Factors determining the use of culverts underneath highways and railway tracks by bats in lowland areas

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Abstract: In urbanising environments the construction of suitable underpasses for bats under highways and railway tracks is becoming increasingly important to avoid habitat fragmentation. Culverts provide valuable and low cost underpasses as they are already an intrinsic part of highway design and many bat species associated with water are likely to follow the streams or canals that flow through them. Bat detectors were employed to study the use of 54 culverts by bats in the Netherlands. The aim of the study was to define the factors that determine bats' use of culverts. Bats were observed in the vast majority of the culverts that were studied, thereby underlining the importance of culverts in habitat de-fragmentation. Species adapted to hunting in open habitats, such as the noctule (*Nyctalus noctula*) and the serotine (*Eptesicus serotinus*), were often recorded in front of the entrance but rarely inside culverts. For the three species that were regularly recorded inside culverts, Daubenton's bat (*Myotis daubentonii*), the pond bat (*Myotis dasycneme*) and the common pipistrelle (*Pipistrellus pipistrellus*), cross sectional area was the most important factor that determined their use of culverts. Height was the most important component of cross sectional area for bats. Length proved a non-significant factor, suggesting that bat underpasses are not affected by the widening of the above-lying infrastructure. Additional guidance by treelines along the banks did not increase the use of culverts by the three species. The implication of the different preferences for cross sectional area on the design of infrastructure is discussed.

Keywords: connectivity, anthropogenic barriers, highways, underpasses, bats.

Introduction

In densely populated areas anthropogenic barriers such as highways and railway tracks can pose a number of problems for flora and fauna. They can lead to habitat fragmentation and when there is a small remnant population this can increase the risk of inbreeding and lead to a loss of genetic variability (Hedrick 2000, Keller & Largiadèr 2003). At the same time the chance of local extinctions increases, by destroying effective meta-population structures (Gonzales et al. 1998). For flying animals such as bats, highways do not constitute complete barriers and it seems unlikely that these two processes play a major role. It has been demonstrated, however, that highways do provide barriers to bat movements (Kerth & Melber 2009). Slow and/or low flying bat species such as the lesser horseshoe bat (*Rhinolophus hipposideros*) and the brown long-eared bat (*Plecotus auritus*) seem reluctant to cross highways at high altitude and their mortality caused by collision with vehicles seems to be higher than among fast hawking, aerial insectivorous bats (Russell et al. 2009, Lesinski et al. 2010). Geoffroy's bats (*Myotis emarginatus*) and Bechstein's bats (*Myotis bechsteinii*) make detours to reach suitable underpasses to cross a highway (Krull et al. 1991, Kerth & Melber 2009), thereby increasing the length of their commuting flight. As most vespertilionid bats make use of the peak in food availability at the onset of the night (Kunz 1973, Swift 1980), a longer commuting flight time can significantly reduce foraging efficiency.

The construction of overpasses and underpasses improves the connectivity of habitats adjacent to highways and is therefore likely to reduce these negative effects. Underpasses are readily accepted and used frequently by slow/low flying bat species (e.g. Bach et al. 2004), in many cases more frequently than green bridges (Bach & Müller-Stieß 2005). Culverts provide valuable underpasses because they generally do not have the illumination or traffic that is present in most tunnels and because many bat species associated with water are likely to follow the streams or canals that lead through them. Because culverts are an intrinsic part of a highway design, the cost of making a suitable culvert underpass is much lower than creating a fauna tunnel.

However, there is limited available data about the appropriate dimensions or other factors that determine the use of bat underpasses. Several studies provide dimensions based on known bat underpasses and expert judgements (Brinkmann 2003, Bach et al. 2004, Limpens et al. 2004, National Roads Authority 2006, Brinkmann 2008). To date no quantitative analysis has been done that relates the characteristics of underpasses with bat usage. Many highways are currently being widened to add traffic lanes to accommodate the increasing number of vehicles. This will increase the length of the underlying tunnels and culverts. It is unclear what the effect of these measures will be on existing bat commuting flight routes. This study was undertaken to define the orthogonal factors that determine the use of culverts underneath highways and railway tracks by bats.

