The Influence of Traffic Noise on Vertebrate Road Crossing Through Underpasses

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Abstract Noise produces multiple effects on ecosystems and it influences habitat use by vertebrates near roads. Thus, it may reduce the effectiveness of mitigation measures installed on roads to alleviate population fragmentation. This study analyses the effects of noise on the use by vertebrates of 19 underpasses at a motorway. It employs generalised linear models to test the effect of three noise indicators at the underpasses and in their vicinity on the crossing frequency of eight animal species. The results show that the road crossings are subjected to high and variable noise levels. Nevertheless, there is no consistent response to noise by vertebrates. This suggests that wildlife use of underpasses is determined more by habitat characteristics than by the levels of noise tolerated. The conclusion is that noise abatement measures on roads in areas of faunal sensitivity should focus on general noise reduction rather than on making individual crossing places quieter.

Keywords Habitat fragmentation · Highway · Indicator · Mitigation · Road ecology · Wildlife passage

INTRODUCTION

Noise generated by human activities is a far-reaching form of environmental disturbance that affects a great diversity of wildlife (Rabin and Green 2002; Barber et al. 2010). Interest in the impacts of noise on ecosystems has burgeoned recently and noise-related effects on physiology, behaviour, spatial distribution and interactions have been demonstrated (Slabbekoorn and Peet 2003; Rabin et al. 2006; Brumm et al. 2007; Parris et al. 2009; Francis et al. 2009). These findings have led to discussion of the feasibility of establishing tolerable noise limits to protect wildlife, as is done routinely with respect to human health

(Blickley and Patricelli 2010). It has furthermore become clear that standardised methods of evaluating the effects of noise on wildlife are needed in order to generate robust data that will support the conclusions made and will guide decision making (Slabbekoorn and Bouton 2008; Pater et al. 2009).

Roads are ubiquitous and noisy infrastructures that have a multiplicity of effects on their surroundings (Forman 2000; Riitters and Wickham 2003; Fahrig and Rytwinski 2009). The most outstanding of these on wildlife is the fragmentation of animal populations, which may culminate in their decline or local extinction (Hunt et al. 1987; Clarke et al. 1998; Lodé 2000). Mitigation measures have been taken in recent decades to avoid this type of problem. They take the form of ‘wildlife passages’ that allow animals, mainly vertebrates, to cross roads safely. These passages take a variety of forms, from enlarged culverts to large ecoducts (Iuell et al. 2003; Glista et al. 2009). Once established they are often the object of systematic monitoring programmes to assess their effectiveness in alleviating the problem. Thus far it is known that the design (size, position over or under the road) and location (e.g. proximity to vegetation cover) of such measures to mitigate population fragmentation are determinants of their utilisation by fauna, but other effects of human disturbance are less well understood (e.g. Clevenger et al. 2001; Ng et al. 2004; Clevenger and Waltho 2005; Mata et al. 2005).

Little is known, in particular, of whether the effectiveness of wildlife passages may be determined by the noise levels that they experience. Such a possibility has only been explored on the Transcanadian Highway within Banff National Park (Clevenger and Waltho 2000, 2005; Clevenger et al. 2001). These studies measured noise within crossing structures and at each end and they suggest that the noise levels in wildlife passages may reduce the road-

crossing frequency of several taxa. Several other studies have also suggested that noise may account for the displacement of particular animal species from habitats nearest to roads, although these have not carried out noise measurements (Thurber et al. 1994; Mace et al. 1996; Gagnon et al. 2007; Roedenbeck and Voser 2008). Hitherto, standardised methods of predicting noise levels associated with traffic have not been applied to the evaluation of the effectiveness of mitigation measures intended to restore the connectivity of vertebrate populations divided by roads.

With this in mind, the present study aimed: (a) to estimate noise levels that may affect different structures used by vertebrates to cross a motorway, by applying a standardised method of acoustic modelling, and (b) to evaluate whether environmental noise pollution by the motorway may determine the use of faunal passages by terrestrial vertebrates, resulting in reduced use of the noisier ones.

