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PERMEABILITY OF ROADS AND RAILWAYS TO VERTEBRATES: THE IMPORTANCE OF CULVERTS

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Abstract

The movement of vertebrates through 17 culverts under roads and railways in Central Spain was analysed over the course of an annual cycle. Passage was detected for amphibians, lizards, snakes, small mammals, rats, hedgehogs, rabbits and several species of carnivorous mammals, including Felis sylvestris *and* Genetta genetta. *The intensity of animal movement, which varied considerably among the groups, was influenced by various factors such as the culvert dimensions, road width, height of boundary fence, the complexity of the vegetation along the route, and the presence of detritus pits at the entrance of culverts. It is concluded that adequately designed culverts can aid the conservation of vertebrate populations.*

Keywords: barrier effect, roads, railways, vertebrates, culverts, Spain.

INTRODUCTION

Roads and railway tracks (henceforth generally included under 'roads') are believed to be one of the main obstacles to the movement of land vertebrates. This type of linear infrastructure generates a 'barrier effect', which involves the blockage or restriction of movement by certain species and/or populations across the roads (Velasco *et al.*, in press). There is a number of ensuing negative consequences: reduction of genetic diversity due to the increase of inbreeding, increased risk of local extinction due to population dynamics and catastrophic effects, a decrease in the ability to recolonize, etc. (Van Gelder, 1973; Leedly, 1975; Leedly *et al.*, 1975; Adams & Geis, 1981; Grossenbacher, 1981; Rusch, 1985; Waechter & Schirmer, 1987; Bennett, 1991; Nunney & Campbell, 1993).

Crossings designed specifically to increase the 'permeability' of roads are a basic corrective measure for the barrier effect, and encompass a wide range of types (Erickson *et al.*, 1978; Ryser, 1985; Schultz, 1985; Langton, 1986; Der Bundesminister Für Verkehr, 1987; Van Lierop, 1988; Brehm, 1989; Carsignol, 1991; Velasco *et al.*, in press). However, very little attention has been paid to the use of culverts under roads as wildlife crossings (but see Camby & Maizeret, 1985; Hunt *et al.*, 1987), in spite of the fact that these structures are commonplace and often coincide with preferential crossing points.

The present paper analyses (i) the passage of various groups of vertebrates through several culverts built some time ago and (ii) the characteristics of these culverts and their environment that encourage their use, with a view to improving their utility as crossings for vertebrates.

METHODS

Characteristics of culverts and roads/railways

Seventeen main types and sizes of culverts for temporary streams were chosen to represent the range of types of transport infrastructure. All were located in the Madrid region (Central Iberian Peninsula), under a motorway (n=2), several local roads (10) and a railway line (5).

In order to characterize the crossings, seven continuous and three discrete variables were measured (see Table 1 for range of variation).

Four continuous variables referred to culvert dimensions: length (CL), height (CH), width (CW) and openness (ON), which was calculated from the three former variables according to the formula CW × CH/CL. A further three variables evaluated characteristics of the road or railway: width used by traffic (RW), total highway width including verges, embankments and cuttings (HW), and height of boundary fence (FH).

The three categorical variables were traffic intensity (TI), vegetation complexity (VC), and presence or absence of detritus pits (DP). Three levels of traffic intensity were considered, low (<100 vehicles per hour), medium (100–500 per hour), and high (>500 per hour). As frequency of trains was always less than 10 per hour, all culverts under railways were considered as of low intensity.

Vegetation complexity was indicative of the characteristics of the vegetation landscape intersected by the road; this was classified as (1) pastures, (2) pastures with maquis and/or scattered woodland, and (3) forest or maquis with scattered woodland. When the vegetation structure was different on the two sides of the road it was assigned the value of the less complex class.

Detritus pits are designed to collect debris that may otherwise block the culverts, and are located at the entrance to, and below the level of, the culvert. The detritus pits extend across the full width of the culverts and end dimensions were 50 cm broad by 50 cm deep in all cases (n=3).

