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SafeBatPaths
Fumbling in the dark – effectiveness of bat mitigation measures on roads

Hop-overs and their effects on flight heights and patterns of commuting bats – a field experiment

Project partners:
Aarhus University, Denmark,
Jasja Dekker Dierecologie, Netherlands
University of The Basque Country, Spain
Flagermus Forskning og Rådgivning, Denmark
Sweco, Denmark

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Authors this deliverable:
Morten Christensen, Sweco, Denmark
Esben T. Fjederholt, Sweco, Denmark
Hans J. Baagøe, Flagermus Forskning og Rådgivning, and the Natural History Museum of Denmark, University of Copenhagen, Denmark
Morten Elmeros, Aarhus University, Denmark

PEB Project Manager: Marianne L. Ujvári

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Executive summary

Roads may have a detrimental effect on bat populations. As all European bat species are of conservation concern, the detrimental effects of roads should be avoided or mitigated. Hop-overs have been suggested as a measure to mitigate the impact of roads on bats. The aim with hop-overs is to reduce the mortality risk by guiding the bats across the roads above the traffic. Hop-over includes different structures, from trees with high canopies that are overhanging the road, to screens that force the bats to increase their flight height across the road.

Information on bats' use of hop-overs is primarily based on incidental observations of bats crossing roads at severed hedgerows, but quantitative studies of the effectiveness of hop-overs are scarce. An experimental test with the lesser horseshoe bat (*Rhinolophus hipposideros*) which is very structure-bound showed that screens were not an effective method to increase the flight height of lesser horseshoe bat, but other species may behave differently.

We examined the effectiveness of hop-overs for the two moderately structure-bound species Daubenton's bat (*Myotis daubenonii*) and soprano pipistrelle (*Pipistrellus pygmaeus*), and collected additional data on western barbastelle (*Barbastella barbastellus*) at four experimental sites and one control site. The effectiveness was evaluated by comparing bat flight patterns before and after two parallel screens were installed across bat commuting routes. The screens were 4 m high and 20 m long. They were installed at natural gaps in commuting routes to simulate a road severance of a commuting route. Bats' flight patterns and flight heights were recorded visually (directly and with infrared video) and with ultrasound detectors with synchronized microphones. Ultrasound recordings of the bats' echolocation calls were used to identify species and assess flight heights.

The proportion of Daubenton's bats and soprano pipistrelles that crossed the hop-over gaps at more than 4 m of heights increased after installation of the screens, while no change was seen for western barbastelles. The percentage of Daubenton's bats that flew over both screens varied from 46% to 85% between sites. 61% of soprano pipistrelles and 89% of western barbastelle flew over both screens at the one site where these species were recorded. More replicates for these two species are needed.

Although the hop-overs and screens showed some potential for reducing bat-vehicle collision risk and did not represent a major barrier for the commuting bats, hop-overs cannot be generally recommended, as their effectiveness is too low at some site. At one site more than 50% of individual bats still crossed the hop-over gaps in hazardous heights, and some individuals appeared to switch to alternative commuting routes which should then be mitigated if needed.

The results from the present evaluation only represent the studied species and probably species with similar flight patterns. Bat species with different flight patterns may respond differently to hop-overs and screens, and further studies are needed understand different bats species' behaviour at hop-overs.

Further research is also recommended concerning the effectiveness of hop-over with different characteristics, e.g. denser tree canopy cover overhanging the road, longer or higher screens, wider gaps (i.e. broader roads), and the effects of light and noise pollution from the road. We recommend that new hop-overs are monitored systematically to collect empirical evidence on their effectiveness.

1 Introduction

Roads and road traffic may affect bats directly through vehicle collisions, and indirectly by habitat deterioration, destruction and fragmentation (e.g. Russell et al. 2009, Abbott et al. 2015, Fensome & Mathews 2016). Bats do not avoid roads and collisions between bats and vehicles can be a significant source of mortality, especially at sites where important bat commuting corridors are severed by roads. Bat populations are very sensitive to expansions of human land use and human induced habitat changes. Bats have long life spans, relative long pre-reproduction periods and low annual reproductive outputs compared to similar sized mammals (Sendor & Simon 2003, Altringham 2011, Chauvenet et al. 2014). This life history makes the status of bat populations very sensitive to variations in survival rates (Schorcht et al. 2009, López-Roig & Serra-Cobo 2014). Lowered bat activity up to 1000m from major roads might be attributed to increased mortality of local bat populations (Berthinussen & Altringham 2015).

All bat species in Europe are of conservation concern (Council Directive 92/43/EEC 1992). To mitigate the negative impact of roads several types of mitigation measures have been suggested (e.g. Highway Agency 2001, 2006, Limpens et al. 2005, National Road Authority 2006, Nowicki et al. 2008, 2016, Brinkmann et al. 2012). Hop-overs have been promoted in a number of publications as a simple mitigation structure that will guide the bats across roads at safe heights above the road traffic and reduce road-related mortality and the fragmentation effect created by the roads.