METHODS

Study Area

The study was conducted at 19 underpasses along a 14.5 km stretch (km 59.4–73.9) of the A-52 motorway in Zamora Province, NW Spain (Fig. 1). Underpasses are homogeneously distributed along the whole stretch, with 84% of them located at less than 500 m from the closest one (maximum 1,580 m). This sector has two lanes in each direction and a maximum speed limit of 120 km h^{-1} . The road is fenced and was opened in 1998. The study stretch is at an altitude ranging from 880–1,040 m and it crosses an undulating rural landscape with gentle gradients. The studied structures comprised 11 small ones (1.8 m diameter pipes and $2 \times 2 \text{ m}$ box-culverts), termed ‘Type 1’ hereafter, and eight larger rectangular-section underpasses with small dirt tracks or ‘Type 2’ structures (average cross-section 7.7 m wide by 4.9 m height, range $4 \times 4 \text{ m}$ to $14 \times 8 \text{ m}$).

Fig. 1 The location of the studied stretch of the A-52 motorway with the monitored underpasses, and of the parallel N-525 road

The area is thinly inhabited (c. 1,500 people in all) and there is no interference from competing noise sources except from the N-525. This two-lane road, with a speed limit of 100 km/h, runs parallel to the A-52 and is used for communication between the small villages of the area. In all the stretch except for 1.35 km this road runs further than 200 m from the motorway. The surrounding environments comprise a mosaic of scrub (37.5%), pastures (35.0%), copses dominated by *Quercus pyrenaica* (19.9%) and bare ground (7.6%), and there is a rich vertebrate fauna that crosses the motorway via different structures (see Mata et al. 2005, 2009a).

The most notable characteristic of the selected stretch, with respect to acoustic modelling, is its uniformity and the lack of junctions all enabling smooth driving. Thus, traffic volume and vehicle types are constant along the whole stretch during any given period and variation in noise levels at different points of the surroundings can be mostly attributed to changes in topography (undulating landscape), in the biotic environment (vegetation cover) and in local motorway features (e.g. embankment height). Temporal variation in noise levels is related to the day/night traffic cycle and to seasonal variation in motorway use: which peaks in summer. A speed measuring station at milepost 72.750 within the study stretch records time, speed and vehicle type (motorbikes, cars, buses and trucks). The parallel stretch of the N-525 has both a fixed and a mobile vehicle speed monitoring station.

Data on Use of Crossing Structures by Vertebrates

The data on the use of crossings by vertebrates are derived from monitoring studies during summer 2002 and winter 2003, which employed two complementary methods: recording tracks on marble dust beds and photographs taken by automatic electronic devices (Mata et al. 2005, 2009a). The crossings were monitored every morning during each season until 10 days of valid data (proper working of cameras or no rainwash of marble dust beds) were obtained for each structure, so 20 days of data were available for each crossing. Data are thus counts of the number of days each animal species was detected crossing through each passage. Data coming from species that could not be distinguished from either tracks or photographs (e.g. small mammals) were combined for the analysis.

Noise Modelling

Noise modelling of the motorway surroundings employed the Predictor Type 7810 programme, Version 5.0, in accordance with the procedure established in the international standard ISO 9613 (Brüel & Kjaer 2005). This model is routinely used during road planning and it was

considered specially appropriate for the study objectives since it takes into account the effect of vegetation on noise propagation. The model was applied to an area extending 250 m to either side of the motorway, using a square grid of virtual receptors placed 15 m apart to obtain a grid of estimated noise levels.

The model is based on the official 1:10,000 map of the area, which shows contours at 10 m intervals (Junta de Castilla y León 2007). This information was complemented by altitude data derived from the construction project of the motorway, to give fuller detail of its principal features (embankments, access to structures) when deriving the digital elevation model that was used.

Vegetation was mapped from orthoimages of the site and was later confirmed in a survey of the whole area. The different formations distinguished were copses, scrub, pastures and herbaceous crops. These were assigned a 'ground value' = 1 for the acoustic modelling and their mean heights were estimated at 5.00, 1.50, 0.25 and 0.25 m, respectively. The map also included elements whose acoustic attenuation capacity was low ('ground value' = 0), such as buildings (height 7.00 m), rural tracks, bare ground and water bodies. The surface of the A-52 was considered a 'flat surface with fine texture' and that of the N-525a as 'normal hard elements' for the purposes of the model (Brüel & Kjaer 2005).