Methods

Study area

Fifty-four culverts underneath highways (24), provincial/secondary roads (11), railway tracks (5) and local roads (14) were studied. All the culverts are located in the Netherlands, the majority in the centre or mid-western part of the country (figure 1). The area is flat, mostly consisting of intensively cattle-grazed meadows interrupted by urban environments and patches of deciduous forest. All the culverts are for canals, streams or ditches with stagnant or slow flowing water. The water surface level of these locations is just below (<1.5 m) the surrounding area, as is typical in lowland areas. Underpasses that contain larger water bodies (canals, small rivers) are usually called bridges but in this study the term culverts is consistently used to avoid confusion.

Figure 1. Map of the Netherlands indicating the locations of the studied culverts.

The culverts were selected in order to obtain a sample containing different dimensions (height, width and length; table 1. photos 1-3). Culvert length is defined as the distance between the two entrances. Culvert height is defined as the distance from the water level to the ceiling of the culvert (photo 4). As larger

Table 1. Dimensions (m) of the studied culverts (n=54).

	Average	Minimum	Maximum
Length	36	3.6	132
Width	8.1	1.4	37
Height	2.1	0.3	6.1

Photos 1-3. Three of the culverts studied, showing dimensional differences. *Photographs: M. Boonman*.

culverts tend to be both wide and tall, culverts with unusual shapes (e.g. narrow and tall underpasses for boats) were included to maintain parameter independence. Culvert dimensions were measured with a Bosch digital range finder. Culverts longer than 80 m were measured by using Google Earth. None of the culverts contained illumination, traffic or physical barriers such as fences or grills.

Measuring bat activity

Bat activity was simultaneously measured in the middle of the culverts as well as in front of one entrance by using Anabat SD II bat detectors (Titley Electronics, Ballina, Australia). The Anabat inside the culvert was placed on a small raft that was secured by two anchors with the microphone directed at a 45 degrees angle between the entrance and the middle of the culvert (photo 5). In culverts with an existing platform for terrestrial animals, the Anabat was placed on top of that platform. All the Anabats were operated at sensitivity 4. This prevented repeated recordings of traffic noise, although it may mean that bat species that emit very low intensity echolocation calls (such as brown long-eared bats) may occasionally have been missed. Bat activity

Photo 4. Length (L), height (h) and width (b) of a culvert. *Photograph: M. Boonman*

was recorded at each culvert for a full night between the 15th of May and the beginning of September 2010 during good weather conditions (no data was collected during nights with heavy rain). Echolocation calls were identified by using Analook software (Titley Electronics, Ballina, Australia) and reference sonogram databases. The shape (frequency modulated (FM) or quasi-constant frequency (QCF)) as well as minimum frequency and the number of pulses per second of recorded bat echolocation calls were used for species identification. The slope and end frequency of echolocation calls can reliably be used for species identification (Britzke et al. 2002, Obrist 2004, Redgwell et al. 2009).

The number of bat echolocation passes, defined as a series of echolocation pulses, was tallied for each Anabat night, resulting in an index of bat activity (Thomas 1988, Broders 2003). The time of sunset and sunrise were used as the beginning and end of each night.

In very short culverts it is possible that bats flying outside will be recorded by the Anabat located inside the culverts. Bats adapt their echolocation calls according to the environment they fly in. For example pulse duration is shortened in confined environments to avoid pulse echo overlap (Kalko & Schnitzler 1989). Figure 2 shows the difference between calls from common pipistrelles (*Pipistrellus pipistrellus*) flying inside the culvert and those of bats flying outside. The echolocation calls of bats flying outside that were accidentally recorded inside the short culverts could be discarded by paying attention to this difference.