A hop-over consists of tall vegetation close to the road verges, e.g. severed hedgerows which are used by bats as a commuting route (Limpens et al. 2005). For some species, e.g. *Pipistrellus* bats, it is advised to clear the lower branches of the trees, assuming that the bats will then increase their flight height to the height of the crowns of the tree. For other, more clutter-adapted species, e.g. *Myotis or Plecotus* bats that tend to lower their flight height when crossing open areas, it is advised to plant and maintain dense vegetation, which the bats cannot pass through or install screens along the road verges, to force the bats to increase their flight altitude when approaching the road. Tree branches overhanging the road creating a continuous cover over the road are assumed to enhance the effectiveness of hop-overs (Limpens et al. 2005, Russell et al. 2009).

At wider multi-lane roads tall vegetation or alternative structures at the central reservation may enhance the effectiveness of the hop-over by reducing the gap-size created by the road and aid the bats to maintain the safer flight height above the traffic. However, sightlines and safety issues on roads may influence to what extent structures at the central reservation is applicable.

Empirical information on bats' use of the hop-overs is scarce. Information has primarily been based on incidental observations of bats crossing roads at severed hedgerows and other commuting routes (Limpens et al. 2005, ChiroMed 2014). The effectiveness of hop-overs has not been tested adequately (Nowicki et al. 2008, Berthinussen et al. 2013). Furthermore instead of decreasing mortality risk, hop-overs could potentially increase mortality rates for some bat species as they become trapped between the vegetation or screening along the road or forage over the road between the vegetation that comprise the hop-over.

Bontadina and co-workers (SWILD & NACHTaktiv 2007) tested the effectiveness of hop-overs for lesser horseshoe bat (*Rhinolophus hipposideros*) in a field-experiment by installing screens across commuting routes. They showed that only a very low proportion of the lesser horseshoe bats crossed the hop-over gap at a safe height. Most bats flew along the screens and crossed the open gap at the ends of the screens at a very low height. The majority of the individuals that flew over the first screen descended between the two screens. These results suggest that hop-overs are ineffective as mitigation measure for lesser horseshoe bats. However, the lesser horseshoe bat is an extremely clutter adapted species, that always flies at a very low height near the ground, or close to vegetation or other structures in open habitats, and therefore experiences a high mortality risk when crossing roads (SWILD & NACHTaktiv 2007). Other more moderately structure-bound bat species may behave differently and increase their flight height when crossing road stretches with barrier or noise screens (Lüttmann 2012, 2013). Bats are also known to cross roads at greater heights at sites with high canopy cover or roadside embankments (Russell et al. 2009, Lüttmann 2012).

Objective of the study

The objective of the present study was to evaluate the effectiveness of hop-overs for common moderately structure-bound bat species, e.g. soprano pipistrelles (*Pipistrellus pygmaeus*) and Daubenton's bats (*Myotis daubenonii*), by examining the bats' behaviour and changes in flight heights when barrier screens were installed at natural open gaps in commuting routes for the bats.

As the H0-hypothesis we expect that hop-overs with screens will not be an effective method to guide commuting bats across roads above the traffic. Four different responses by the bats are possible:

1) The bats fly over the first barrier screen, but descend to a lower hazardous height between the screens.
2) The bats fly along the first screen at their normal low flight height and fly in between the screens at low height.
3) The bats fly along the screen at their normal low flight height to cross the open gap at the ends of the screens at low height.
4) The bats turn around when encountering the barrier and fly back along the commuting route.

The first two responses would increase the mortality risk for bats as the bats spend longer time at low heights over the road. The third response would have no effect on the mortality rates as the vehicle-collisions just occur at the end of the screens. The fourth response would result in an increased barrier effect of the road.

As the alternative H1-hypothesis we expect that hop-overs will be an effective measure, i.e. the hop-overs will not act as barriers, and they will increase the proportion of bats that crosses the hop-over gaps over both screens.

2 Methods

2.1 Study design

To test the effectiveness of hop-overs we experimentally manipulated the conditions in bat commuting routes with open stretches by installing artificial vertical screens across the commuting route to simulate the presence of a hop-over at a road. Two temporary barrier screens (20m long and 4m high) were placed across the bat commuting route parallel to one another with a distance of approximately 8-10 meters between them. The screens were constructed of camouflage nets hanging in a vertical position on poles. The experimental manipulation of commuting routes was replicated at four sites to examine the plasticity and variability of bat behaviour. A fifth site was used as a control site.

The flight patterns and flight height of bats when they crossed the hop-over gap were recorded for two nights before the screens were installed. After the screens had been installed the flight patterns and height of bats were recorded for a minimum of three nights. The first survey was made on the night immediately after the screens were installed. The two remaining surveys were made one and two weeks later, to give the bats time to habituate to the obstacles in their commuting route. At one site the screens were maintained for four weeks to record potential habituation over a longer period. The site was surveyed each week. At the control site the flight patterns and height of bats were recorded five nights over a period of eleven weeks during which the studies at the experimental sites were carried out.

Observations and recordings started near sunset and continued for two hours, until after bat activity had peaked. The surveys were only conducted on nights with favourable weather conditions, i.e. warm, still nights to avoid weather dependent variations in bat activity (Annex A and B).

2.2 Recording and observation

Bat activity, flight heights and behaviours were recorded by: 1) direct visual observations, which is possible during the long twilight period in northern Europe during summer, observations with a night vision scope (Javelin 221) and infrared video camera (Sony Handycam FDR-AX33), and 2) with ultrasound detectors with two synchronized microphones (see below for description of type and application).