Table 1. Range of variation in variables related to culvert, road/railway and environmental characteristics

	CL (m)	CH (m)	CW (m)	ON (m)	RW (m)	HW (m)	FH (m)	TI (1–3)	VC (1–3)
Mean	13·1	1·2	1·2	0·2	7·5	20·8	1·1	2·1	2·2
SD	4·06	1·10	0·74	0·31	1·91	5·66	0·83	0·90	0·90
Maximum	26·0	4·0	3·0	1·0	10·0	30·0	2·0	4·0	4·0
Minimum	10·0	0·4	0·6	0·02	5·0	11·0	0·0	1·0	1·0

CL, Culvert length; CH, Culvert height; CW, Culvert width; ON, Openness; RW, Road width; HW, Total highway width; FH, Fence height; TI, Traffic intensity; VC, Vegetation complexity. These last two variables are considered in three classes (see text).

Animal track recording

Use of the culverts was determined by means of the animal tracks found inside them, using marble dust to facilitate their identification. Marble dust is odourless, permits high-quality impressions, and its density renders it almost unaffected by air currents that often form inside such tunnels and which would impair the clarity of prints in lighter material. The dust was laid in a band 50 cm wide and 1 cm thick across the whole width of the culvert near the centre (Fig. 1). A plastic sheet was laid underneath to avoid capillary moisture penetrating from the soil (Bider, 1968).

Track identification using Bang and Dahlström (1983) and Brown *et al.* (1992) was restricted to vertebrates. Each record included the species, whenever possible, or faunal group, the number of tracks and their direction.

Sampling was carried out at four seasonal periods over a complete annual cycle. Each period consisted of four sampling days, except for culverts in areas with wild ungulates (n=4) where, owing to their low density, the number of visits per period was eight. In two sampling periods (summer and winter), a fuller analysis was made of the relationship between the use of the crossing and the areas near the road by different faunal groups. This was done by means of two 'roadside' bands of marble dust laid near both ends of the culvert and 2–4 m from each side of the road surface, and two 'distant' bands 40–50 m from the culvert (Fig. 1). Their dimensions were 1·0 × 0·5 m, and the animal tracks found were recorded daily.

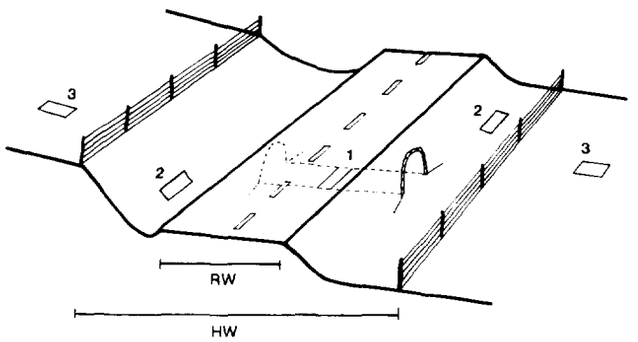

Fig. 1. Location of the marble dust bands (1, culvert; 2, road side; 3, distant) and the boundary fences (not to scale). RW, road width used by traffic; HW, Total highway width.

Data treatment

The total data for animal crossings were corrected for the number of days during which the marble dust trails were laid. Likewise, as the use of the crossing may depend on the abundance of vertebrates in the surrounding area, an index (CI) was calculated to standardize for this factor, according to the formula

$$CI = CTD/(CTD+ETD),$$

where CTD is the number of tracks per day inside the culvert and ETD is the total number of tracks per day on the two distant bands. The value of the index ranged from 0 to 1, with the highest values corresponding to the most used culverts in terms of vertebrate crossings and abundance in the surrounding area. Data concerning the cases where no tracks were recorded in the culvert and in the distant band were regarded as indeterminate, and not included in the analysis.

Spearman's rank correlation coefficient was used to ascertain the relationship between the continuous culvert variables and the use of culverts by fauna. Differences in use of the culverts in relation to the categorical variables (TI, VC and DP) were analysed using Kruskal-Wallis and Mann-Whitney U-tests (Zar, 1984).

Because of the low number of observations for some species, the tracks were grouped into four large classes: (a) reptiles; (b) small mammals up to the size of a hedgehog; (c) rabbits; and (d) carnivorous mammals. Amphibians were excluded from the analyses owing to the low number of tracks recorded (Table 2). Raw data for culvert characteristics and crossings are available upon request.