A.-J. Haarsma provided data from 21 of the 54 culverts. She counted the number of bat passes hour^{-1} with a Pettersson D240 bat detector (Pettersson Electronics, Uppsala, Sweden) during similar weather conditions in the same time of the year. While present at the entrance, she determined both visually and acoustically whether bats were flying inside or outside culverts. By listening to the amplitude of the bat pulses and alternating the direction of the microphone of the detector between the middle of the culvert and towards the area outside, it was determined whether or not bats were flying inside the culverts. Visual observations in the early evening provided additional information on the bats' flight paths. The number of bat passes was thus quantified both inside and outside the culverts. Tests were performed to see if the two different methods to measure bat activity (Anabat versus Pettersson D240) revealed different results.

Photo 5. An Anabat detector, placed on a small raft. *Photograph: M. Boonman*

Definition of use

Culverts where no bats were recorded either inside or in front of the entrance were not used in the analysis because it was unclear why bats were not using these culverts. The bats may have been absent on that particular night or the location could have been outside their geographical range. Only when bats were present (which was clear when they are recorded in front of the entrance) was there a possibility that they might use the culvert.

Culverts where bats were recorded in front of the entrance, but not inside, were defined as ‘unused’. Culverts where bats were recorded inside but the number of bat passes was lower than 0.55 hour^{-1} were defined as ‘incidentally used’. Many bat species such as Daubenton’s bats (*Myotis daubentonii*) use well-defined commuting routes between the roost site and foraging area that many individuals traditionally use (Rieger et al. 1990). Even though these vital commuting routes are protected under European law (The Habitats and Species Directive 92/43/EEC), there is no definition separating them from random flight routes of a single individual. For the purpose of this study I defined a regularly used commuting route as a route that at least two individuals used to fly from their roost site to their foraging area and back. If a culvert is part of such a route than it would have at least four bat flights through it per night. During the shortest night (June 21) this results in 0.55 bat passes hour^{-1}. The use of this value is speculative as 1. the duration of the night varies through the year and 2. the number of recorded bat passes is a relative measure of bat activity that does not necessarily correspond to the number of bats that pass. However, in the absence of a better definition, this value is useful for differentiating between well used and incidentally used commuting routes and is at least better than an arbitrarily chosen value.

Culverts where the number of recorded bat passes exceeded 0.55 hour^{-1} were thus defined as ‘used’.

Statistical analysis

The use of culverts by bats was related to the following parameters: method used to