The official measuring stations of the Dirección General de Carreteras, Ministerio de Fomento, provided traffic data for the years of the study (Ministerio de Fomento 2002, 2003). This was complemented by other data supplied by the same institution in order to have the numbers, types and speeds of vehicles on each carriageway during the study months in 2002 and 2003. They showed that the A-52 carried 8,741 vehicles day⁻¹ at mean velocities of 134.7 km h⁻¹ for light vehicles and 92.2 km h⁻¹ for heavy ones. The N-525 carried 823 vehicles/day at variable velocities, below 50 km h⁻¹ in the urban stretch of the village of Asturianos.

The noise model divided the day into four periods (Lmorning, Lday, Levening, Lnight) as stated by the EU legislation (Ministerio de la Presidencia 2007). The analyses employed the period that most affected the different study species. Thus, Lday (09:00–19:00 h) was used for lacertids and Lnight (22:00–06:00 h) for the remaining species and for evaluating the variable diversity of species using each underpass. The data used corresponded to receptors set at 40 cm above the ground for foxes and *Canis* spp. (dogs and wolves) and 10 cm above the ground in all other cases, given the different sizes of the animals studied. Noise variables were expressed as dB(A) in all cases since it is the standard for road planning. Moreover, it was considered adequate for the study as noise differences amongst passages would be parallel if using other noise

filters like dB(C) and because dB(A) filter gives a larger gain to higher frequencies (over 1,000 Hz) to which most mammals are most sensitive (Heffner 1998).

Statistical Analyses

The statistical analysis employed generalised linear models (GLMs) with a logarithmic link function and a Poisson error distribution, given that the response variables were counts. The response variables were the number of days in which each species used each underpass (range 0–20) and the total number of species detected at each underpass studied. Values of parameter statistics were corrected for overdispersion (StatSoft 2002) and significance threshold fixed at $P = 0.05$.

Three alternative indicators of the noise to which the accesses and surroundings of the underpasses are subjected were used as predictor variables:

- MaxNoisAcc (Maximum Noise level in Accesses), defined as the maximum noise level estimated for receptors located within the access areas to the structures (a 25 m-radius semicircle measured on the map around each underpass).
- AveNoisAcc (Average Noise level in Accesses), defined as the arithmetic mean noise level in the same areas as in (a).
- AveNoisSur (Average Noise level in the Surroundings) defined as the arithmetic mean of noise levels estimated for receptors located in the environment through which animals approach the underpasses (a 200 m-radius semicircle around each one in the map).

The analysis was only performed for species or faunal groups that used more than 30% of the underpasses so three GLMs were finally evaluated, one for each noise indicator, for response variables corresponding to:

- A complete analysis, including the category factor 'Pass type', for the variable 'number of species that used each faunal crossing', and for data on the crossing frequency of small mammals and *Canis* sp. (*Canis familiaris* plus *C. lupus*).
- An analysis restricted to Type 1 structures of the crossing frequencies of small mustelids (*Mustela nivalis* plus *M. erminea*), water voles (*Arvicola* sp.) and lacertids.
- An analysis restricted to Type 2 structures of the crossing frequencies of hares (*Lepus granatensis* plus *Oryctolagus cuniculus*), badgers (*Meles meles*) and foxes (*Vulpes vulpes*).

A prior test of parallelism of the covariates (noise indicators) was performed in analyses that included the category factor 'Pass type', between factor levels. All

statistical analyses were performed using STATISTICA 6.1 (StatSoft 2002).

RESULTS

The model showed that the surroundings and accesses of the A-52 underpasses were subject to noise levels in excess of 55–60 dB(A) in most cases and some of them near or above 75 dB(A) (Table 1). The difference in traffic between day-time (482 vehicles h^{-1}) and night-time (209 vehicles h^{-1}) resulted in a noise increase of about 5 dB(A) during the day. Data obtained from modelling at 40 cm above ground level were 0.5–0.8 dB(A) louder than those 10 cm up shown in Table 1. It was also shown that different underpasses, and their surroundings, were subject to very different noise levels (see ranges in Table 1), as a result of the specific design features of each underpass and variation in relief and vegetation.

