Use of wildlife crossing structures by medium sized and large mammals

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Abstract. The use of 20 wildlife overpasses (green bridges) and 23 underpasses (10 viaducts, 6 river crossings or culverts, 7 wildlife underpasses) by medium sized and large mammals as well as about two dozens of small mammal underpasses and several non-wildlife passages have been studied during winter and spring 2004 and 2005. The study was carried out at three motorways, three highways and three state main roads in southern Germany (Baden-Württemberg) and at one motorway in northern Germany (Mecklenburg-Vorpommern). Amongst the observed animals were red deer, fallow deer, roe deer, wild boar, European hare, red fox, racoon dog, badger, beech marten (as well as pine marten and polecat) and otter. The results document that green bridges and larger viaducts were used most intensively (by about 85% of all animals recorded). The use of the smaller river crossings, culverts and small mammal underpasses was, with only 15% of all recorded animals, low. Fox, hare and roe deer accounted for about 72% (videos) and 89% (tracks) of passage crossings by animals. Using different multiple regression analyses eight of some 28 independent variables proved to be of significant influence in some cases on the use of green bridges by the species investigated: width showed a positive, length and age of the bridges as well as the amount of wooded area on the bridges, noise, human activities, number of roads leading to the bridges and buildings in their nearby neighbourhood a negative relation. The barrier effect of the roads studied seems to be mitigated sufficiently by the crossing structures although crossing rates are substantially lower than before road construction.

Key words: motorways, highways, mammals, use of wildlife passages, Baden-Württemberg, Mecklenburg-Vorpommern

1. Introduction

Over the last two to three decades, in Europe most governmental nature conservation and traffic agencies as well as NGO's have become increasingly aware of the effects that roads have on wildlife (Bright 1993; Bennet 1997; Trombulak & Fissel 2000; Forman *et al.* 2002; Trocmé *et al.* 2003). Significant advances in understanding the impacts and developing solutions have led to a large amount of handbooks in order to mitigate the effects (SETRA 1993; Hlavač & Andel 2002; Iuell *et al.* 2003; Carsignol *et al.* 2005; Iuell 2005; FGSV in prep., etc.).

Meanwhile most European countries have realized crossing structures for wildlife at least with larger motor or high ways. But there are only a view studies assessing the effectiveness of the different types of these wildlife passages (Clevenger & Waltho 2005; Hardy *et al.* 2003) or the results are spurious because of their failure to address masking effects of confounding variables (site, size, design, age, activity, traffic noise, habituation of animals etc.). Furthermore most studies focused only on specific over- or underpasses than to compare different types of crossing structures.

During the last three years an investigation was carried out in Germany to evaluate the use of different types of wildlife and non-wildlife over- and underpasses by medium sized and large mammals (three additional studies occupied badger, dormice and bats; Herrmann 2006; Müller-Stieß 2006; Bach & Müller-Stieß 2006; for the complete report see Georgii *et al.* 2006). The study was financed by the Federal Ministry of Transport, Building and Urban Affairs as well as the transport agencies of some regional governments. The results show, that only green bridges and viaducts were used intensively. In the case of green bridges the influence of some variables (e.g. noise, human activity, vegetation structure) proved to be of statistical significance.

2. Study area and methods

One part of the study was carried out in Baden-Württemberg (southern Germany) at three motor ways (A8, A96, A98), three high ways (B31neu, B33neu, B464) and three state main roads (L113neu, L1100, L1207). The other study area was a section of the A20 motor way in Mecklenburg-Vorpommern (northern Germany). Both study areas differ in landscape (Fig. 1), the former showing mainly hilly terrain with a small scale mixture of meadows, fields and forests the latter mainly consisting of large scale farm land with only scarce forests. Main medium-sized to large mammals in both parts are roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), European hare (*Lepus europaeus*), red fox (*Vulpes vulpes*), badger (*Meles meles*), especially beech marten (*Martes foina*) but also pine marten (*Martes martes*) and polecat (*Mustela putorius*), racoon dog (*Nyctereutes procyonoides*), in the A20 area also red deer (*Cervus elaphus*), fallow deer (*Dama dama*) and the otter (*Lutra lutra*). Otter, polecat and pine marten are threatened species (according to the red data books of Germany or the FFH-categories).

