Do dry ledges reduce the barrier effect of roads?

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ABSTRACT

Wildlife crossing structures combined with fencing seek to improve permeability and habitat connectivity across roads and reduce wildlife-vehicle collisions. However, the presence of water inside culverts can seriously limit their effectiveness. The implementation of dry ledges can be a good measure to allow crossing when flooded. So far, there is a lack of knowledge on the effectiveness of dry ledges combined with fencing for a wide diversity of vertebrates. The main goal of this study is to evaluate how the presence of dry ledge affect culvert use for Mediterranean mesocarnivores (red fox *Vulpes vulpes*, stone marten *Martes foina*, European badger *Meles meles*, European otter *Lutra lutra* and common genet *Genetta genetta*). Between January and March 2008, wooden dry ledges were placed in 15 of 32 surveyed culverts. Additionally 100 meters of small mesh size and buried fences were installed along each side of all culverts. During one year we used video surveillance and track-plates to detect crossing events over seven consecutive nights per season in each monitored culvert. We evaluate the relative importance of dry ledges on culvert use and compare the number of road-kills within a 100 m buffer radius around the culverts before and after fence installation and culverts that were never fenced (control culverts). Although different species responded to culvert features differently, the presence of dry ledges was the most relevant feature explaining crossing events, in particular, for stone martens and genets. The fencing used did not reduce mammals road-kill prevalence. Our results imply that in order to improve culvert use, road managers should take into account the placement of ledges on culverts that remain flooded most of the year (more than 3 cm of water-depth). We also suggest exploring the role of ledge size and construction materials to increase the likelihood of being used by foxes and badgers.

Keywords:

Retrofitting culverts
Mitigation measures
Mesocarnivores
Road permeability

1. Introduction

The negative effects of high traffic roads on animal populations have been intensively described in the last decades (Cain et al., 2003; Clevenger et al., 2003; Farhig and Rytwinski, 2009; Forman and Alexander, 1998; Klar et al., 2009). For many species roads create barriers to migration, dispersal and genetic exchange through the inhibition of crossing movements and the additional mortality due to collisions with vehicles (e.g. McGregor et al., 2008; Rondinini and Doncaster, 2002; Shepard et al., 2008; Strasburg, 2006; Rytwinski and Fahrig, 2012). Nowadays, there is a growing interest to mitigate these impacts by means of a wide variety of measures (Corlatti et al., 2008; Glista et al., 2009). Examples are the construction of underpasses and overpasses to maintain landscape

connectivity (Clevenger and Waltho, 2000; Foster and Humphrey, 1995) and the use of fences, one-way gates, reflectors and/or warning signs (Aresco, 2005; D'Angelo et al., 2006; Klar et al., 2009; Reed et al., 1974; Sullivan et al., 2004; Ujvári et al., 1998) to reduce mortality.

Special attention has been paid to the use of drainage culverts as potential underpasses, due to the large number present along roads, their relative low cost (Mata et al., 2008), and to their well-documented use by many terrestrial vertebrates (Clevenger et al., 2001; Grilo et al., 2008; Ng et al., 2004; Rodríguez et al., 1996; Yanes et al., 1995). Nevertheless, the presence of water inside many culverts may limit their use as passages (Serronha et al., 2012). The installation of dry ledges can be a good management measure to allow crossing when flooded (e.g. Meaney et al., 2007). In spite of this, for many vertebrates such as carnivores, the information on the effectiveness of dry ledges in terms of increased permeability is still scarce. Equally, there is few information on the effectiveness of fencing road sections for carnivores and small mammals. Jaeger and Fahrig (2004) suggested that fencing may not be worth due to high costs and the limitation of animal movements which may be

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Figure 1. Study area and location of the monitored passages along the A2 and A6 highways in Portugal.

even more harmful than mortality. One interesting solution is fencing just the road sections with high incidence of road-kills (e.g. Klar et al., 2009) but when road-kills data is limited, we argue that the complementary use of fences combined with crossing structures, as suggested by several authors (e.g. Boarman et al., 1997; Dodd et al., 2004), may be also effective in reducing the road mortality.

The main goal of this study is to evaluate the effectiveness of dry ledges combined with fencing for mesocarnivores in culverts flooded part of the year by addressing the following questions: 1) what is the relative importance of ledges combined with fencing on culverts use? 2) which water-related descriptors influence the use of ledges? and 3) does complementary fencing reduce mammals mortality? We expect the effectiveness to be different according to species life history traits. A priori, we expect dry ledges to be more effective for smaller and water-reluctant species. Knowledge on these topics will provide support for a better understanding on the effectiveness of dry ledges, and therefore, reduce the overall impact of the road network in a cost-effective way.