The statistical analyses nevertheless show that there were very few cases in which the underpass use by vertebrates was correlated with the noise levels detected near the underpasses or at their entrances (Tables 2, 3 and 4). Neither the diversity of species using each underpass nor the crossing frequencies of lagomorphs and foxes were correlated ($P > 0.10$) with any of the noise indicators. Marginally significant positive correlations were found between the crossing frequencies of *Canis* sp. (Table 2) and small mustelids (Table 3) and the maximum noise levels in underpass accesses.

There were significant positive correlations between the crossing frequencies of small mammals and lacertids at a particular structure and the noise level to which that underpass was exposed. To be specific, underpass use by lacertids was significantly correlated with the maximum noise level in underpass accesses and with the average noise level in their surroundings (Table 3), whereas that of small mammals was significantly correlated with the average noise in the surroundings (Table 2).

Table 1 Mean ($\pm$ SD) values of noise indicators estimated at 10 cm above ground level in the accesses and surroundings of crossing structures of the A-52 motorway

	Lday in dB(A)		Lnight in dB(A)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
MaxNoisAcc	74.0 $\pm$ 5.1	59.8–79.0	69.2 $\pm$ 5.3	55.3–74.5
AveNoisAcc	69.1 $\pm$ 4.6	57.3–74.3	64.6 $\pm$ 4.6	52.8–69.8
AveNoisSur	60.7 $\pm$ 1.7	57.5–63.1	56.0 $\pm$ 1.7	52.5–58.2

Noise indicators, as explained in the text, are maximum and mean noise levels in accesses (MaxNoisAcc and AveNoisAcc), and mean noise level in the surroundings (AveNoisSur)

Table 2 The relationship between crossing frequency of the A-52 by different vertebrate species via underpasses (Types 1 and 2) and noise levels

	Noise effect			Underpass type effect (Type 1)		
	Estimate $\pm$ SE	Wald st.	<i>P</i>	Estimate $\pm$ SE	Wald st.	<i>P</i>
Species richness						
MaxNoisAcc	0.0190 $\pm$ 0.0177	1.16	0.282	−0.1216 $\pm$ 0.0884	1.89	0.169
AveNoisAcc	0.0085 $\pm$ 0.0210	0.17	0.684	−0.1094 $\pm$ 0.0935	1.37	0.242
AveNoisSur	0.0015 $\pm$ 0.0568	<0.01	0.978	−0.0980 $\pm$ 0.0922	1.13	0.289
Small mammals (<i>n</i> = 130)						
MaxNoisAcc	0.0461 $\pm$ 0.0383	1.46	0.229	0.3272 $\pm$ 0.1825	3.21	0.073
AveNoisAcc	0.0270 $\pm$ 0.0424	0.41	0.524	0.3430 $\pm$ 0.1973	3.02	0.082
AveNoisSur	0.2367 $\pm$ 0.1123	4.44	0.035	0.2841 $\pm$ 0.1779	2.55	0.110
<i>Canis</i> sp. (<i>n</i> = 27)						
MaxNoisAcc	0.1005 $\pm$ 0.0550	3.34	0.067	−1.1508 $\pm$ 0.3044	14.29	<0.001
AveNoisAcc	0.0766 $\pm$ 0.0604	1.61	0.205	−1.1232 $\pm$ 0.3330	11.38	<0.001
AveNoisSur	0.1635 $\pm$ 0.1690	0.94	0.333	−1.1520 $\pm$ 0.3724	9.57	0.002

Coefficients resulting from the generalised linear model are shown, adjusted for each species and noise indicator in the underpass accesses and surroundings. Coefficients of the factor ‘underpass type’ correspond to the situation at type 1 underpasses. *Wald st.* Wald statistic, *n* number of days each species was recorded using the crossing structures. See text for definition of the three noise indicators

Table 3 The relationship between crossing frequency of the A-52 by different vertebrate species via narrow underpasses (Type 1; see ‘Methods’ section) and noise levels