The mean road density in Baden-Württemberg is nearly twice as high (0.78 km/km^2) than in Mecklenburg-Vorpommern (0.43 km/km^2). The traffic volume of the ten roads varies from only about 1.700 to more than 63.000 vehicles per 24h-day. All motor and high ways are fenced, but not the state main roads. The study involved 20 green bridges, 10 viaducts, 7 wildlife underpasses for large animals, some 20 underpasses for small mammals, 6 river crossings and culverts (Fig. 2 and Table 1) as well as non-wildlife over- and underpasses (for use by farmers, foresters or public traffic, n=38). Their age ranges from three to sixteen years according to the age of the roads. Vegetation on the green bridges or below the viaducts varies from nearly pure meadow, open parts mixed with shrubs to completely wooded. Most crossing structures involve gravel (in some cases also paved) roads which were used by humans.

Fig. 1. Air photos showing typical landscape examples from Baden-Württemberg (above) and Mecklenburg-Vorpommern (below). Google Earth

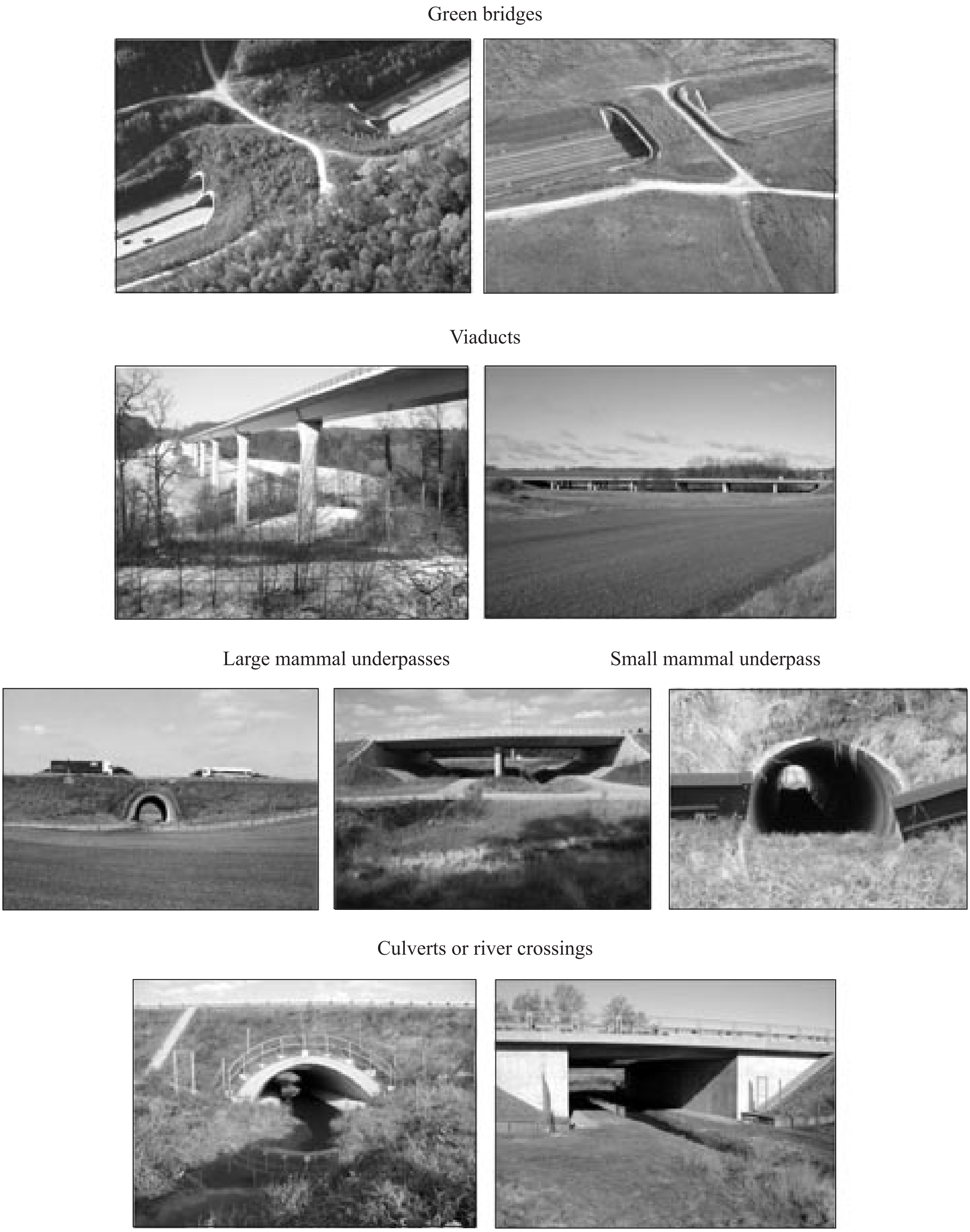

Fig. 2. Examples of the different crossing structures investigated

Table 1. The main wildlife passages involved in the study; further crossing structures were non-wildlife passages for use by farmers, foresters, recreationists or even public traffic (joint-use passages); parantheses show abbreviations used in figures