Visual observation

Observers and the video camera were located approximately 10m from the ends of the screens overlooking the central part of the hop-over between the two screens and the commuting route immediately before the first screen. Infrared lights were positioned between the screens, near the first screen and parallel to the camera to illuminate the bats. The observers also had a manual ultrasound detector (Pettersson D1000) to detect and identify approaching bats.

The behavioural responses by the bats when approaching and crossing the screens were classified into four groups (Table 1) and quantified e.g. number of bats flying above both screens.

Table 1 – Definition of different flight patterns of bats at the hop-overs with screens based on visual observations.

Flight behaviour	Description
Over screens	The bats successfully crossed above both screens.
Between screens	The bats flew in between the screens, either because it descended after crossing over the first screen or circumvented the first screen and flew at low level along the imaginary road between the screens.
Around screens	The bats followed the screen only to cross the open stretch (the road) at the normal low flight altitude at the end of the screens.
Turn around	The bats turned around and flew back on the commuting route, i.e. the screen acted as a barrier to bats movement.

Ultrasound detection

The bat activity at the hop-overs and flight heights across the open section were also recorded with automatic ultrasound detectors with two synchronized microphones. The microphones were placed on poles in the middle of the open section of the commuting route or next to the screens. One microphone was placed 8 metres above the ground and the second microphone was placed at ground level (approximately 0.5 m). The flight height was estimated from the time difference between recordings of individual bat calls with the two microphone (Figure 1).

Additional bat detectors were placed in the vicinity of the hop-overs along the commuting routes to record bat activity in the surroundings.

All ultrasound detectors used in the study produced real-time full-spectrum recordings to enable species identification (Pettersson D500X and D1000X, Pettersson Elektronik AB and Song Meter SM2, Wildlife Acoustics Inc.).

Song Meter SM2 and Pettersson D500X detectors were used for automatic recording of bat activity. The Song Meter SM2 detector has two input canals. Song Meter SM2s were used with two synchronised microphones on parallel tracks to detect the flight height of the bats when they crossed the hop-overs. D500X detectors were used to record bat activity in the commuting corridors in the vicinity of the hop-overs. Pettersson D1000X detectors with both heterodyne and time expansion systems were used for the manual recordings.

Analysis of ultrasound recordings

For species identification of the ultrasound recordings, we used ‘Batsound’ software from Pettersson Elektronik AB. ’Batsound’ was also used to measure time differences between the recordings from the two synchronised microphones (Figure 1). The bat passes recorded with the SM2s and synchronised microphones were classified into ‘above’ and ‘below’ the height of the screens (4 metres). The time lag between the microphone recordings indicated different distance from the bats to the microphones at ground level and at 8 metres, e.g. if the bat call was first recorded on the lower microphone, the bat was flying below 4 metres.

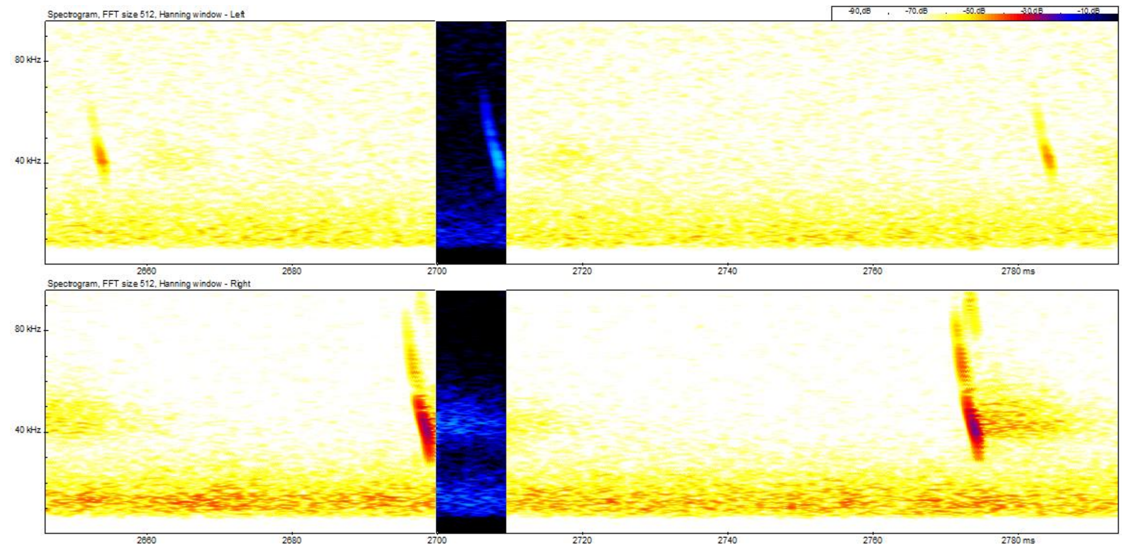

Figure 1 - Example of time lag between bat ultrasound signals (Daubenton's bat). The time lag between the microphone recordings indicates different distance from the bats to the microphones at ground level (lower diagram) and at 8 m (upper diagram). Here the bat call is first recorded on the lower microphone, indicated that the bat was flying below 4 m.