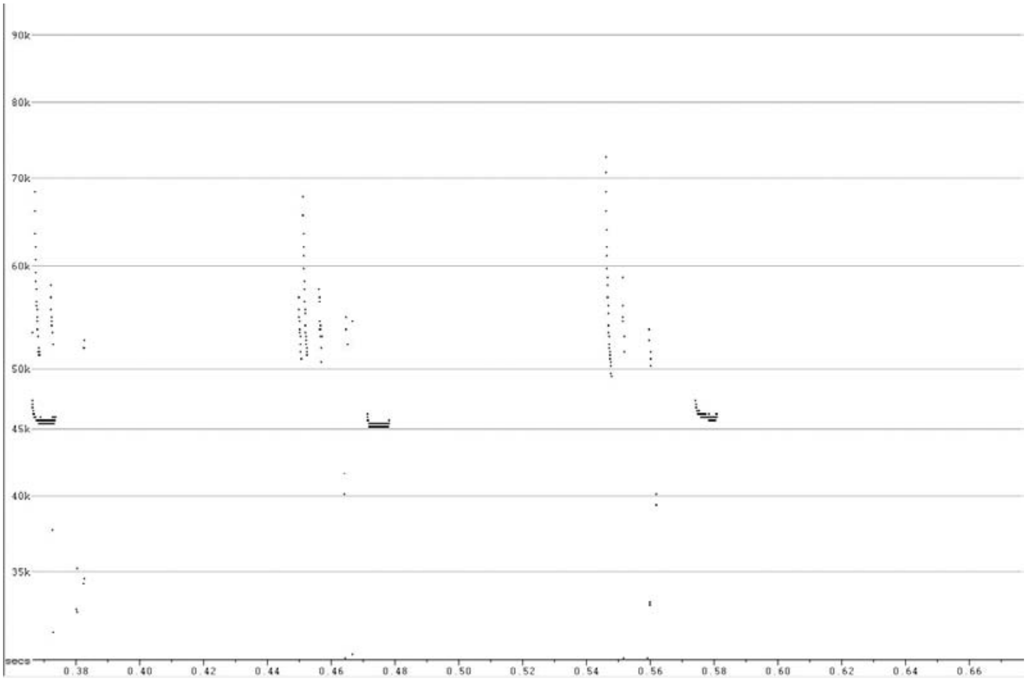

Figure 2. Sonogram of two common pipistrelles recorded by an Anabat detector. One is flying through a culvert (three vertical pulses above) and the other is flying outside (three pulses below).

measure bat activity (Anabat versus Pettersson D240), length (distance between both entrances), width, height, cross sectional area and additional guidance. Culverts for a water body with tall vegetation (>2 m) along the banks were defined as culverts with additional guidance. The guidance is called additional because the water body itself is a guiding structure that bats tend to follow (Lookingbill et al. 2010). Because cross sectional area (width x height in rectangular culverts) is strongly related to width and height, it was only used in the analyses as an alternative to both parameters (to avoid multi-collinearity). Other factors such as the position of the culvert relative to the surface were excluded from the analysis as this varied little between the studied locations.

It was not possible to use multiple linear regression in a consistent way to identify the factors that determine the use of culverts by all species. Each species required its own set of transformations to avoid violations of the required conditions of multiple linear regression. A plausible definition of culvert usage was used to transform the number of bat passes into a dichotomous variable. Logistic regression was subsequently used to obtain a comparable result for each bat species and to avoid the overrepresentation of locations with a large number of bat passes. The response variable is binary in logistic regression. Unused and incidentally used culverts (see definition of use) were included in the analysis as 0, while used culverts were defined as 1.

Other analysis techniques were used to provide further information on how bat activity is related to the significant parameters (as revealed by the logistic regression analysis). Multiple linear regression was used when the number of bat passes did not violate the required conditions. Otherwise negative binomial regression was used.

The minimum dimensions of culverts used by bats were determined in two ways. First, they were determined directly by using the

Table 2. Results of the logistic regression analysis. For each species the significance level of all parameters is given. Width and height were only analysed as a substitute for cross sectional area. ns= not significant.

	Parameter	Wald χ^2	Significance level (*P*)
Daubenton's bat	method	2.0	0.15 ns
(*n*=45)	additional guidance	0.52	0.47 ns
	length	0.77	0.38 ns
	cross sectional area	6.1	0.014
	width	2.6	0.11 ns
	height	5.2	0.023
Pond bat	method	1.9	0.17 ns
(*n*=25)	additional guidance	0.042	0.84 ns
	length	0.022	0.88 ns
	cross sectional area	4.0	0.047
	width	2.1	0.15 ns
	height	0.083	0.77 ns
Common pipistrelle	method	0.88	0.35 ns
(*n*=52)	additional guidance	0.29	0.59 ns
	length	0.67	0.41 ns
	cross sectional area	10.4	0.001
	width	4.5	0.034
	height	6.9	0.009

Table 3. Lowest height (m) and cross sectional area (m^2) of culverts that bats used (>0.55 bat passes $hour^{-1}$) and incidentally used (0-0.55 bat passes $hour^{-1}$).

Lowest height (m)	Incidentally used culverts	Used culverts
Daubenton's bat	0.4	0.9
Pond bat	0.4	1.0
Common pipistrelle	1.5	1.5
Lowest cross sectional area (m^2)		
Daubenton's bat	1.2	2.2
Pond bat	1.2	6.4
Common pipistrelle	8.0*	7.5

*Incidental use of culverts was not frequently observed in common pipistrelles. One of the used culverts had a smaller cross sectional area than the smallest incidentally used culvert.

minimal height and cross sectional area of the culverts used (and incidentally used) by bats. However, these minimal values can represent coincidental outliers that are not representative for the species. The minimal dimensions were therefore also calculated by using the best fitting logistic regression model containing the factor 'cross sectional area'. The probability of Y=1 (culvert is used by bats) was calculated by using the logistic function (Agresti 2007).