RESULTS

Crossings: species

In total 1,202 tracks were recorded in the culverts. The average for all vertebrates combined was 3·8 tracks per culvert per observation day (Table 2). The highest frequencies were mice (*Apodemus sylvaticus* in all individuals captured for identification purposes, n=13; 64 % of the total of tracks per day), shrews *Sorex* spp. (13%), and rabbits *Oryctolagus cuniculus* (10%). Cats, mostly wildcats *Felis sylvestris*, comprised the largest number of carnivorous mammals (1·4%), followed by foxes *Vulpes vulpes* (1·1%) and genets *Genetta genetta* (0·6%).

Small mammals were recorded in all the culverts. Only three (18%) were not used by reptiles, two of

Table 2. Movement through culverts expressed in number of tracks per day

	All	Amphibian	Lizard	Snake	Shrew	Rat	Hedgehog	Mouse	Rabbit	Weasel	Genet	Cat	Fox	Dog
Mean	3·78	0·03	0·23	0·02	0·53	0·05	0·01	2·51	0·33	0·01	0·02	0·04	0·03	0·01
SD	2·15	0·06	0·28	0·04	0·49	0·07	0·05	1·49	0·40	0·02	0·09	0·07	0·07	0·03
Maximum	8	0·19	0·88	0·13	1·63	0·19	0·19	5·19	1·25	0·06	0·38	0·22	0·28	0·13
Minimum	0·19	0	0	0	0	0	0	0·09	0	0	0	0	0	0
%	100	0·8	6·1	0·6	12·8	1·4	0·3	64·4	10.0	0·3	0·6	1·4	1·1	0·3

which were the only ones sampled under a motorway. Rabbit and carnivore crossings were verified in 59% and 65% of the culverts, respectively, with the notable fact that none of the three culverts which had detritus pits was used by either of these two faunal groups.

Crossings: seasonal variation

Most vertebrate crossings occurred during spring and summer, with a minimum in autumn (Table 3). Small mammals had the highest percentage of recordings in all periods, and no significant differences were found between seasons (Kruskal-Wallis test, K=3·301; $p>0·05$), although their relative contribution varied between 92% of all tracks in spring and 60% in summer. The passage of carnivores also revealed no significant seasonal differences (K=1·217; $p>0·05$), although records in spring were somewhat lower.

Reptiles and rabbits showed the greatest seasonality in use of culverts, with an increase in relative importance in the summer sample, though only significantly so for the former group (K=34·527; $p<0·01$ and K=5·448; $p>0·05$, respectively).

Table 3. Mean tracks per day for all culverts by seasons and fauna groups

	All	Reptiles	Small mammals	Rabbits	Carnivores
Spring	4·35	0·04	4·02	0·22	0·07
Summer	4·36	0·88	2·61	0·73	0·14
Autumn	2·68	0·04	2·40	0·08	0·15
Winter	3·02	0	2·55	0·32	0·15
CV	24·4	180·0	26·1	82·8	30·3

Seasonal variability of mean values is expressed using the coefficient of variation (CV=100 standard deviation/mean).

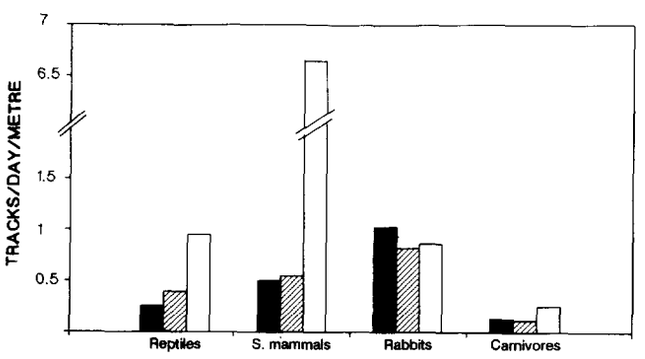

Fig. 2. Mean number of tracks per day per metre of band in distant (■) and roadside (▨) bands, and inside (□) the culverts.

Road environment and culvert usage

The numbers of tracks per day observed for reptiles, small mammals, rabbits and carnivores in the roadside bands (Fig. 2) did not differ significantly from those in the distant bands (Wilcoxon test, z=0·562, 0·315, −1·023 and −0·122, respectively; $p>0·05$).