2. Methods

2.1. Study area

The study was carried out in Alentejo province of southern Portugal along A2 (95 km) and A6 (150 km) highways sections (the intersection of both highways is located at 38° 36' N and 8° 38' W, Fig. 1). These highways under a private concession (BRISA Auto-Estradas de Portugal, S.A.) were built between 1996 and 2001 and have an annual average daily traffic of 13,949 vehicles and annual average night time (6pm to 6am) traffic of 5536 vehicles. On average, there are two crossing structures per kilometer of which more than 70% are drainage culverts. Both highways have livestock exclusion fencing (unburied, 150 cm height with 12 cm mesh size) which is generally ineffective in preventing crossing for almost all mammals (Grilo et al., 2009).

Land cover in the vicinity of the highway is representative of the typical Mediterranean landscape dominated by cork oak

woodlands (*Quercus suber*) and holm oak (*Q. ilex*) that alternate with cereal crops. Excluding the two largest cities in the region, which have a population density of 1980 inhabitants/km², the population density in the study area is 21 inhabitants/km². The studied highways border four Rede Natura 2000 sites (Sado, Cabreia, Monfurado and Caia) each of which host a high carnivore richness (Santos-Reis and Petrucci-Fonseca, 1999).

2.2. Data collection

We surveyed 32 culverts along segments of these two highways: 13 circular culverts (1 and 1.5 m of diameter) and 19 squared culverts (ranging from 2 × 2 to 4 × 4 m). Between January and March 2008, wooden dry ledges of 50 cm width were placed 30 cm from the ground in 15 culverts: three circular culverts (1 and 1.5 m of diameter) and 12 squared culverts (ranging from 2 × 2 to 4 × 4 m). Ledges were installed in those culverts with a higher probability of being flooded during the rainy seasons (average water depth 5 ± 4 cm and average water cover 54 ± 30%). In April 2008 and in addition to the livestock exclusion fences, 100 meters of small mesh size fences (2.5 cm wide) were installed (50 cm of height and buried 50 cm to avoid under-passing) along each side of 32 culverts surveyed, totalizing 12.8 km of fence, and 32 other similar culverts (with the same shapes and sizes as described above) were randomly selected in order to better control the role of fencing.

We used video surveillance and track-pads to detect the use of culverts by mesocarnivores. Two cameras with movement and heat sensors were oriented towards one entrance of each culvert and a fine layer of marble dust, with 120 cm of length, was placed covering the entire culvert width. Monitoring was conducted over seven consecutive nights per season in each culvert for one year after ledge installation. Every day video batteries were replaced and track pads were checked. Culverts were described in terms of spatial and temporal features over the monitoring period (Table 1). Spatial features include culvert features (presence of dry ledge, vegetation at the entrance, distance from culvert entrance to highway and openness), and the surrounding landscape within a buffer of

Table 1

Summary of variables included in the candidate models (description of the variables, mean and range).

Variables description	Mean	Range
SPATIAL FEATURES		
<i>Culvert features</i>		
Ledge		without ledge = 0; with ledge = 1
Openness (height x width) (m ²)	5.7	1–12
Vegetation height at the entrance (m)	0.43	0–9.75
Distance from culvert entrance to highway (m)	14.8	0–70
<i>Surrounding landscape (300 m buffer)</i>		
Cork oak woodland (%)	38.6	0–100
Understorey vegetation (%)	24.4	0–100
Urban areas (%)	1	0–100
Riparian vegetation type	–	shrubs = 1; trees = 2
Position of riparian vegetation	–	parallel = 1; perpendicular = 2
TEMPORAL FEATURES		
Weather	1.86	dry = 1; wet = 2; rainy = 3
Water depth inside (cm)	3.4	0–50
Water depth outside (cm)*	4.1	0–40
Water cover (%) ^a	36.5	0–100
Traffic (vehicles/day)	192	66–574
Season ^b	–	Spring, Summer, Fall, Winter

^a used exclusively for the role of water variables on dry ledge use.

^b whenever season was a significant variable, it was transformed into binary dummy variables: presence/absence of spring, summer, fall or winter.