The statistical analysis was done by using SPSS (PASW statistics 18.0; SPSS Inc., Chicago, IL, USA).

Results

Forty-six (85%) of the 54 culverts studied were used by bats. In the other eight culverts, bats were registered in front of the entrance but not inside. Culverts were used as a part of the bats' commuting route but also as a foraging

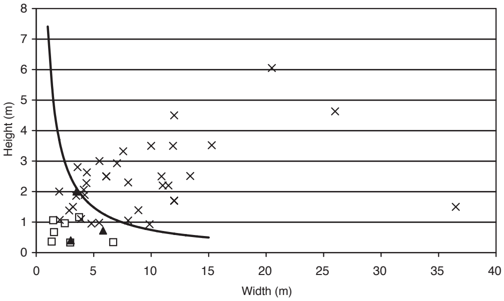

Figure 3. The use of culverts by Daubenton's bats in relation to height and width. Open square = unused, solid triangle = incidentally used, cross = used. The line indicates the cross sectional area with a 95% probability of usage. Height =7.4 / width; *n*=45.

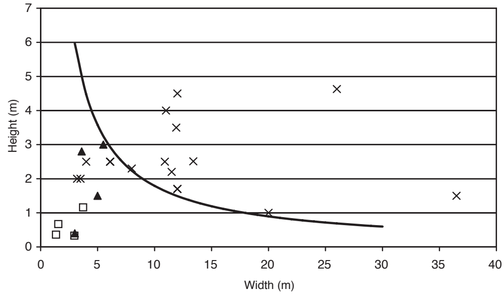

Figure 4. The use of culverts by pond bats in relation to height and width. Open square = unused, solid triangle = incidentally used, cross = used. The line indicates the cross sectional area with a 95% probability of usage. Height =18 / width; *n*=25.

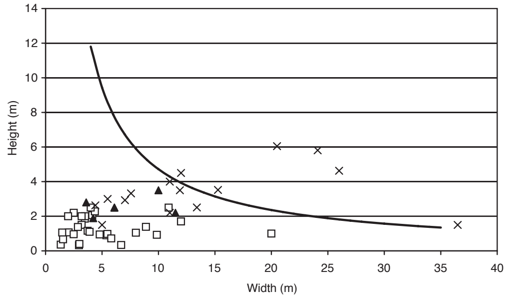

Figure 5. The use of culverts by common pipistrelles in relation to height and width. Open square = unused, solid triangle = incidentally used, cross = used. The line indicates the cross sectional area with a 95% probability of usage. Height =47 / width; *n*=52.

Table 4. Cross sectional area (m^2) of culverts that have an 80, 90 and 95% probability of being used. Values were calculated using the best fitting logistic regression model with the parameter cross sectional area.

	80%	90%	95%
Daubenton's bat	5.4	6.5	7.4
Pond bat	12	15	18
Common pipistrelle	36	42	47

area, as shown by frequently recorded feeding buzzes. The distinction between commuting and foraging bats was not made as commuting bats also occasionally catch prey items (Britton et al. 1997). In one culvert a day roost of Daubenton's bats was present.

The following species were recorded in front of the entrance of the culverts: whiskered/Brandt's bat (*Myotis mystacinus/brandtii*), Daubenton's bat, pond bat (*Myotis dasycneme*), common pipistrelle, soprano pipistrelle (*Pipistrellus pygmaeus*), Nathusius' pipistrelle (*Pipistrellus nathusii*), noctule, serotine and brown/grey long-eared bat (*Plecotus auritus/austriacus*).

Of these nine species only Daubenton's bat, pond bat, common pipistrelle, noctule and serotine were recorded regularly. The number of recorded bat passes varied from less than 0.1 to 312 hour^{-1}. The highest number of bat passes was recorded at the leeward side in front of the entrance of a culvert where a large group of common pipistrelles was foraging.