Neither were there significant differences between abundance of rabbit and carnivore tracks per day per metre of band recorded in the culverts and in the distant bands (z=−0·534 and −0·841, respectively; $p>0·05$). However, the abundance of tracks of reptiles and small mammals was higher inside the culverts than on the distant bands (z=2·830 and 3·575, respectively; $p<0·01$).

No significant correlations were detected among the small mammals between tracks through culverts ($n=17$) and in the distant bands (r=0·218; $p>0·05$). However, there were positive correlations among rabbits (r=0·647; $p<0·01$), carnivorous mammals and reptiles (r=0·510 and r=0·470, respectively; $p<0·05$).

Crossings: influential factors

Most of the culvert and road variables seemed to influence vertebrate crossing, although there are notable differences between groups. All the continuous variables had significant correlations with the vertebrate crossings. The crossing index (CI) for small mammals ($n=17$) was correlated negatively with road width and length of the culvert (r=−0·505 and −0·506, respectively; $p<0·05$), and positively with height (r=0·635; $p<0·01$), width (r=0·549; $p<0·05$) and openness (r=0·731; $p<0·01$). The crossing indices for rabbits ($n=10$) and carnivores ($n=12$) were negatively correlated with total highway width (r=−0·573 and −0·554, respectively; $p<0·05$) and, for rabbits, with height of boundary fence (r=−0·824; $p<0·01$); for carnivores the last relationship was almost significant (r=−0·497; $p<0·05$).

Passage of reptiles was negatively affected by the presence of detritus pits (U=21·0, $n_1=3$ and $n_2=10$; $p<0·05$). In relation to vegetation complexity, significant differences were only found for the crossing index of small mammals (K=7·419; $p<0·05$), which was one-third lower in the roads surrounded by pasture.

DISCUSSION

Faunal differences

The results demonstrate that culverts are used by a wide range of vertebrates. Comparison of abundance of

tracks per metre of band inside the culverts with those in the distant areas suggests that there is no positive avoidance or reluctance to use the culverts exhibited by any faunal group. For reptiles and small mammals the number of tracks per day per metre was higher inside the culverts than on distant bands.

Most crossings were by small mammals (77%) and abundance of this group was similar in the roadside band to that in the surrounding habitat, unlike the findings of Adams and Geis (1983) on other roads. Furthermore, their tracks were much more abundant within the culvert. Considering the small home range of these animals, the culverts were most probably used more as a link between belts of disturbed terrain on the two sides of the road than between distant areas. The ground surface inside the culverts is normally covered in soil and debris deposited by the previous flows of water and presumably provides a less hostile environment for these animals than the open roadway. This may explain the high degree of acceptance.

Reptile crossings through culverts seem to be frequent only in the case of the lizards (6% of all vertebrate tracks). Acceptance of the culverts by reptiles is high and, as in the case of the small mammals, their tracks were more abundant within the culvert than on the distant band. The small home range of many lizards (Stamps, 1977) makes the utilization of culverts unlikely as a channel for movement between distant areas. In contrast, the two tracks of the eyed lizard *Lacerta lepida*, a species with a much larger territory, might reflect a journey between much more distant areas. The important fact is that the culverts allow the passage of reptiles and possibly increase the permeability of roads and railways. Amphibian crossings were probably underestimated in the sample results, as field work was interrupted on rainy days when the marble dust was affected by water. After a rainy day in winter, 75% of the culverts registered anuran crossings.

Rabbits leave a large proportion of all tracks found in culverts; their relatively widespread movements must encourage the acceptance of culverts in their journeys between either side of the road.

As a rule, the response of carnivorous mammals to transport infrastructure varies between the attraction exhibited by the most generalist species, and its avoidance by those most sensitive to human interference (Rusch, 1985). In this analysis, although the differences in the number of tracks per day for all carnivores by the road and the more distant habitats were not significant, they are more frequent in the latter.

Although crossings by medium-sized wild carnivores were a small percentage of the total tracks observed (less than 4%), the high wildlife value and the conservation problems associated with these species make the utilization of culverts as road and railway crossings particularly important. The movement of carnivores through culverts, mentioned previously (Camby & Maizeret, 1985; Hunt *et al.*, 1987), permits mobility among areas that are intersected by the road in the absence of specific tunnels for vertebrates.