	Estimate $\pm$ SE	Wald statistic	<i>P</i>
Lacertids (<i>n</i> = 22)			
MaxNoisAcc	0.4487 $\pm$ 0.1985	5.11	0.024
AveNoisAcc	0.2773 $\pm$ 0.1800	2.37	0.123
AveNoisSur	1.1365 $\pm$ 0.2557	19.76	<0.001
Water voles (<i>n</i> = 32)			
MaxNoisAcc	−0.1294 $\pm$ 0.1198	1.17	0.280
AveNoisAcc	−0.2435 $\pm$ 0.1129	4.66	0.031
AveNoisSur	−0.2114 $\pm$ 0.3270	0.42	0.518
Small mustelids (<i>n</i> = 35)			
MaxNoisAcc	0.2389 $\pm$ 0.1224	3.81	0.051
AveNoisAcc	0.1628 $\pm$ 0.1126	2.09	0.148
AveNoisSur	0.3525 $\pm$ 0.2441	2.09	0.149

Coefficients resulting from the generalised linear model are shown, adjusted for each species and noise indicator in the underpass accesses and surroundings. *n* number of days each species was recorded using the crossing structures. See text for definition of the three noise indicators

In contrast, the crossing frequency of water voles via type 1 structures was significantly negatively correlated with the mean noise level in underpass accesses (Table 3), and that of badgers via type 2 structures was significantly negatively correlated with the average noise level in the surroundings (Table 4).

The analyses further show consistency of each species or species-group with respect to the sign (positive or negative) of its correlation with the three noise indicators.

Table 4 The relationship between crossing frequency of the A-52 by different vertebrate species via wide underpasses (Type 2; see methods) and noise levels

	Estimate $\pm$ SE	Wald statistic	<i>P</i>
Lagomorphs (<i>n</i> = 43)			
MaxNoisAcc	0.0478 $\pm$ 0.0729	0.43	0.512
AveNoisAcc	0.0342 $\pm$ 0.0854	0.16	0.688
AveNoisSur	0.3204 $\pm$ 0.2738	1.37	0.242
Eurasian badger (<i>n</i> = 63)			
MaxNoisAcc	−0.0201 $\pm$ 0.0503	0.16	0.689
AveNoisAcc	−0.0144 $\pm$ 0.0680	0.05	0.832
AveNoisSur	−0.4269 $\pm$ 0.1009	17.90	<0.001
Red fox (<i>n</i> = 61)			
MaxNoisAcc	0.0069 $\pm$ 0.0434	0.03	0.874
AveNoisAcc	0.0096 $\pm$ 0.0543	0.03	0.859
AveNoisSur	0.2191 $\pm$ 0.1590	1.90	0.168

Coefficients resulting from the generalised linear model are shown, adjusted for each species and noise indicator in the underpass accesses and surroundings. *n* number of days each species was recorded using the crossing structures. See text for definition of the three noise indicators

They also reveal significant differences between use of the two underpass types by *Canis* sp. (Table 2): dogs and wolves more often cross through the wider underpasses.

DISCUSSION

The results show that faunal crossings at motorways are subject to high noise levels but that their frequency of use

is not affected in any consistent way by the range of noise levels encountered in the present study. Rather, the existence of both positive and negative correlations between the crossing frequencies of different species and noise levels points to other environmental variables, more than noise, being the main responsible for the patterns detected.

It must first be highlighted that acoustic modelling with internationally standardised procedures puts the analysis of the effects of noise on wildlife on a firm basis and it confers several advantages (Pater et al. 2009). Direct field measurements in the study site show noise levels in the surrounding of passages to be close to 60 dB(A) during the day, according to experience (e.g. Forman et al. 2003) and data obtained from models. However, noise modelling enables including in analyses larger areas and longer periods of noise measurement and it also makes it possible to move towards separating the effects of noise from those of other types of habitat perturbation resulting from roads (Barber et al. 2010). Therefore, this procedure allows an explanatory variable to be employed that corresponds better with the real-life situation experienced by animals more closely than is possible from spot noise measurements (e.g. Clevenger and Waltho 2000, 2005; Clevenger et al. 2001). Due to the fact that road noise depends on individual events of vehicles passing by, noise measurements are in any case dependent on the precise situation during experiment and real-time behavioural studies carried out simultaneously to traffic recording are needed for a better understanding of animal response to noise (Gagnon et al. 2007). In our case, results are conditioned by the temporal resolution of data (day vs. night conditions) and no further insight can be done.