Species that ignore culverts

Of the five species that were recorded regularly in front of the entrance, noctules and serotines were never or rarely recorded inside the culverts. Noctules were recorded at 21 locations but never inside the culverts. Serotines were registered at 31 locations but were only recorded inside three culverts. These three culverts were exceptionally spacious (cross sectional area 120, 124 and 140 m^2).

Species that use culverts

Daubenton's bats, pond bats and common pipistrelles were recorded regularly inside the culverts. The logistic regression analyses showed that the variable 'method' was not a significant factor for any of the three species (table 2), i.e. the two methods used to determine bat activity (Anabat and Pettersson D240) revealed similar results. Culvert length and additional guidance were not significant in explaining the use of culverts by any of the three species. Cross sectional area was a significant factor for all three species. In separate analyses cross sectional area was replaced by width and height. Height was a significant factor for Daubenton's bat and common pipistrelle. Width was only significant for common pipistrelle, but with a lower significance level than height. Height was thus the most important component of the cross sectional area for Daubenton's bat and common pipistrelle (table 2).

For pond bats and common pipistrelles the number of passes inside the culvert was positively correlated to the cross sectional area (pond bat: linear regression, F=17.3, df=24, P<0.05; common pipistrelle: negative binomial regression, likelihood ratio χ^2=35.2, df=50, P<0.01). For Daubenton's bat this correlation was not significant for all culverts (linear regression, F=0.037, df=44, P>0.05) but was significant after root transformation of the number of bat passes in culverts with a cross sectional area of less than 30 m^2 (linear regression, F=5.9, df=36, P<0.05). Culverts where no bats were registered almost invariably had a small cross sectional area and in spacious culverts many bat passes were recorded.

The smallest culverts used by bats

The minimal height and cross sectional area of the culverts that were used (and incidentally used) by bats are shown in table 3. These were also calculated by using the best fitting logistic regression model containing the factor "cross sectional area". These models were significant for all species (table 2). Table 4 shows the cross sectional area corresponding to the probability that a culvert is used by each bat species (when the bats are recorded in front of the entrance). There was a clear difference between the three species. Daubenton's bats used culverts with the smallest cross sectional area, while common pipistrelles only used the more spacious culverts. Figures 3-5 show the minimal height and width of a culvert suitable for bats. The line corresponds to a probability of 95% of a culvert being used. The line divides the used culverts (crosses) from the incidentally used (triangles) and unused culverts (squares).

Discussion

In this study, the vast majority of the culverts were used by bats. Bats were recorded in all culverts, except the smallest ones (cross sectional area <4 m^2). The culverts that were studied were not a random sample. Small culverts and those with odd shapes were over-represented in the study, compared to their occurrence in 'the field'. Therefore the actual percentage of the culverts used by bats might even be higher than our results suggest. This underlines the importance of culverts in countering habitat fragmentation.

Species that ignore underpasses

Fast hawking, aerial insectivorous bats are less likely to use underpasses such as culverts. They are adapted to flying in open areas by their wing morphology (high aspect ratio, pointed wing tips) and echolocation (narrowband QCF pulses of a long duration; Norberg & Rayner 1987, Fenton 1989). These species are able to cross highways above traffic height, but might not do so when there is no guiding, tall vegetation. Northwest European bat species belonging to this category are: noctule, parti-coloured bat (*Vespertilio murinus*) and serotine (Limpens et al. 2004). The results of this study are consistent with these findings. Noctule bats were never observed inside culverts and serotines only in the most spacious ones. In Germany serotines have regularly been observed in tall underpasses (L. Bach, unpublished data). Although it seems unnecessary to take these three species into account when constructing underpasses in lowland areas, this could be different in areas with taller underpasses, such as highland areas.