2.3 Study sites and species

A number of locations were surveyed to find five suitable study sites, where a commuting route for Daubenton´s bats and soprano pipistrelles along a hedgerow or other landscape structures was intersected by an open area. Daubenton´s bats and soprano pipistrelles were selected as focal species as they are widespread and common in most of Europe, but they have different flight behaviours when crossing open areas. When commuting across an open stretch away from clutter soprano pipistrelles normally fly at medium heights (2-10 m), while Daubenton's bats usually fly lower over the ground or water surfaces (often between 0.1 m and 5 m) (e.g. Baagøe 1987, Møller and Baagøe 2011). Low-flying species are particular at risk when commuting across a road.

Four sites were selected as experimental sites where screens were installed to manipulate the conditions for commuting bats. A fifth site acted as the control site where no manipulation of the commuting route occurred. Daubenton's bat commuting routes were present at three study sites and the control site. Although soprano pipistrelle was present at most sites, a major commuting route for this species was only present at one site. Additional data on other commuting bat species were recorded if they occurred in large numbers at a study sites.

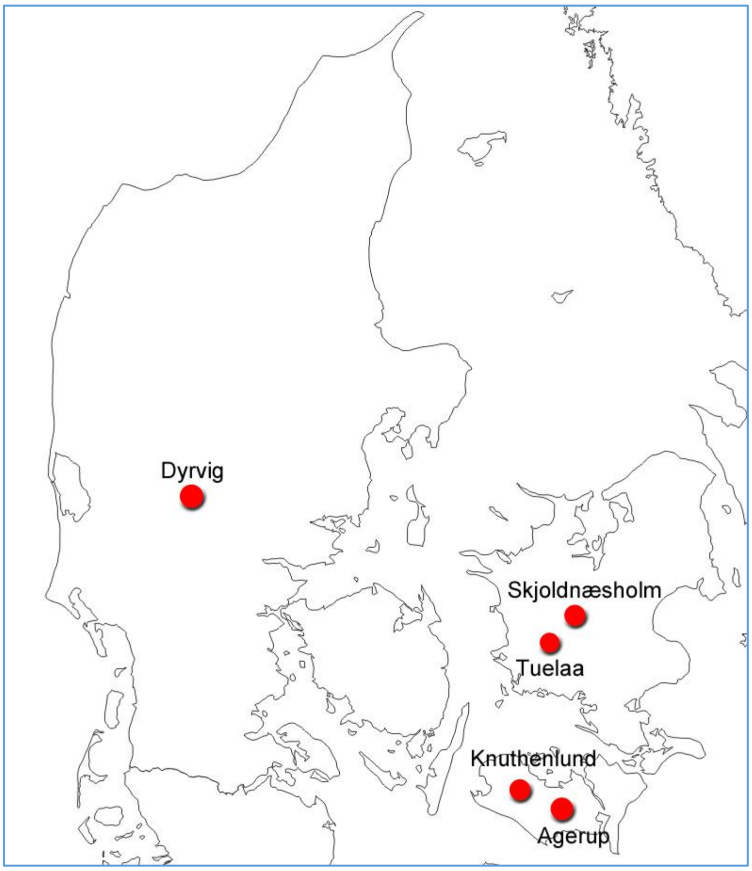

Figure 2 – Location of study sites included in the study in Denmark.

Site 1 – Tuelaa

The Tuelaa-site was located at an old road running parallel to a new major road. The old road was lined with large deciduous trees. A commuting route for Daubenton’s bat followed a small river that crosses under the road (Figure 3). Normally the majority of the Daubenton's bats passed the road through the underpass for the river (app. 1.5 m high x 5 m wide). During the experiment the opening was blocked by tarpaulins to force the bats cross over the road.

Common noctule (*Nyctalus noctula*), serotine (*Eptesicus serotinus*), Nathusius's pipistrelle (*Pipistrellus nathusii*) and soprano pipistrelle were also recorded at the site, but they did not use the river as a commuting route, but tended to fly along the tree lines bordering the road.

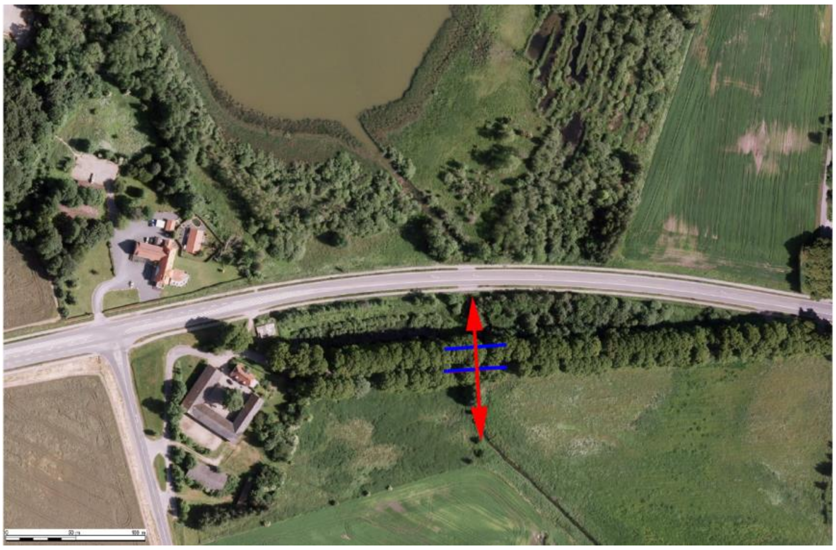

Figure 3 – Site 1 (Tuelaa). Main commuting route for Daubenton´s bats (red arrows) and screen positions (blue lines).

