blanco 1998). These surveillance systems were hidden near the entrances of each culvert. Two pairs of one camera and an infrared illuminator pair with 56 automatic-activation infrared light-emitting diode (YIL-56DS), and an infrared light capacity of up to 3 m, were respectively positioned to film the inside and the outside of each culvert (see also Mateus et al. 2011). For every event recorded, we registered the animal's species, the direction of the individual's movement, and the type of crossing (successful or attempted). A successful crossing was defined when an animal passed through a culvert and did not pass back through the same opening within 2 min; this helped to avoid multiple counts of any animal that stayed near the culverts' entrance. A crossing was considered to be "attempted" when an animal entered the culvert but returned within 2 min by the same entrance or when it approached a culvert but did not enter.

Each crossing was also described on the basis of the individual's behavior towards the culvert. Reluctant behavior in relation to culverts was defined when any animal took more than 4 s to cross the distance between the two cameras (approximately 5 m) as it was entering or leaving the culvert.

Data analysis

Effects of seasonality on culvert use

A univariate analysis was performed to examine the relationship between culverts use with each season using generalized linear mixed models (GLMM) with Poisson distribution and log link function for each species. The number of successful crossings was the response variable and culvert ID was the random effect to avoid pseudoreplication among culverts (Bolker et al. 2009). When residuals indicated overdispersion, the data was refitted with a quasi-Poisson model.

Effect of culvert, highway, and surrounding landscape features on culverts use

Each drainage culvert was characterized by using a list of 15 independent variables incorporating culvert-, highway-, and landscape-related features (Table 1). Culvert-related features included structural features such as culvert width, length, area, openness, and shape. These features have been shown to have an effect on how different vertebrate species utilize culverts (e.g., Clevenger et al. 2001; Mata et al. 2008). Culverts were additionally characterized in terms of internal presence of water, presence of vegetation at the entrances within a 50-m buffer around the culvert (a reasonable distance to measure in the field), and distance from highway pavement.

Road-related features included daily average traffic volume and number of existing passages (overpasses, underpasses, and culverts) in a 500-m buffer around each culvert (source: Brisa—Auto-estradas de Portugal S.A.). The surrounding landscape at each entrance was characterized within a radius of 500 m on the basis of the percentage of land covered by forest (oak woodlands and pine woodlands), open areas, and understory, the distance to water sources, and the orientation of riparian vegetation in relation to the culvert axis.

Similar to the previous analyses, a five species-specific GLMM with Poisson distribution and log

Table 1 Summary of culvert-, highway-, and landscape-related features including designation, definition, and range

Variables	Definition	Range
Culvert-related features		
Culvert width	Culvert width (m)	1–4
Culvert length	Culvert length (m)	1–4
Culvert area	Culvert section area (m^2)	0.79–9
Openness	Width × height/length	0.014–0.209
Shape	1—circular; 2—square	1; 2
Water inside the culvert	0—absence; 1—presence (if cover the entire culvert base)	0; 1
Vegetation at the entrance	0—absence; 1—one culvert side; 2—on both culvert sides[a]	0; 1; 2
Distance to highway	Distance from the culvert to the travel lane of the highway (m)	9–30
Highway-related features		
Traffic volume	Mean 2005/2006 average daily traffic volume (vehicles/day)	2,227–12,096
Number of crossing structures	Number of crossing structures[b]	2–6
Landscape-related features		
Forest	Oak or pine woodlands (%)[b]	20–100
Open areas	Extensive agriculture[b]	0–60
Understory cover	Shrub cover[b]	0–60
Distance to water sources	Distance to the nearest streams, ponds or lakes (m)	510–18,695
Orientation of riparian vegetation	0—absence; 1—parallel on both culvert sides; 2—parallel on one side and perpendicular on the other; 3—perpendicular on both culvert sides	0–3
Water presence[c]		
Water depth	Water depth (cm) (if cover the entire culvert base)	0–90
Water cover	Percentage of water cover on the culvert base	0–100