With respect to the results obtained, it is noteworthy that the noise levels at and near the underpasses are high and indeed mainly exceed the usual standards for tolerable noise (e.g. see Zegel (1997) for USA, or Ministerio de la Presidencia (2007) for the implementation of EU legislation). A noise level of 65 dB(A) is often taken as the guideline threshold for preventing negative psycho-physiological health effects on humans, although annoyance and communication disturbance arise in the range 55–60 dB(A) and some physiological effects are obvious at lower noise levels (Vallet 2001). It has similarly been shown that deleterious physiological effects on wildlife emerge at noise levels above 55–60 dB(A) (Barber et al. 2010).

With this in mind, it is notable that noise levels within a considerable distance (200 m) of the faunal underpasses exceed 55 dB(A) at night and 60 dB(A) in most cases during the day. And they are approximately 10 dB(A) higher within 25 m of the underpasses and at their entrances. Clevenger and Waltho (2000, 2005) give somewhat lower spot measurements of diurnal noise at

underpass entrances (mean $\pm$ SD = 62.6 $\pm$ 6.5 dB(A)) at the Transcanadian Highway despite more (but slower) traffic there. However, noise measurements in Spanish road stretch with ungulate collisions also showed average noise levels close to ours, in the 67.0–74.5 dB(A) range (Peris et al. 2007). There is insufficient knowledge at present to allow noise standards for wildlife to be established (Ministerio de la Presidencia 2007; Blickley and Patricelli 2010). Anyhow, it is undeniable that underpass entrances, and motorway surroundings in general, are currently subject to noise levels that are capable of causing a range of negative effects on physiology, behaviour and interactions amongst vertebrate species (Slabbekoorn and Peet 2003; Parris et al. 2009; Barber et al. 2010). It is also noticeable that large variation in noise levels exists amongst underpasses.

However, taken together, our results on the extent to which vertebrates use crossing structures seem to reveal indirect effects of habitat characteristics rather than changes due to noise levels. This is the most parsimonious explanation for the existence of both positive and negative correlations between crossing frequencies and noise levels, despite there being a suggestive negative correlation between the crossing frequencies of badgers and water voles and some indicators of noise pollution. Badgers are known to suffer both from high mortality on roads and from high levels of disturbance due to them (Clarke et al. 1998). Nevertheless, the badger is strongly attracted to woody habitats with dense vegetation (Virgós 2001). Similarly, water vole distribution is strongly associated with dense riparian vegetation that protects them from predators (Barreto et al. 1998). Thus, the effects of habitat degradation by man on water voles are less marked, except where these involve large-scale habitat transformation, such as the construction of rock or concrete embankments (Barreto et al. 1998; MacDonald et al. 2002). Cover of trees and shrub in the 200 m surrounding underpasses ranges between 13 and 86% and the densest vegetation in the study area corresponds with the deepest undulations of the terrain, which traditionally have been subject to less intense human exploitation from farming or livestock raising. The topography and vegetation density within such areas combine to reduce noise pollution close to the road as it is shown by the negative correlation between the percentage of tree and shrub cover in the surrounding of underpasses and average noise level in those areas (Spearman rank correlation $r = -0.59$; $N = 19$; $P = 0.008$). Thus, the attraction of badgers and water voles to particular underpasses was probably due to the vegetation near them being denser and not to them being quieter.

The simplest explanation, along the same lines, of why some species seem to prefer to cross via the noisiest underpasses is that there is some correspondence between

these and habitat features. Thus, the tendency for small mammals and lacertids to cross via the noisiest underpasses significantly more often seems to be due more to their using the more open habitats rather than to a preference for noisy places. The poikilothermic nature of lacertids makes them dependent on habitats that have ground patches exposed to direct sunlight (Díaz and Cabezas-Díaz 2004). Small mammals are probably more abundant in early successional patches of the landscape mosaic (Torre and Díaz 2004). It may similarly be reasonable to suppose that the marginally significant tendency for small mustelids to appear at the noisier sites is due to the presence there of the small vertebrates on which they prey (Palomo et al. 2007; Mata et al. 2009b).