Site 2 – Dyrvig

The site was located in a landscape dominated by farmland with small patches of meadow, forest and heathland. A well-defined Daubenton's bats commuting route from a small colony in the forest east of the study site followed a hedgerow toward a small river which served as feeding habitat for bats (Figure 4). Serotine, Nathusius's pipistrelle and common pipistrelle (*Pipistrellus pipistrellus)* were also recorded at the site in low numbers.

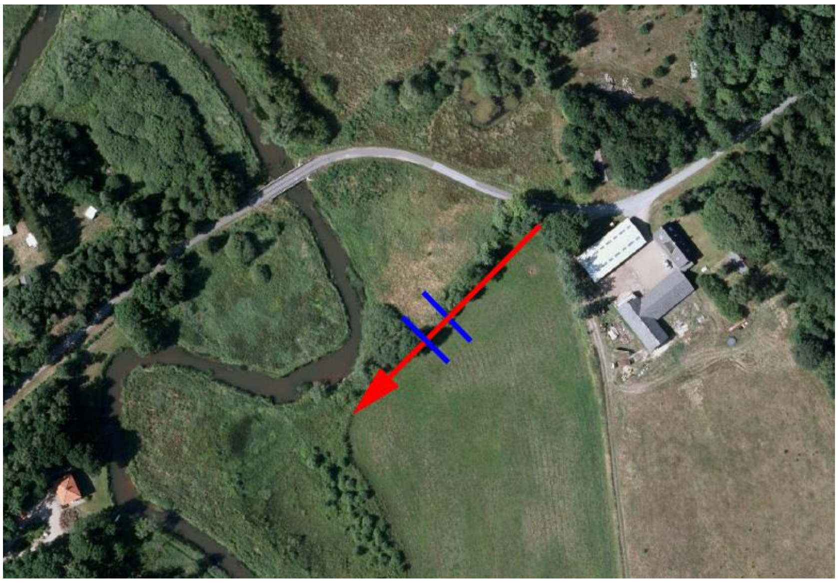

Figure 4 – Site 2 (Dyrvig). Main commuting route (red arrows) and screen position.

Site 3 – Agerup

The site was located in a park with forest and a lake near a manor house surrounded by an arable landscape, but is a part of a number of small forested areas connected with hedgerows etc. A small lake surrounded by forest is an important foraging habitat for the local bats (Figure 5, 6). A colony of Daubenton's bat is located in a hollow tree in the forest south of the lake. The bats commuted from a forest track across a meadow with herbaceous vegetation towards the lake. The Daubenton's bat commuting route was well defined during the evening when the Daubenton's bats left the colony. The screens were placed in a position where the bat could not pass around one end of the screens.
The site had a rich bat community with eleven species including Daubenton's bat, common noctule, serotine, western barbastelle, Nathusius's pipistrelle, soprano pipistrelle, brown long-eared bat (*Plecotus auritus*) and some rare *Myotis* species.

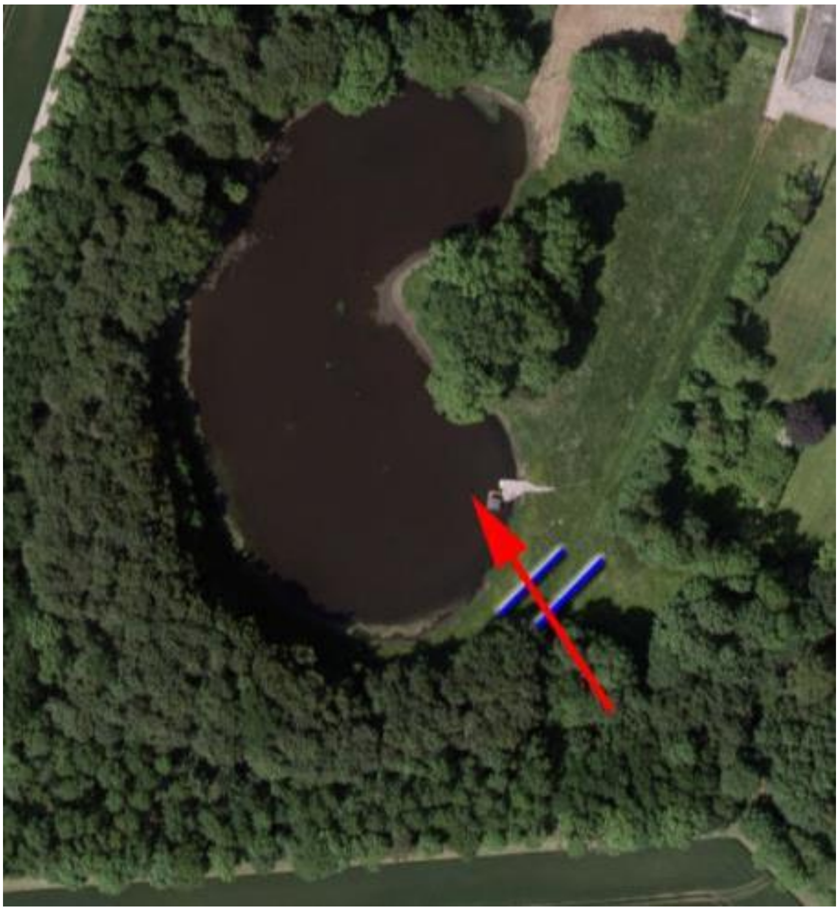

Figure 5 – Site 3 (Agerup). Main commuting route (red arrows) and screen positions (blue lines).