Species that typically use underpasses

Bat species that use underpasses relatively often and seem hesitant to cross highways at high altitude are those species that are adapted to dense environments (particularly foliage-gleaning bats), and also trawling bats (Norberg & Rayner 1987, Bach et al. 2004). In Northwest Europe species belonging to this category are the vespertilionid species of the genus *Myotis* and *Plecotus* and rhinolophid species. Their wing morphology (low aspect ratio, low wing loading) allows manoeuvrable flight which is necessary for flying in confined spaces, such as culverts. Their echolocation (broad-band FM pulses of short duration in vespertilionids) is clutter-resistant, enabling the bats to detect small obstacles within confined areas. The bats' behaviour also seems to play a role. Pond bats are not very well adapted (by wing morphology and echolocation) to confined habitats (Norberg & Rayner 1987, Britton et al. 1997) but nonetheless they frequently use underpasses because of their habit of flying close to the water surface. In this study, two species that belong to this category, Daubenton's bat and pond bat, were frequently observed inside culverts. It is important to consider the requirements of these species when designing new underpasses or changing existing ones.

Factors determining the use of the culverts

For all species there was a substantial variation in the number of recorded bat passes within and in front of culverts. Wind, distance to the nearest roost site and the amount of foraging exhibited by bats in culverts are probably among the most important factors contributing to this.

In this study, the cross sectional area was the most important factor determining the use of underpasses by bats. Among all species the number of bat passes increased with increasing cross sectional area. Height was the most important component of the cross sectional area in this study. This is not surprising since culverts are generally not constructed for very narrow (<1 m), slow flowing or stagnant water bodies. In lowland areas, where this study took place, culverts are almost invariably wider than they are tall. It is likely that width may be more critical for bats in upland areas where many culverts for seasonally fast-running streams are narrow and tall.

It has been noted that, in order to be used by large terrestrial mammals, underpasses need to be more spacious when the length is increased (van Nierop 1988, Ministerie van Verkeer en Waterstaat 2005). Because of their echolocation system, bats are distinctly different in this aspect. Bats are less hesitant to travel through extremely long tunnels, as shown by hibernating bats which can use (artificial) caves with a length of several kilometres. Length was not a significant factor in determining the use of culverts in this study. Thus, there is no reason to assume that longer underpasses (up to 130 m length) are used less frequently by bats than short ones. This result is significant, now that many highways are being widened to add traffic lanes to accommodate more vehicles.

Additional guidance (tree lines) was also not significant in determining the use of culverts by Daubenton's bats, pond bats and common pipistrelles. Guiding structures could nonetheless be an important factor as the water body itself is a guiding element that bats tend to follow (Lookingbill et al. 2010). Guiding structures have been reported to be important factors explaining the use of green bridges by bats (Bach & Müller-Stieß 2005).

The smallest culverts used by bats and the implications of this

This study shows that knowledge about the appropriate cross sectional area is of critical importance when constructing suitable bat underpasses. A larger cross sectional area leads to an increase in usage, although there is probably a certain saturation level. This saturation level is of minor importance because it probably represents a large number of foraging bats. The aim of constructing bat underpasses is to maintain vital commuting routes, rather than to create foraging habitats. It is therefore more useful to determine the smallest cross sectional area of underpasses that are used more than incidentally, as done in this study.

This cross sectional area differs per species, it is 7 m^2 for Daubenton's bats, 18 m^2 for pond bats and 47 m^2 for common pipistrelles (based on a probability of 95% that a culvert is used). This interspecific difference is in accordance with Schaub & Schnitzler (2007) who found that commuting common pipistrelles flew at higher altitude and maintained a larger distance from vertical background structures than commuting Daubenton's bats. The minimal required cross sectional area of suitable bat underpasses has also been reported by Brinkmann (2003), Bach et al. (2004), Limpens et al. (2004) and Brinkmann (2008), based on known bat underpasses and expert judgement. Their values are substantially lower (2-3 m^2 for Daubenton's bat and 16 m^2 for common pipistrelle) than those calculated by this study. Their reported values are likely to represent the smallest underpasses where bats were observed, and could reflect coincidental outliers that are not representative for the species. A few locations were found during this study where Daubenton's bat and common pipistrelle frequently use very small culverts (2 and 8 m^2 respectively; table 3). But taking this minimal value ignores the fact that there are many underpasses with the same dimensions where bats are present but not using them. It is therefore important to construct bat underpasses that are larger than the reported minimal values.