Differences amongst animal species in response to noise cannot be discarded either, but two lines of evidence go against this explanation. Reptiles are known to have a restricted auditory awareness (Peterson 1966), a fact that could underlie the trend detected around road passages. However, carnivores and small mammals have broader auditory spectra and higher awareness (Heffner 1998) and we found divergent results amongst them. Thus, it does not seem that only animals with more auditory capacity respond to noise in underpasses. Besides, the spectral distribution of traffic noise is approximately constant for different noise levels and dominated by frequencies below 1,000 Hz (Cornillon and Keane 1977) lower than those to which mammals are more responsive to (4,000–15,000 Hz; Heffner 1998).

Our results differ from those obtained at the Transcanadian Highway in Banff National Park. There, most species whose use of underpasses correlates with noise levels are affected negatively by it (Clevenger et al. 2001; Clevenger and Waltho 2005; see, however, Clevenger and Waltho 2000). The fact that the Transcanadian Highway runs through a forest-dominated landscape that is little disturbed by humans together with habitat selection considerations of the forest species that were the object of the study in the Rockies, may explain the Canadian findings.

Does this mean that animals are unaffected by noise levels in faunal underpasses in habitats such as those of our study area? Almost certainly not, given that noise probably results in generalised under-use of faunal crossings as a by product of the road edge effect (Forman 2000; Forman and Deblinger 2000). It is thus predictable that vertebrate communities near roads may change in species-composition and population densities through changes in both abiotic conditions (including noise cf. Reijnen et al. 1995) and biotic ones (e.g. through roadkill). The outcome of this process of habitat degradation is equivalent to the existence of a major barrier to vertebrate movement posed by the road and its surroundings (Pungetti and Romano 2004; Anderson and Jenkins 2006; Gagnon et al. 2007). Faunal passages will not be more or less effective as a function of

noise levels within this disturbed context, but all of them will be less effective than they would be in a quieter environment.

High noise levels near roads, and at faunal crossings in particular, may result in consequences that are hard to predict. Environmental noise, at the levels detected in this study, is known to affect vocal communication in species that depend on it (Slabbekoorn and Peet 2003; Brumm et al. 2007; Parris et al. 2009), and it may determine the species-composition of a community (Francis et al. 2009). Although intraspecific communication in most of the species involved in this study relies on scent (mammals) or vision (lacertids), it has recently been shown that ambient noise may alter predator–prey relationships by lowering the effectiveness of alarm calls and through masking adventitious sounds, such as those made by a moving animal on the ground (Rabin et al. 2006; Goerlitz and Siemers 2007). The extent to which ‘soundscape’ changes determine interspecific relationships in a given territory is unknown (Rabin and Green 2002; Barber et al. 2010) but this possibility will enliven the debate on the possible trap effect of faunal passages on prey species (Little et al. 2002; Mata et al. 2009b).

Our results indicate that, from a practical standpoint, road noise mitigation measures intended to protect the surrounding fauna should be focused on the large-scale general problem of the edge effect of a road on its surroundings rather than on the acoustic protection of individual faunal passages. Such measures may involve the road itself, e.g. by using noise-absorbent surfaces, or the behaviour of vehicles, e.g. by speed limitation, in areas of faunal protection. This approach would be more effective than reducing noise around underpasses, at least within the conditions (traffic, animal species) and scales (area, time frames) of the present study. At a smaller scale, efforts should probably centre on avoiding materials and construction styles that result in very noisy underpass interiors, such as using concrete boards that produce noise levels during the passage of heavy vehicles even higher than those reported here. Finally, since this is the first attempt to apply standardised methodology to evaluate the possible effects of noise on the functionality of faunal passages, further similar investigations would be desirable, to underpin the conclusions of the present study and to help understand in which situations addressing the effects of noise will be most appropriate.

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