[a] Within 50 m radius

[b] Within 500 m radius

[c] Used only for univariate analysis regarding water depth and cover

link function was selected to assess the culvert-, highway-, and landscape-related features that are thought to influence culvert use. The number of successful crossings was used as the response variable (Zuur et al. 2009). Culvert ID and season were used as random effects to avoid pseudoreplication (Bolker et al. 2009). Prior to this analysis, the association between culvert features was investigated using Spearman's rank correlation in order to reduce the effects of multicollinearity. For any pair of independent variables that resulted in an $r \geq 0.50$ (with $p < 0.05$), the variable with the smallest biological meaning was removed. The candidate models for GLMM analysis were designed using four sets of variables corresponding to the following hypotheses: (1) culvert structure affects the use of culverts, (2) crossing events are related to highway features, (3) characteristics of the surrounding landscape explain the crossings, and (4) the interaction of the best previous models explains the crossings. Because we detected overdispersion in our residuals, standard errors were corrected using a quasi-Poisson model. In this case, the Akaike's information criterion (AIC) is not defined; thus, we had to compare two models M_1 (full model) and M_2 (nested model) using the F test statistic. To do so, a full model was initially used, nonsignificant terms were then removed (nested model), and this process was repeated until a model containing only significant variables was produced.

Additionally, using a GLMM univariate analysis for each species, predictions were made as to how water cover (in percent) and depth inside the culvert (Table 1) would affect the likelihood of culvert use by carnivores during the wet seasons (autumn and winter). Culvert ID and season were used as random effects to avoid pseudoreplication.

Species behavior within culverts

The behavioral attributes (reluctance or nonreluctance) of each individual crossing were also analyzed. The influence of specific culvert structural features (Table 1) on the behavior of animals entering and leaving a culvert was, therefore, examined. This was carried out using five species-specific GLMM with binomial distribution and logit link function for behavior data (reluctant=0 and no reluctant=1) and culverts as random effect.

All statistical tests were performed using the *lme4* (Bates et al. 2011) and *nmle* (Pinheiro et al. 2012) packages in R version 2.10.1 (R Development Core Team 2011).

Results

Crossing events

A total of 405 successful crossings were recorded. This is equivalent to 0.68±0.01 crossings/culvert/day (mean±standard deviation). Of these crossings, 42 % was performed by Eurasian badgers (*Meles meles*), 20 % by stone martens (*Martes foina*), 20 % by Eurasian otter, 10 % by common genet (*Genetta genetta*), and 9 % by red fox (*Vulpes vulpes*). On 60 other occasions, animals approaching the culvert did not effectively cross through the structure, resulting in 67 % of successful crossings for red fox (successful crossings/(successful crossings+crossing attempts)), followed by 87 % for stone marten and genet and 91 % for Eurasian badger and Eurasian otter. None of the other mesocarnivores potentially occurring in the region (e.g., weasel *Mustela nivalis*, polecat *Mustela putorius*) approached the surveyed culverts during the study period.

Effects of seasonality on culverts use

Carnivore species exhibited different responses to culverts in each of the four survey seasons (Fig. 2). The univariate analysis show that red fox crossings are positively associated with spring, whereas in summer, culverts were significantly more frequently used by stone marten and genet than in other seasons. The results of this study also showed that, in winter, otters use culverts more often than in other seasons (Table 2).

Effects of culverts and highway features and surrounding landscape on culverts use

The effect of culvert-, highway-, and landscape-related attributes on culvert use varied among species (Table 3). We observed a number of trends in culvert use exhibited by the study species: (1) the presence of water had the strongest negative influence on culvert use by stone marten and genet; (2)

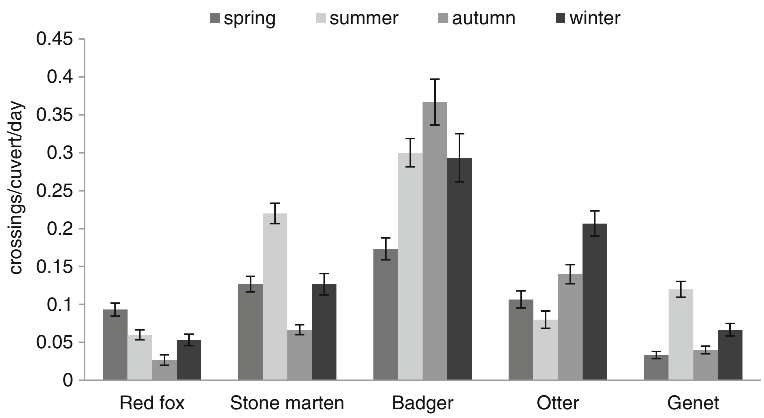

Fig. 2 Successful crossing rate in each season and standard deviation

there were few recorded observations of culvert use by red fox when culverts were in open areas; (3) stone marten unexpectedly tended to avoid culverts with vegetation cover at the entrance; and (4) otters tended to cross through culverts with riparian vegetation oriented towards the culvert.