Seasonal variability

Seasonality in culvert use varied considerably among faunal groups. Carnivores and small mammals were those that revealed the least seasonality while reptiles had the greatest variability. The largest number of recordings was during summer, when reptiles accounted for over 20% of all vertebrates, between eight and 15 times more than those during the rest of the year. This phenomenon coincides with the increase in lacertid activity during the warmest months of the year in the centre of the Iberian Peninsula (García Paris *et al.*, 1989).

Although the seasonal differences in the number of tracks of rabbits are not significant, it appears that they are more abundant in summer when the population is at its highest in Spain (e.g. Soriguer, 1981).

In general, it appears that the seasonal variations in culvert use are related to the abundance of animals in the surrounding habitat. The positive correlation between the number of tracks in the culvert and in the distant bands in all groups, except small mammals also indicates a dependence of use of culverts on animal abundance.

Culvert characteristics

Vertebrate crossing is related to some of the characteristics of the culverts and their surroundings, and important differences among the faunal groups were revealed.

The dimension of the tunnels is considered as one of the most important variables in the design of passageways for vertebrates (Ulbrich, 1984; Ballon, 1986). In this study, the dimension of the culvert only appeared to affect the crossing index of small mammals, while the other groups were affected to a greater extent by other variables. However, the majority of the culverts studied was sufficiently large to allow the passage of medium-size vertebrates, and it should be pointed out that culverts of smaller dimensions would limit the passage of medium- and large-size mammals.

The crossing index of medium-size mammals (rabbits and carnivores) was affected by the total width of the road and not by the width of road used by the traffic. The change in the complexity of vegetation on the roadside verges appears to impose an additional obstacle to the passage of these vertebrates (SETRA, 1985). However, other factors unrelated to the road must influence the use of culverts by carnivores. Just one of the selected tunnels, located in an area of pasture provided all records of genet crossings, and approximately half of those of wildcats, even when at least eight culverts (47%) coincided with the distribution area of both species (Virgós & Casanovas, 1993).

In these groups the crossing index was also related negatively to the height of boundary fence. While adequate fence design can help to direct fauna towards crossings (Brehm, 1989; Podloucky, 1989; Carsignol, 1991), the fences in the study sample, which are representative of the state of most culverts in the Spanish road network, do not allow access to culverts, and therefore hinder their use. The accidental installation of

a 2 m high fence to enclose two of the selected crossings that were previously used habitually by wild ungulates led to the total absence of recordings of these animals in the 24 sampling days.

Finally, a very important factor in culvert utilization is the presence of detritus pits. Their presence is related negatively with the efficiency of culverts as reptile crossings, and none of the culverts with detritus pits was used by rabbits or carnivores. This type of culvert structure is being installed most frequently in recent years, in detriment to the 'permeability' of the road for vertebrates by culverts.

CONCLUSIONS

The present study shows that culverts can constitute a traffic-free crossing for vertebrates between habitats on the two sides of a road. These may be important for local populations and even for rare species such as wildcats and genets that are capable of using them.

It has been suggested that both tunnels for vertebrates and water culverts should be installed separately (SETRA, 1989). In practice, however, the absence of specific tunnels under most roads, and the reduction in costs of not having to provide special passages when culverts are used by fauna, endow the latter with particular importance for conservation.

When it is intended to encourage vertebrate crossings through culverts, the fences of the roadway should never under any circumstances block the entrance to the culverts and should be constructed so as to funnel animals towards the culverts. It has been suggested by other authors (e.g. Bennet, 1991; Carsignol, 1991), that this funnelling effect can be augmented by artificially increasing the vegetation cover around and towards the entrance of the tunnel. Also detritus pits should be eliminated, or modified using ramps.

The adaptation and improvement of culverts to encourage vertebrate crossings involve minimal outlay in comparison with overall costs and the provision of special tunnels. They are an effective method of increasing the permeability of highways, and thus of lessening the barrier effect. However, owing to the relatively low sample number, further data are needed to check on the value of particular design features for wildlife.

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