crossing structures	quantity	width[1] (meters)	height (meters)	length (meters)	vegetation
green bridges (gb)	20	23-201	-	23-120	pure meadow, totally wood, mixed
viaducts (vd)	10	58-440	5.5-55	*	pure ground, mainly meadow, partially wood
large mammal underpasses (lu)	7	6-44	2.4-8	45-95	pure ground, partially meadow
culverts[2] (cu)	6	3.2-15	1.8-4.3	35-68	mainly pure ground
small mammal underpasses[2] (su)	20	0.8-2,0	0.8-2.0	35-55	pure ground

Explanations: [1]from the perspective of the animals (between fences or walls); [2]circular and box shaped; *equal to road with

We monitored the passage of animals using infrared video cameras recording at least four nights during March or April 2004 and 2005 (on green bridges and at wildlife underpasses) and track counts during at least five days from December to February in the same years (at all crossing structures). In some cases also sand beds and digital trail cameras (Cuddeback® , DeerCam®) were installed. We defined the intensity of passage use as the number of animals from each species seen on the videos per night or the amount of tracks in snow per 24h-day. Data on the observed species in the neighbourhood of the roads there sampled by interviewing hunters, foresters or other people experienced with the local situation, because field estimation of population densities would have been to time consuming and not financeable. Intensity of road side use by the species was recorded by monitoring tracks along transects (distance to road verge or fences about ten meters).

Using multiple regression analysis (Zar 1999) we investigated the influence of 28 (roe deer: 29) independent variables on the species' use of the 20 green bridges (variables shown in Table 1 and 2 and additionally e.g. location of passages, distance to canopy etc.). For the other crossing structures their number were too small or the use by animals too less for statistical treatment. We used models including the whole group of mammals as well as models regarding only roe deer, fox and hare (the three most frequent species). Differences between mean values were tested by simple or paired t-test (Zar 1999), aspects of use of vegetation structure by compositional analysis (Aebischer *et al.* 1993). In some cases the regression results explain differences in the intensity of species' passage with relatively high R2-values (0.56 to 0.86).

Data were collected in 2004 and 2005, for some green bridges there are also data available from 1994 and 1995.

3. Results

3.1. Species

Summarizing the 117 video nights and 43 tracking days we recorded a total of 1441 and 2126 animals, respectively, crossing the different types of passages. As Figure 3 shows, hare, fox and roe deer accounted for 72% (videos) and 89% (tracks) of the recorded animals. Next frequent species were badger, martens (pine and beech marten, species not distinguished) and wild boar. Red deer, fallow deer, otter and racoon dog made up only 2-3% of all species recorded. The category 'others' comprises mainly domestic cats.

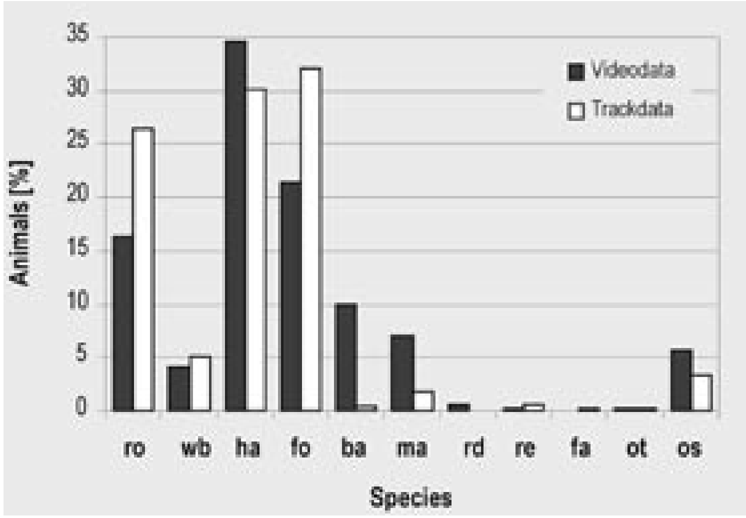

Fig. 3. Roe deer (ro), wild boar (wb), hares (ha), fox (fo), badger (ba), martens (ma), racoon dog (rd), red deer (re), fallow deer (fa), otter (ot) and other mammals (os) as percentage of all animals observed (re, fa, ot live only in the A20 area)