300 m (percentage of cork oak woodland, understory vegetation, urban areas and riparian vegetation type and position). Temporal features comprise weekly changes such as weather, water cover, water depth inside and outside the culvert, traffic at night and season surveyed (Table 1). We used mammals' road-kill data recorded by BRISA staff in charge of the daily maintenance of the highways in the period of 20 months before and after fencing.

2.3. Data analysis

We used Generalized Linear Mixed Models (GLMM) to test the effect of spatial and temporal features on culvert use and a logit link with species crossing (crossing vs. no crossing along each week representing one season) as response variable (Zuur et al., 2009) and culvert ID as a random effect to avoid pseudo-replication among culverts and to control for any idiosyncratic effect associated to each culvert (e.g., shape or size).

First, we analyzed the effect of the presence of dry ledges and several additional variables on the probability of culvert use by comparing crossing events presence and absence. A set of models was designed for each species guided by four general hypotheses: 1) culvert features influence their use by carnivores; 2) culvert use is explained by the surrounding landscape; 3) weekly changing features or seasonality affect culvert use; or 4) the combination of the previous hypotheses explain culvert use. We also constructed a null model that includes no explanatory variables. Prior to modeling, we searched for confounding effects among culvert attributes using Spearman's rank correlation (Zar, 1999) in order to reduce the effects of multicollinearity. From any pair of independent variables that reported $r > |0.5|$ ($p < 0.05$) we removed the independent variable with the smallest correlation with the response variable. For example, culvert length was highly correlated with distance to the highway, which in turn explained better the use of culverts and therefore was retained for further analyses. Models were ranked according to Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). Model accuracy was examined to assess how

Table 2

Parameter estimates (β , standard error S.E. and p-values) for the best models explaining the probability of using culverts to cross the highways.

Species model	Variables	β	S.E.	p-value
red fox	intercept	−1.059	0.6090	0.081
	Ledge	−1.397	0.860	0.104
	Winter	−1.757	0.846	0.038
	Fall	1.143	0.565	0.040
stone marten	intercept	−1.814	0.5600	0.001
	Ledge	1.292	0.589	0.028
	Riparian vegetation position	0.438	1.186	0.235
	Summer	−0.876	0.544	0.107
badger	intercept	0.667	0.307	0.029
	Ledge	−1.170	0.438	0.007
otter	Water depth inside	−0.292	0.115	0.011
	intercept	−2.368	0.890	0.007
	Weather	−0.493	0.2677	0.065
genet	Riparian vegetation type	0.784	0.412	0.056
	Riparian vegetation position	0.647	0.421	0.124
	intercept	−5.511	1.021	<0.001
	Ledge	1.532	0.578	0.008
	Verge length	0.054	0.025	0.035
	Riparian vegetation type	0.739	0.418	0.076
	Traffic	0.010	0.002	<0.001

well the best model ($\Delta AIC = 0$) fits the data using quantile-quantile plots. Spatial autocorrelation of residuals was analyzed with spline correlograms with 95% pointwise bootstrap.

We estimate the likelihood of ledge use within the 15 culverts with ledges installed in relation to water features: the percentage of water in the culvert (water cover), water depth inside and depth outside the culvert (Table 1). We run univariate GLMM with a logistic link using species ledge use (ledge use = 1 and no use = 0 in a given week) as response variable and culverts as a random effect as explained above.

Finally, we evaluated the effect of the additional fencing to reduce mammals mortality by addressing two hypotheses: H1) no differences in mortality are explained by local population density changes. H2) differences in mortality are explained by the effect of fencing. We compared the number of road-kills within a buffer of 100 m radius around 32 fenced culverts occurred during 20 months before and after fencing. If we found differences between this time periods, we compared data for each period with 32 other culverts with similar shape and size that were never fenced in order to control stochastic population density changes. Both analyses took into account the surrounding landscape expressed by the existence of forest within the 100 m buffer around the culvert. Hypotheses (H1 and H2) were tested using a GLMM with a Poisson distribution, where the number of road-kills was the response variable and culverts a random effect.

We performed all statistical analysis using lme4 (Bates et al., 2011), glmmML (Broström and Holmberg, 2011), ncf (Bjornstad, 2009) packages in R version 2.13.2 (R Development Core Team, 2011).

3. Results

We recorded a total of 397 successful mesocarnivore crossings (0.44 crossings/culvert/day). Of these crossings 30% were performed by Eurasian badger, 23% by stone marten, 12% by Eurasian otter, 20% by common genet and 15% by red fox.