By applying the estimates obtained for the univariate analysis regarding water cover and depth (Appendix), it was observed that all species, apart from otters, are less likely to use a culvert when water depth inside was higher than 3 cm (Fig. 3a). On the other hand, otter tend to use culverts more often when water reaches 50 cm in depth. It was also observed that red foxes, stone martens, and genets are less likely to use culverts that are covered internally with more than 70 % water. This finding is inversely true for otters, which respond positively to this factor (Fig. 3b).

Species behavior towards culverts

Red fox and genet were not included in the GLMM analysis as there was lack of data regarding crossings made by these two species. Four

Table 2 Summary of univariate analysis of the relationship between successful crossings and season for each carnivore species (coefficient estimates)

Variables	AIC	ΔAIC	W_i	Estimate	SE	*Z* test	Significance
Red fox							
Autumn	77.59	0	0.398	−0.949	0.545	−1.742	0.081
Spring	77.85	0.26	0.350	0.693	0.354	1.959	0.050
Null	79.64						
Stone marten							
Autumn	110.6	1.6	0.302	−0.862	0.341	−2.527	0.012
Summer	109	0	0.671	0.724	0.228	3.172	0.002
Null	116.6						
Badger							
Spring	134.4	0	0.398	−0.613	0.214	−2.871	0.004
Null	141.9						
Otter							
Winter	101.7	0	0.709	0.641	0.231	2.773	0.006
Null	107						
Genet							
Summer	90.83	0	0.826	0.944	0.329	2.873	0.004
Null	96.98						

We only show the seasons with AIC<2

AIC Akaike's information criterion, Δ*AIC* AIC_i−minAIC, W_i Akaike's weight, *SE* standard error, *Z test* significance of the *Z* test

Variables	Estimate	SE	*Z* value	Significance
Red fox				
Intercept	−0.476	0.326	−1.460	0.144
Open areas	−0.045	0.023	−1.999	0.046
Stone marten				
Intercept	0.572	0.299	1.914	0.055
Vegetation at entrance	−0.045	0.016	25.962	<0.001
Water presence	−1.113	0.440	−2.532	0.011
Otter				
Intercept	−1.308	0.622	−2.102	0.036
Orientation of riparian vegetation	0.513	0.262	1.954	0.050
Genet				
Intercept	−0.243	0.277	−0.877	0.380
Water presence	−2.181	0.662	−3.296	0.001

Table 3 Quasi-Poisson models for each species (coefficient estimates)

SE standard error, *Z test* significance of the *Z* test

culvert structural features explained the behavior of the remaining species when entering and leaving a culvert: (1) culvert width, (2) culvert length, (3) water presence, and (4) the presence of vegetation at the entrance of a culvert. However, these features do not fully explain the behavior of badgers when they enter culverts and otters when they leave culverts (Table 4). Stone martens seem to be more reluctant when entering long culverts and when leaving culverts with water. In contrast, no reluctant behavior was observed for badgers leaving culverts with vegetation at their entrances. Otters were also seen to move at higher speeds when they passed through wide culverts.

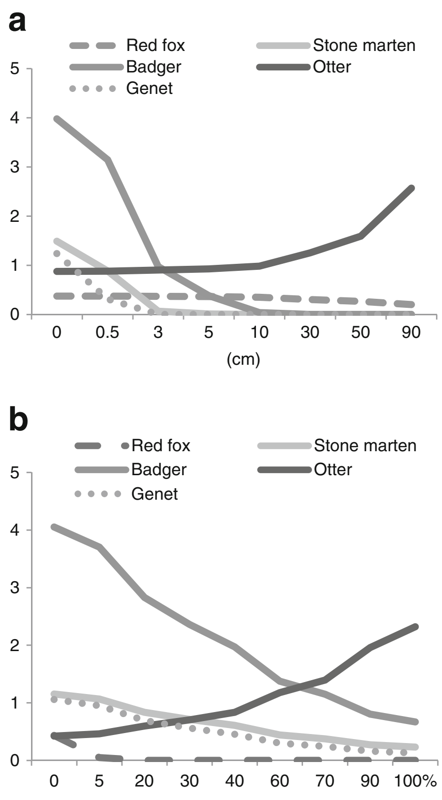

Fig. 3 Number of carnivore crossings per day in culverts obtained from the GLMM Poisson models related with water depth (in centimeters) (**a**) and percentage of cover (**b**)

Discussion

Several studies have already documented that drainage culverts can be used as crucial tools to improve habitat connectivity and thereby mitigate the barrier effect caused by roads for carnivores in a Mediterranean context (see Yanes et al. 1995; Mata et al. 2008; Grilo et al. 2008). Our results are in accordance with these studies, but go further to highlight the role of seasonality and water presence on culvert use. These results are further supported by our observations of carnivore behavior when entering or leaving drainage culverts. Moreover, we documented that species respond differently to culvert-, road-, and landscape-related attributes.