Figure 6 – Screens at Site 3 (Agerup). The two poles for the synchronised ultrasound recording of bats are seen.

Site 4 – Knuthenlund

The landscape at Knuthenlund consists of mixed agricultural lands, with park and forest. The study site was located between a large forest with good roosting habitats for bat and the parkland area with several small ponds and farm buildings. The commuting route that followed a hedgerow between the forest and the parkland (Figure 7) was mainly used by soprano pipistrelles and western barbastelles. A low number of Daubenton's bat also commuted along the hedgerow. Common noctules, serotines and Nathusius's pipistrelles were also recorded at the site.

Figure 7 – Site 4 (Knuthenlund). Main commuting route (red arrows) and screen positions (blue lines).

Control site - Skjoldnæsholm

The landscape at the site comprised parklands with ponds, a lake and old deciduous forest. An important commuting route for Daubenton's bat connected a pond and a lake along the forest edge and through the park (Figure 8). A colony of Daubenton's bats was located in the deciduous trees close to the shore of the pond approximately 25 m north of the mast position. Apart from Daubenton's bat the site has a rich bat community including common noctule, serotine, Nathusius's pipistrelle and soprano pipistrelle.

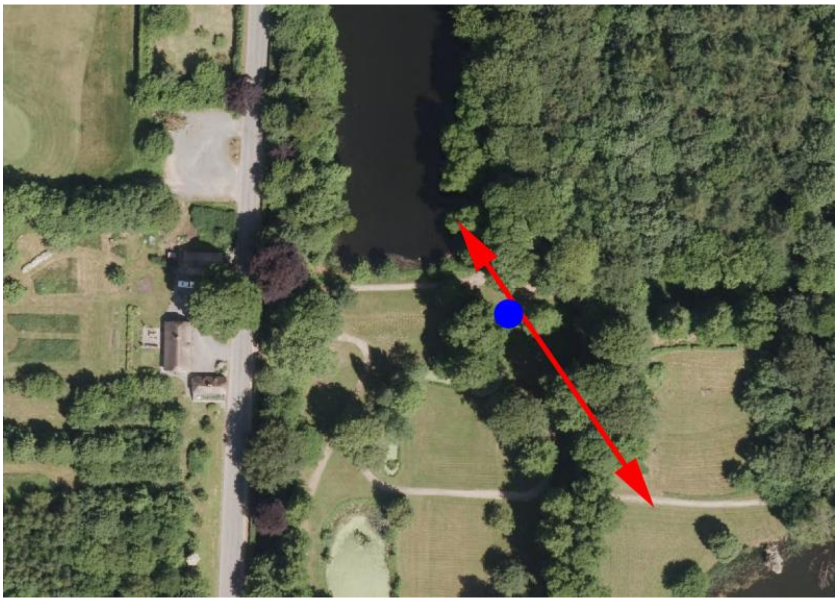

Figure 8 – Control site (Skjoldnæsholm). Main commuting route (red arrows) and mast position (blue dot)

Statistical analysis

The number of bats that crossed the hop-over gap below and above 4 m before and after the screens were installed was tested by χ^2-test. For the analyses of flight heights we only used estimates from the ultrasound detectors with synchronized microphone. We distinguished results obtained the first night after the screens were installed and results gathered in subsequent surveys (5-28 nights after installation). Only the later were compared to the 'before' surveys statistically, as we assumed that the bats' reaction to the new obstacles in the commuting route the first night would differ from their reaction after habituation. At the control site the first two surveys were categorised as 'before' and the next two survey nights as 'after'. Behavioural patterns of the bats as recorded by visual observations were analysed χ^2-test or Fisher's exact tests.

Each site is analysed separately to detect site specific variations within species. Only data on species with sufficient numbers for statistical analyses are presented.

3 Results

3.1 *Flight height*

The bats' flight height when crossing the hop-over gap in the commuting route was estimated with the ultrasound detectors with synchronised microphones. Flight heights were categorized as either below or above 4 m which was the height of the screens. The bats observed flying below 4 m over the gap after the screens were installed either crossed at the ends of the screens, descended or flew between the screens.

Site 1 - Tuelaa

When the original commuting route through the underpass was blocked most of the Daubenton's bats commuted over the road, but some individuals flew along the road instead. Before the screens were installed a relative large proportion of the Daubenton's bats crossed the hop-over site at heights above 4 m compared to the other sites (Figure 9). The large trees lining the road may have influenced the flight height and behaviour of the Daubenton's bats at this site.
After the screens were installed a significantly larger proportion of Daubenton's bats crossed the hop-over site at heights above 4 m (77% after, 54% before) (χ^2 = 9.2, P < 0.005), but 23% of the bats still crossed at a hazardous height below 4 m. There was no difference between the first and the second survey after the screens were installed (χ^2 = 0.39, N.S.).