The best models show that the presence of a dry ledge was associated to the use of culverts by all non-aquatic species (Table 2, Appendix A). The importance of the remaining variables varied among species. In fact, this feature has AIC weights (AIC_{wi}) ranging from 0.42 to 0.85 (Appendix B). Interestingly, stone marten and genet crossings were positively associated to the presence of

dry ledges while red fox and badger crossings were associated to the absence of dry ledges (Table 2). Even though we expected differences in culvert use among seasons between species, only the red fox best model show that fox crossings were positively associated with fall ($AIC_{wi} = 0.77$), and had a negative relationship with winter ($AIC_{wi} = 0.80$), and stone marten crossings were negatively related with summer ($AIC_{wi} = 0.58$) (Table 2). The absence of water influenced positively badger crossings with a weight AIC of 0.86 (Table 2). Riparian trees and their orientation to the culvert seem to be positively associated with otter crossings ($AIC_{wi} = 0.42$ and 0.50, respectively). In contrast, during dry weeks otters seemed to avoid using culverts (Table 2). Surprisingly, we observed that traffic volume influence positively genet crossings (AIC weight = 0.72) as well the distance from the culvert entrance to highway (AIC weight = 0.71). Spline correlograms with 95% bootstrap showed no spatial autocorrelation in any species (results not shown). Quantile-quantile plots show that no major departures from model assumptions were detected.

In general, all species except otters used more the ledge than the ground in the rainy seasons (Figure 2). Interestingly, stone martens and genets started to use the ledges immediately after the ledge placement (in summer). Few data for red fox crossings ($n = 11$), badger crossings ($n = 5$) and otter crossings ($n = 8$) regarding water depth and width precluded including them in further analyses. Models for stone martens and genets show that water depth was the variable that better explains the use of dry ledges

Table 3

Univariate analysis using GLMM for the likelihood of ledge use: Akaike Information Criterion (AIC), coefficient estimate (β), standard error (S.E.), test Z significance (p-value) for stone marten ($n = 62$) and genet ($n = 38$).

Species	Variables	AIC	β	S.E.	p-value
stone marten	intercept		-0.14	1.34	0.91
	water cover	53	0.05	0.02	0.01
	intercept		-0.30	1.17	0.79
	water depth inside	48	5.67	3.56	0.11
	intercept		1.67	2.13	0.43
genet	water depth outside	57	0.73	0.35	0.04
	Null	71	1.87	0.81	0.02
	intercept		0.23	0.65	0.71
	water cover	38	0.02	0.01	0.03
	intercept		0.71	0.69	0.30
	water depth inside	41	0.38	0.32	0.23
	intercept		-0.24	0.65	0.71
	water depth outside	33	1.54	0.83	0.06
	Null	43	1.34	0.59	0.02

(Table 3). However, stone marten was more influenced by water depth inside, and genet by water depth outside the culvert. Figure 3 show that stone martens more likely used dry ledges above 1 cm of water depth inside the culvert while genets responded better to water depth above 3 cm outside.

Mammal road mortality was very similar before (20 road-kills) and after (19 road-kills) fencing period within the 100m radius around the 31 fenced culverts. We found no differences

Figure 2. Floor (black bars) or ledge (grey bars) crossing index (number of crossings/culvert/day) for each mesocarnivore species.

Figure 3. Probability of ledge use for stone marten (black line) and genet (grey line) in relation to water depth.

between fenced and unfenced culverts before fence implementation (20 roadkills) and scarce differences appeared between these culverts after fencing (19 and 13 roadkills respectively). In particular, small mammals, mostly rabbits (*Oryctolagus cuniculus*), were road-killed in similar numbers before (7 road-kills) and after (9 road-kills) fencing. Equally, no big differences were found on the records of carnivores before ($n = 12$) and after fencing ($n = 9$) in fenced culverts and neither in unfenced ones ($n = 4$ and $n = 5$ respectively). As expected from the raw numbers, the null model showed the lowest AIC (Appendix D).