Table 4 Summary of univariate analysis of the relationship between reluctance and nonreluctance behaviors with structural culvert features for each carnivore species (coefficient estimates)

Models		AIC	ΔAIC	AIC weight	Estimate	SE	*Z* value	Significance
Stone marten								
Enter	Null	48.99	0.38	0.05				
	Intercept				4.372	2.555	1.711	0.087
	Culvert length	48.61	0		−0.059	0.040	−1.474	0.140
Leave	Null	48.99	5	0.267				
	Intercept				1.139	0.406	2.805	0.005
	Water presence	44.02	0	0.291	−1.8327	1.290	−1.420	0.156
Badger								
Leave	Null	53.04	0.9	0.219				
	Intercept				−2.8585	0.648	−4.411	0.000
	Vegetation at the entrance	52.19	0	0.334	0.2512	0.1262	1.991	0.047
Otter								
Enter	Null	46.87	2.1	0.118				
	Intercept				−1.2468	1.0024	−1.244	0.214
	Culvert width	45.05	0.3	0.292	0.9096	0.4431	2.053	0.040

We only show the variables with AIC lower than the AIC of the null model

AIC Akaike's information criterion, Δ*AIC* AIC_i−minAIC, W_i Akaike's weight, *SE* standard error, *Z test* significance of the *Z* test

Not surprisingly, this study shows that simply surveying during dry seasons provides only a partial picture and can lead to biased results regarding species life history traits. Our findings show that the intensity of use of culverts is affected by specific phenological periods. Higher use of culverts is correlated to periods with high levels of activity, such as during mating seasons and times when species have young to feed (Blanco 1998). At these times of behavioral change, individuals tend to increase their rate of movement and enlarge their territories, increasing the likelihood of encountering culverts. For example, stone martens and otters used culverts more regularly during the mating period (summer and winter, respectively). Red foxes used culverts more often in spring, which coincides with their period of final gestation and the feeding of young. These results are supported by the work of Mata et al. (2009), which examined the passages used during summer and winter and found marked seasonality on passages used by red foxes, badgers, and genets. Similarly, previous research has demonstrated that high mortality associated with vehicular collisions involving carnivores is strongly correlated with periods of mating and the feeding of young (Grilo et al. 2009).

The most novel finding from our research is the role of water in the use of culverts by carnivores. All species (except otters) tend to avoid culverts when the internal water depth and the percentage of floor covered by water increases. Our results suggest that only a few centimeters of water (3 cm) appeared to be enough to discourage animals from crossing through a culvert (Rossell and Velasco 2001). More importantly, water inside culverts seems to act as an effective barrier to stone martens and genets, both forest-dwelling species that selected culverts without water independent of the season. This finding was further supported by the exhibition of reluctant behavior in stone marten when leaving a culvert containing water. In contrast, and as expected in view of the species lifestyle (a semiaquatic species that uses water to move and forage—Kruuk 2006), the presence of water had a positive effect on the use of culverts by otters. We predicted that otters were more likely to use culverts that contain more than 70 % of water cover and 50 cm of water depth. The method of surveillance used allowed a more robust form of data collection on otter behavior towards culverts. However, differences in otter densities could be affecting the different findings among published studies (Ascensão and Mira 2006; Mata et al. 2005, 2008; Grilo et al. 2008).