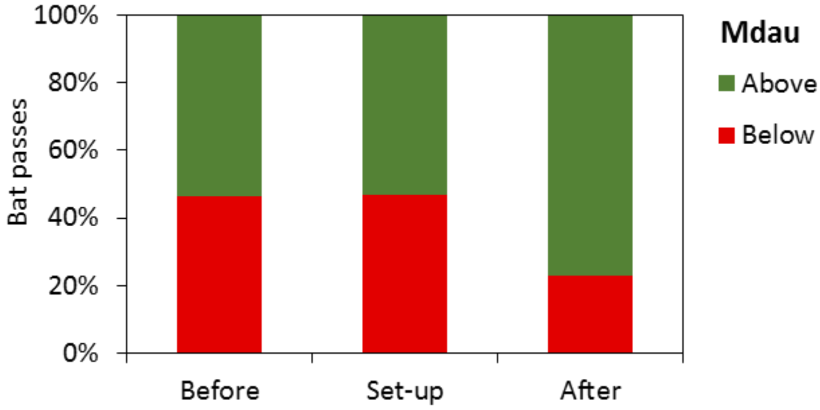

Figure 9 – Percentage of Daubenton's bats (Mdau) passes of the hop-over above and below a height of 4 meters at Site 1 (N = 289) based on the recordings with ultrasound detectors with synchronised microphones.

Site 2 - Dyrvig

At the Dyrvig site, most Daubenton's bats flew low across the hop-over gap in the hedgerow before the barrier screens were installed. There was a 5-fold increase in the percentage of Daubenton's bats that crossed the hop-over gap at safe height after the screens were installed (χ^2 = 9.1, P<0.005) (Figure 10). There was no difference between the first and the second survey after the screens were installed (χ^2 = 0.53, N.S.).
During the four week 'post-construction' survey period the number of Daubenton's bats that used the original commuting route along the hedgerow declined. Some bats altered their

commuting route by diverting away from the hedgerow approximately 50 m before the hop-over, and crossed the adjacent meadow just next to the screens. Furthermore, bat activity increased at an alternative commuting route located along trees and hedgerows approximately 200 m north of the original route (Figure 11).

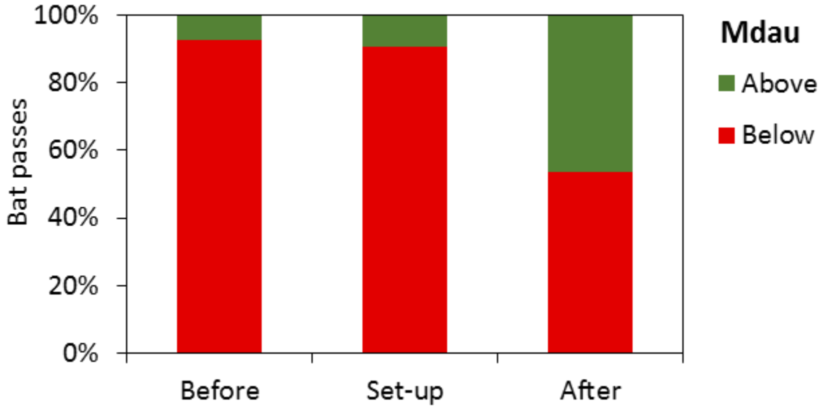

Figure 10 – Percentage of Daubenton's bats (Mdau) passes of the hop-over above and below a height of 4 meters at Site 2 (N = 88) based on the recordings with ultrasound detectors with synchronised microphones.

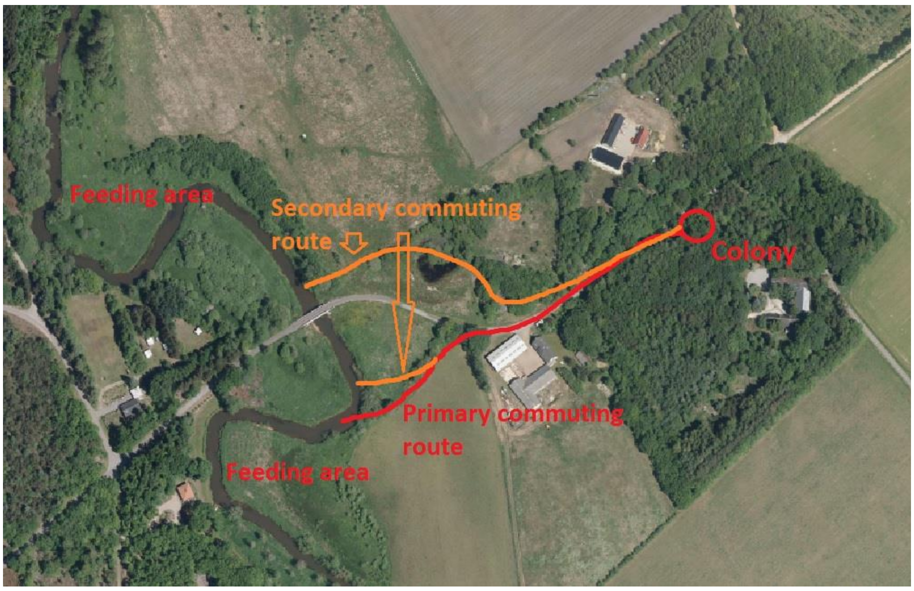

Figure 11 – Primary and alternative commuting routes and the approximate location of the roost site at Site 2. The use of the alternative routes increased during the post-construction survey period.