If bats prefer to maintain a certain distance to both horizontal and vertical obstacles (Schaub & Schnitzler 2007), an underpass with a width/height ratio of one would be preferable to a wide and low underpass with the same cross sectional area. Most of the studies mentioned above are based on findings from upland areas where the width/height ratio of culverts is closer to one (lower) than in lowland areas. Therefore the cross sectional area of suitable bat underpasses might be lower in upland areas.

The width of a water body can only be slightly adapted and is thus a more or less fixed value that road constructors have to work with. The minimal height of a culvert that is suitable for bats can be determined by using this width and the cross sectional areas from table 4 or figures 3-5. This minimal height should not be less than the minimal height of culverts in which bats were observed (table 3) to stay within each species' recorded range. In lowland areas the construction of large underpasses can be expensive as large amounts of soil are required for the ramp to attain an elevated height. Increasing the width by incorporating the banks of the water body into the underpass can reduce these costs. Common pipistrelles only used very spacious culverts. In practise it may often not be affordable to construct underpasses with suitable dimensions for this species. Compared to Daubenton's and pond bat we can expect this species to use overpasses, such as green bridges, more easily (Bach & Müller-Stieß 2005). The construction of hop-overs to create an overpass for bats is generally recommended (Limpens et al. 2004), but their use has never been systematically determined.

Every highway reconstruction provides an opportunity to create suitable or better bat underpasses. Most environmental impact assessments discuss baseline survey data extensively and only briefly deal with the most important part: mitigation measures. In the U.K., it is standard procedure to monitor the effectiveness of mitigation measures, but this is not the case in the Netherlands. It is therefore usually not known whether these mitigation measures are effective. A major step forward will be to set aside a budget within highway (re) construction projects, to improve knowledge about the effectiveness of mitigation measures.

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Samenvatting

Welke factoren bepalen het gebruik van duikers onder wegen en spoorlijnen door vleermuizen?

De aanleg van geschikte voorzieningen voor vleermuizen onder wegen en spoorlijnen wordt steeds belangrijker om versnippering van leefgebieden te voorkomen. Duikers vormen waardevolle voorzieningen omdat veel vleermuizensoorten die gebonden zijn aan water geneigd zijn de watergangen te volgen die door de voorzieningen stromen. Daarnaast zijn duikers goedkoop omdat ze een intrinsiek onderdeel van een weg vormen. Het gebruik van 54 duikers door vleermuizen werd onderzocht met bat detectors. Deze studie had tot doel om de factoren te bepalen die het gebruik van duikers door vleermuizen verklaren. Vleermuizen werden in het merendeel van de duikers vastgesteld, waarmee het belang van duikers in de ontsnippering van infrastructuur werd onderstreept. Soorten die aangepast zijn aan een open omgeving zoals de rosse vleermuis en de laatvlieger werden vaak voor de ingang van duikers geregistreerd, maar zelden of nooit in duikers. Van de drie soorten die regelmatig in duikers werden vastgesteld, de watervleermuis (*Myotis daubentonii*), de meervleermuis (*M. dasycneme*) en de gewone dwergvleermuis (*Pipistrellus pipistrellus*), was de dwarsdoorsnede de meest belangrijke factor waarmee het gebruik van duikers verklaard kon worden. ‘Hoogte’ was de meest belangrijke component van de dwarsdoorsnede voor vleermuizen. De lengte bleek geen significante factor. Dit suggereert dat vliegroutes van vleermuizen onder wegen geen effect ondervinden van wegverbreding. Additionele geleiding in de vorm van opgaande begroeiing langs de oevers had geen effect op het gebruik van de duikers door de drie soorten. De geschikte dwarsdoorsnede verschilde per soort. Watervleermuizen gebruikten de duikers met de kleinste dwarsdoorsnede, gevolgd door de meervleermuis en de gewone dwergvleermuis. Deze resultaten kunnen gebruikt worden bij de aanleg of reconstructie van infrastructuur.

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