4. Discussion

The recent development of landscape ecology emphasizes the importance of habitat connectivity for population viability (Clergeau and Burel, 1997). Road planning efforts towards reducing barrier effects and wildlife-vehicle collisions are critical for a sustainable road network management (Forman et al., 2003). To ensure successful mitigation it is important to identify the species favored by these measures and to examine the best design and placement. Our results highlight the importance of dry ledges in drainage culverts to maintain habitat connectivity for forest dwelling species such as stone marten and genet and the need of further research on ledge design in particular for foxes and badgers as well fence design and placement to prevent mammals-vehicle collisions. In fact, there is considerable evidence suggesting that water prevents culvert use by stone martens and genets and consequently dry ledges seem to be a useful measure to promote their use. We noticed that all species with the exception of otters used more dry ledges during the rainy seasons, suggesting ledges are used when water is present. Despite the correlation between water cover and depth, the latter seems to be more important to explain the likelihood of use of dry ledges by stone martens and genets. Interestingly, stone martens and genets used ledges immediately after installation and even during the dry period (summer), which suggests that they respond very well to this new structure. As ledges were not randomly installed but rather in those culverts more likely to be flooded for longer, the selected culverts are positively associated to streams and their associated riparian vegetation. In fact, variables related with vegetation in the entrance (vegetation height and riparian vegetation) had also an important role on culvert use. One explanation for this fact is that, being forest-dwelling species, stone martens and genets, tend to use culverts

with developed vegetation outside the culverts because it provides cover, shelter and prey (Grilo et al., 2008; Matos et al., 2008; Rodriguez et al., 1996) but only when dry. Unexpectedly, red foxes and badgers seem to avoid culverts with dry ledges. Three reasons may explain this finding. Both foxes and badgers may need time to adapt to new structures. In fact, we documented that badgers only started to use the ledges on a regular basis four months after ledge installation (fall 2008). Alternatively, the presence of a ledge may reduce the openness ratio of the culverts. Several studies recorded that carnivores tend to use larger culverts (Grilo et al., 2008; Mata et al., 2008, 2009) and the presence of ledges may reduce openness ratio, which may decrease the likelihood of culvert use. Finally, sampling design may indicate that foxes and badgers prefer culverts that are dry along the year irrespective of the presence of ledges.

We also detected that traffic disturbance seems to influence genet crossings which seems to prefer culverts within high traffic volume sections. Nevertheless, genets select those culverts located far away from the highway (those with a wide road verge). Interestingly, the relationship between genet crossings and culverts far from the road pavement was also found by Ascensão and Mira (2006). Unexpectedly, we found weak support for the hypothesis that seasons corresponding to higher mobility and abundance increase the likelihood of culvert use, except for the red fox. Foxes are more likely to use culverts in fall, maybe because juveniles are still in dispersion (Blanco, 1998). Winter seems to be the season with fewer crossings which is supported by a previous study on mortality in the same highways (Grilo et al., 2009), where we found fewer records, suggesting low activity rates in this season.

We suggest to place ledges wherever there are no suitable crossing structures to provide safe highway crossings within the distance of the species daily movements (Bissonette and Adair, 2008). In the case of stone martens and genets, if there are no dry crossing structures within 1000 m (average daily movements according to home-range estimates based on Santos-Reis et al., 2004), we recommend to place at least one dry ledge.

In the light of the small sample, road-kill results must be interpreted as indicative but not fully conclusive. Opposite to the expectation, complementary fencing did not reduce the road-kill rates. Several factors may explain these results. Firstly, implementation of the small mesh buried fence was not long enough, and just 100 m on each side may be too short, in particular, for meso-carnivores with large spatial requirements (Cavallini and Lovari, 1994; Genovesi et al., 1997; Lindstedt et al., 1986). In fact individuals could walk around the fence and enter the road without even taking a long detour. Secondly, fences do not have any structure to prevent climbing as Klar et al. (2009) proposed for the wildcat and this does not limit the trespassing capacity of individuals able to climb it. However, we could expect differences in ground dwelling species because fences were buried, in particular for species with small home-ranges. Neither this was the case, showing the inefficacy of this fencing design. Finally, the reduced duration of the study may not allow us to find differences in the road-kill rates.

5. Conclusions

In summary, we found that dry ledges can be a useful management action to improve the use by some species of flooded drainage culverts as crossing structures. To do so, we should take into account not only the number and complementary sizes of crossing structures (Mata et al., 2008) but also identify where streams intersect with roads and place ledges in structures likely to be flooded (minimum 3 cm depth) during most or part of the year. Additionally, we strongly recommend exploring the role of ledge design and

construction materials to increase the likelihood of being used by other species.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.ecoleng.2013.04.005>.

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