3.2. Use of different crossing structures

When analysing the video data and the track data, both reveal green bridges and viaducts as the crossing structures most intensively used by the species studied (Fig. 4), despite the fact that viaducts are build for other purposes. Unexpected was the only moderate use of large mammal underpasses by ungulates although they have been build especially for these species. On the other hand use of all underpasses showed that predators (fox, badger, martens, otters) and in some cases also hares had no problems to use even the smaller ones. Whereas the ungulates used the green bridges mainly for crossing the road, hare or badger and fox use them as feeding habitat also or have been observed leaving scent or urine marks.

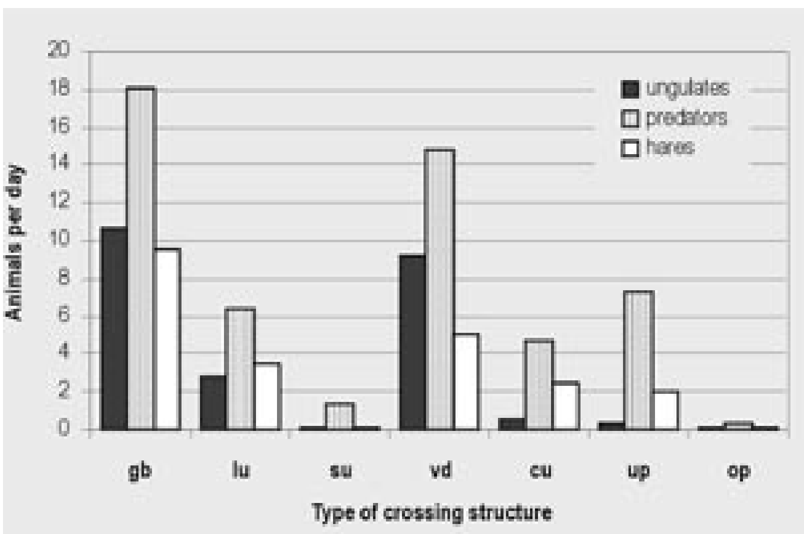

Fig. 4. Use of the seven types of crossing structures by the species investigated; species grouped into ungulates, predators and hares; gb – green bridges, lu – large mammal underpasses, su – small mammal underpasses, vd – viaducts, cu – culverts, up – non-wildlife underpasses, op – non-wildlife overpasses

3.3. Influence of constructional and environmental attributes of green bridges on their use by mammals

In the case of green bridges the sample was large enough for treatment with statistical methods. Of the 28 independent variables tested eight proved to be of influence on the use of this kind of overpass in some cases (Table 2).

3.3.1. Age

With the video data the multiple regression revealed age of the green bridge to be a significant factor explaining green bridge use by all observed mammal species ($p=0.016$): the younger the buildings the less intensive was the frequentation by the animals. This was confirmed by the fox data alone also ($p=0.004$). On the other hand there exists a strong correlation between the age and the amount of wooded area on the green bridges ($r=0.802$): the older the bridges the more of the surface is covered with wood. The regression analysis showed, that this is of influence on the age-dependend use of the overpasses because a higher amount of wooded area results in less animals crossing the green bridges ($p<0.001$).

This can dampen the effect of age so far that there is no difference recognizable between younger and older performance data. This became obvious when we compared the actual data with those from 1994/95 of the same seven green bridges (Fig. 5). Notwithstanding the ten year difference in the vegetation development there is a highly significant correlation between the number of species' passages in 1994/95 and 2004/05 ($r=0.905$, $p<0.005$).