Besides water, a number of other variables also affected the use of culverts. For example, the orientation of riparian vegetation was positively related to the use of culverts by otters. Although riparian vegetation reflects a constant source of water which is crucial for otter's movement and food availability, these structures are also provide shelter (Prenda and Granado-Lorencio 1996). Otter's behavior towards the entrances of culverts also supports this result: as they moved with higher speed in wider culverts, otters have low confidence in culverts that appear to have less available cover. The absence of natural objects (e.g., vegetation, wood, stones) inside culverts is translated into a low cover availability which decreases the confidence of otters in using culvert as the width increases. In contrast, this study also showed that vegetation at the entrance of a culvert negatively affected the use of that culvert by stone martens. This is an unexpected behavior for a forest-dwelling species because the presence of vegetation should theoretically reduce the mistrust of these animals towards artificial structures, such as culverts, by providing the perception of habitat continuity (Hobbs 1992; Palomares and Delibes 1993; Virgós 2001; Santos-Reis et al. 2004; Matos et al. 2009). In fact, Mata et al. (2005) and Grilo et al. (2008) also found no significant relationship between the presence of vegetation at a culverts' entrance and overall culvert use.

Our study represents the first attempt to analyze the use of culverts by mesocarnivores over different seasons. It is also the first study to examine the behavioral responses exhibited by mesocarnivores when they encounter a culvert. Overall, this study goes on to provide a more complete view of the role culverts play in the lives of mesocarnivores. Thus, there are several issues that should be taken in account when examining the role of these structures in the maintenance of habitat connectivity. Firstly, there is the effect of mesocarnivore activity on the results, meaning that the interpretation of the results should consider the season the survey was conducted in. Furthermore, one important question should be addressed when a survey of this nature is completed: is a low frequency of culvert use related with overall low species activity or with water presence within culverts? If a low frequency of use is related with low activity level, culvert-related factors, such as water content, would have no influence on eventual culvert usage. In the second case, the presence of water in a culvert, we should examine if this lack of culvert use also corresponds to breeding and/or dispersal periods. During these periods, limitation of movement due to avoidance behavior towards culverts may change the demographic structure of populations as it alters genetic exchange (e.g., Row et al. 2007). Another important issue is the diversity of responses of mesocarnivores towards culverts. Previously, Mata et al. (2005) suggested the establishment of differently sized crossing structures to allow complementary use by terrestrial vertebrates. Our findings suggest that the diverse nature of attributes associated to different culverts, i.e., presence/absence of water and presence/absence of vegetation at the entrances, accounts for the wide range of responses towards culverts from different species in the mesocarnivores community. Therefore, as suggested by Bissonette and Adair (2007), a number of culverts, each with a range of characteristics (vegetation plantation at entrance and dry ledges in culverts with water in most part of the year), should be placed within an area similar to the average daily movement distance of mesocarnivores. This should be done in order to promote a regular use of such structures by the whole community and thereby may aid the maintenance of habitat connectivity for this *taxa*.

Acknowledgments The authors thank Brisa—Auto-Estradas de Portugal S.A. for providing the financial and logistical support for this project. Special thanks to Rui Raposo, Alexandre Pirra, Rui Casado, Joaquim Nobre, Pedro Pomar, and Gertrudes Ferro for their help in transporting and setting up the equipment. We would also like to thank all the volunteers that collaborated with us to complete the field work and view the videotapes. C. Grilo was supported by Ph.D. (SFRH/BD/10600/2002) and postdoctoral (SFRH/BPD/64205/2009) grants from the Fundação para a Ciência e Tecnologia. We also would like to thank John A. Bissonette for the valuable critical comments on the manuscript.

Appendix

Table 5 Univariate analysis of the relationship of number of successful crossings and water depth and cover for each species

Variables	Estimate	SE	*t* value	Significance
Red fox				
Intercept	−0.829	0.4429	−1.873	0.0821
Water depth	−0.428	0.337	−1.271	0.224
Intercept	−0.983	0.439	−1.972	0.069
Water_cover	−0.007	0.008	−0.866	0.401
Stone marten				
Intercept	0.398	0.329	1.209	0.227
Water depth	−1.044	0.636	−1.640	0.101
Intercept	0.143	0.370	0.387	0.699
Water_cover	−0.016	0.007	−2.236	0.025
Badger				
Intercept	1.381	0.297	4.652	0.000
Water depth	−0.469	0.184	−2.551	0.011
Intercept	1.400	0.295	4.746	0.000
Water_cover	−0.018	0.005	−3.492	0.000
Otter				
Intercept	−0.136	0.371	−0.367	0.714
Water depth	0.012	0.011	1.048	0.295
Intercept	−0.857	−0.857	−0.857	0.063
Water_cover	0.017	0.006	3.160	0.002
Genet				
Intercept	0.212	0.315	0.673	0.501
Water depth	−2.765	1.348	−2.051	0.040
Intercept	0.056	0.283	0.197	0.844
Water_cover	−0.021	0.008	−2.697	0.007

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