Table 2. Eight out of some 28 independent variables which proved to be significant factors explaining the green bridge use by medium-sized and larger mammals (using multiple regression analysis); all other variables failed or nearly failed to be of significance. Rank is based on sum of squares (relative importance) of this variable

Attribute	**Video data**			
	Beta	SE	P-value	Rank
all species	$R^2 = 0.56$			
gb_age[1]	-0.552	0.063	0.000	1
gb_wood[2]	-0.042	0.007	0.000	2
anth_use[3]	-0.579	0.233	0.038	3
roe deer	$R^2 = 0.76$			
road_numb[3]	-0.722	0.235	0.013	1
gb_length[4]	-0.040	0.014	0.020	2
build_envir[5]	-0.149	0.074	0.074	3
red fox	$R^2 = 0.65$			
gb_age[1]	-0.203	0.054	0.004	1
anth_use[3]	-0.804	0.301	0.023	2
Attribute	Track data			
	Beta	SE	P-value	Rank
all species	$R^2 = 0.86$			
build_envir[5]	-0.086	0.027	0.009	1
road_numb[6]	-0.449	0.147	0.012	2
gb_width[7]	0.007	0.002	0.015	3
gb_noise	-0.041	0.017	0.040	4

[1]date when build (1989, 1990, …); [2]amount of wooded area on green bridges (percent of whole surface); [3]number of people or cars per 24h-day in three categories (1, 2, 3); [4]from entrance to entrance; [5]number of buildings in the nearer environment of green bridges; [6]number of paved or unpaved roads on green bridges; [7]in meters between the fences; [8]dB(A) in the middle of green bridges

3.3.2. Vegetation and other structural features

Another influence of vegetation as well as other structures became apparent when we compared the use of the different structural features on the green bridges like wooded areas, meadows (or open parts, respectively), roads and the earth mounts at the outer edges. So, for example, the animals used the open parts of the green bridges more and the wooded areas less intensive than it would be expected from the percentage of area of this structures. Especially hares, badgers and foxes preferred to walk on the gravel roads. Compositional analysis to these data showed a clear ranking for the preference of the different structures (p=0.0073): open parts > gravel roads > wooded parts > earth mounts.

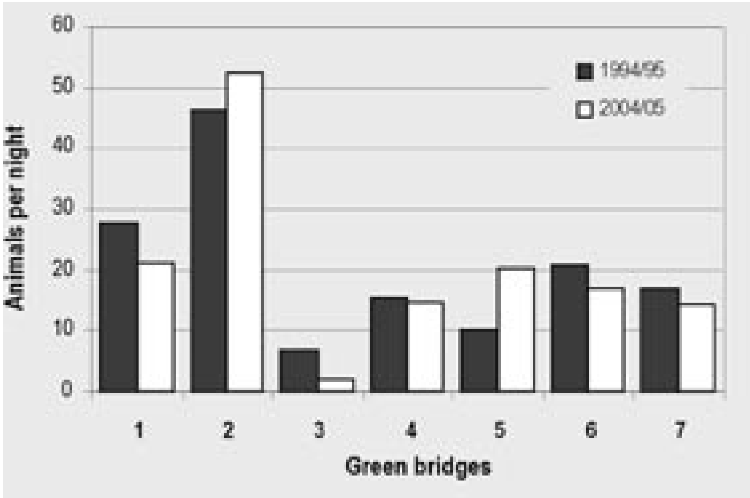

Fig. 5. Species' use of seven green bridges comparing video data recorded in 1994/95 and in 2004/05

3.3.3. Width

Pfister *et al.* (1997, 1999) were the first who showed that the intensity of use of green bridges by medium-sized and larger mammals increases according to the width of the buildings. In the actual investigation this could be confirmed with the multiple regression analysis using the track data for all species (p=0.015; but not with the video data). When using only the track data of roe deer it was interesting to see, that this species showed a significant negative reaction to the length of the green bridges as well (p=0.020).

For all other crossing structures there seems to be a relation between use intensity and width as well, but without statistical significance.

3.3.4. Traffic noise

Since long traffic noise is considered to be a factor making habitats near roads to be avoided by birds as well as mammals (Trocmé *et al.* 2003). But studies measuring this effect are scarce. In the present investigation we measured noise on the green bridges and at the road verges near by using hand-held noise meters (Integrating Impulse Sound Level Meter, Type 2226, Brüel & Kjaer, Denmark) with special emphasis on irregular noise bursts (e.g. extra noisy high-speed vehicles, trucks). Because of the noise lowering effect of earth walls or screens on the overpasses these traffic noise peaks were about 17 to 39 dB(A) lesser than at the road side (73-78 dB).

Applying multiple regression analysis to the track data of all species studied showed that less noisy green bridges were used significantly more intensively than more noisy ones (p=0.040). With the video data this relation was only nearly significant (p=0.070).

3.3.5. Human presence

Most of the investigated crossing structures (even the green bridges) are joint-use passages mainly with gravel but in some cases with smaller traffic roads also. Furthermore, in the nearby surroundings of most over- and underpasses there were additional roads as well as buildings like e.g. farm houses or barns. This enhances the presence of people at the crossing structures.

In the case of green bridges the multiple regression analysis with the video data of all species revealed that the recorded human activities on the bridges has a significant negative influence on their frequentation by wild animals (p=0.038). The same was true for the fox (p=0.023). On the over hand, when regarding the track data, the more indirect indices showed the same effect: The higher the number of roads leading to the green bridges or of buildings in their nearby neighbourhood the less was the use of the bridges by roe deer (p=0.013 and p=0.074, respectively) as well as by all species (p=0.012 and p=0.009).

3.4. Mitigation of the roads barrier effect by combinations of crossing structures

Estimating the mitigation effect of crossing structures is rather difficult especially because of the lack of quantitative crossing data without the road or without wildlife passages. In one case of our study there were such data. This was the B31neu, a three lane high way near the lake Constance in Baden-Württemberg (Southern Germany). Data were collected there when the road was just under construction (Jenny *et al.* 1993) using track counts in its earth bed. Since completed and opened for traffic there were six green bridges on only ten kilometres of the B31neu (with distances between 1000 and 2500 meters and some 15 additional small mammal underpasses as well as non-wildlife over- and underpasses).

Whereas the mean total of daily crossings in 1993 was 680 animals (the same species like in the actual study) the number of crossing animals in 2004/05 amounts to only some 125. Data from an additional investigation of the badger in the surroundings of the B31neu (Herrmann *et al.* 1997; Hermann 2005) confirmed these results. Despite of the high number of over- and underpasses the crossing rate of this species declined from 4.6 animals per kilometre in 1993/94 to only 1.7 in 2004/05.

But one should not look at crossing rates only. The data from the A20 suggest that there is an important other effect of combining different crossing structures: it widens the permeability of a road for the spectrum of species to cross safely. So e.g. otters were never recorded on green bridges but in the adjacent culverts.

4. Discussion

The findings from this study show that a sufficient size of over- and underpasses is one of the most important factors to meet the demands of medium-sized and large mammals as was shown already by Pfister *et al.* (1999) and for culverts by Clevenger *et al.* (2001, 2005). For the group of species investigated this seems to be more important than the design. We draw this assumption from the result, that there was no obvious effect of the ten year vegetation development on green bridges when comparing frequentation data from 1994/95 and 2004/05. The increase in species' passages with age of green bridges probably is more due to learned behaviour passed on by individual animals. But there can be no doubt that for small vertebrates or invertebrates convenient habitats on or under/in passages are essential (Pfister *et al.* 1997). Thus design should be orientated towards the demands of the latter species much more than to those of larger mammals.

Together with the width of green bridges human activities and associated factors like roads on or near the passages as well as buildings in their nearby surroundings and traffic noise seem to be important attributes to influence the frequentation of crossing structures by animals also. Whereas human disturbance is well known to influence behaviour of wild animals (e.g. Bowles 1997; Herrmann 2001; Knight & Cole 1991), up to now literature gives only little evidence of these factors influencing crossing structure use by mammals (Clevenger *et al.* 2001, 2005).

In the present study all other tested variables failed to show significant effects on species' use of the different crossing structures. Possibly this was due to the varying features of the surrounding habitats, differences in the density of the populations present, specific behavioural traits of individual species or other, unknown, factors. On the same reason it is difficult to predict how a special type of crossing structure will work in a special situation. In some cases the low species' use especially of wildlife underpasses was obviously due to design problems as e.g. fences at the entrances, flooding during wet periods or missing vegetation cover nearby. Moreover some animal species, like e.g. red deer, are reluctant to use confining structures (Reed *et al.* 1975; Ward 1982). And last but not least the sample periods of only four nights (videos) or five days (tracks) are very short to give an complete picture of what is going on at the passages (Malo *et al.* 2005).

We are aware that the present study does not say anything about the real effectiveness of the over- and underpasses investigated. But just this undoubtedly is the most important but only seldom answered question when regarding the success of mitigation measures (effects on long-term conservation of fragmented populations, genetic exchange across the road, re-colonization success etc.). To investigate these aspects is most urgent task in the future because the most effective measures should be applied predominantly in order to use resources efficiently.

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