Site 3 - Agerup

Before the barrier screens were installed most Daubenton's bats commuted relatively low across the meadow between the forest road and the lake. A large proportion of Daubenton's bats flew over the screens the first night after installation of the screens (Figure 12). During the two surveys after the screens were installed most passes of Daubenton's bat crossed over the screens ($\chi^2 = 91.7$, $P < 0.001$). There was no difference between the first and the second survey after the screens were installed ($\chi^2 = 0.04$, N.S.).

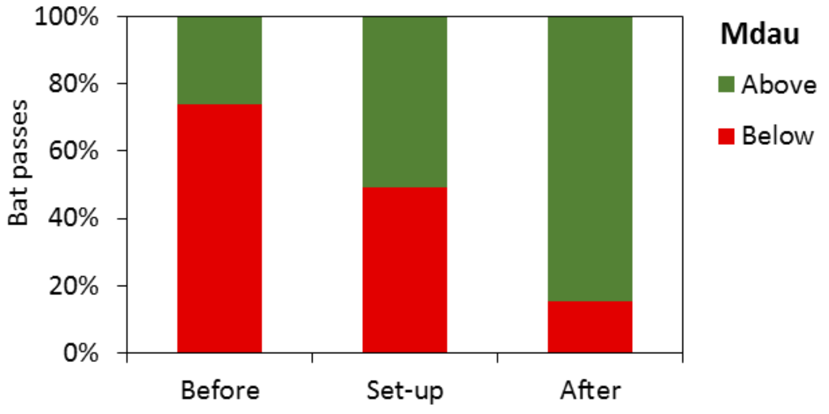

Figure 12 – Percentage of Daubenton's bats (Mdau) passes of the hop-over above and below a height of 4 meters at Site 3 (N = 349) based on the recordings with ultrasound detectors with synchronised microphones.

Site 4 - Knuthenlund

The first night after the installation of the screens a large proportion of soprano pipistrelles turned back or flew around the screens to cross the open stretch at low height next to the screens (Figure 13). After one and two weeks of habituation a larger proportion of the soprano pipistrelles crossed over the screens ($\chi^2 = 10.7$, $P < 0.005$). There was no difference between the two surveys after the screens were installed ($\chi^2 = 0.49$, N.S.).

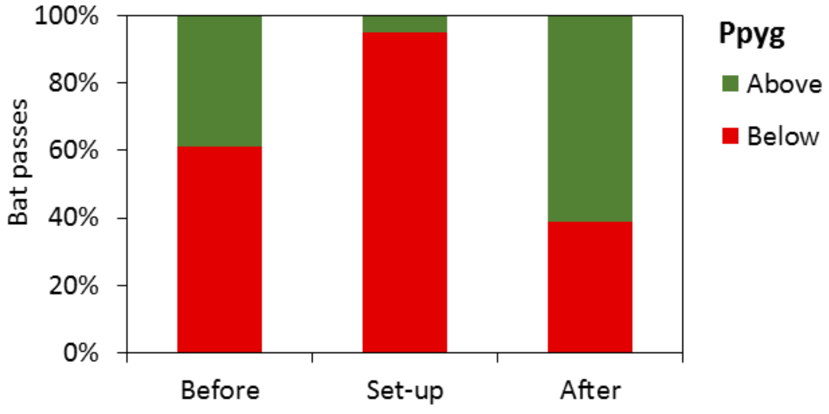

Figure 13 – Percentage of soprano pipistrelle (Ppyg) passes of the hop-over above and below a height of 4 meters at Site 4 (N = 323) based on the recordings with ultrasound detectors with synchronised microphones.

Most of the barbastelles that used the commuting route along the hedgerow flew relatively high across the hop-over gap before the screens were installed (87%) (Figure 14). This pattern did not change after the screens were installed (89%, $\chi^2 = 0.04$, $P < 0.9$). There was no difference between the two surveys after the screens were installed ($\chi^2 = 0.42$, N.S.).

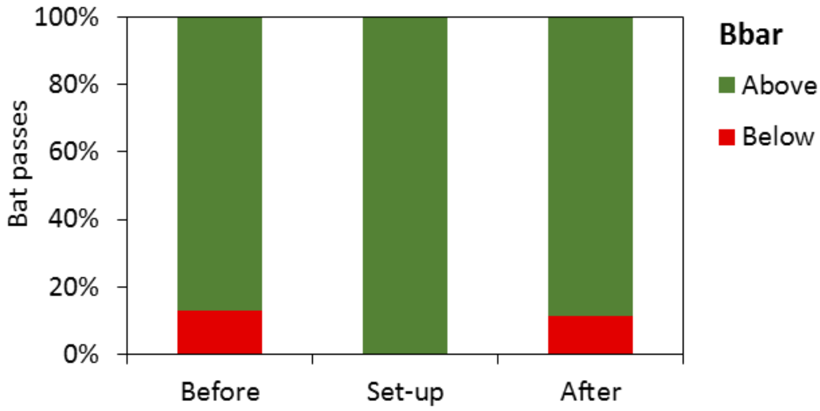

Figure 14 – Percentage of western barbastelle (Bbar) passes of the hop-over above and below a height of 4 meters at Site 4 (N = 62) based on the recordings with ultrasound detectors with synchronised microphones.

Control site - Skjoldenæsholm

At the control site without screens the percentage of Daubenton's bat passes over the imaginary hop-over gap at heights above 4 meters did not change between the first to the fourth survey night (Figure 15). The fifth survey night was excluded from the statistical analyses because only seven bat passes was recorded.

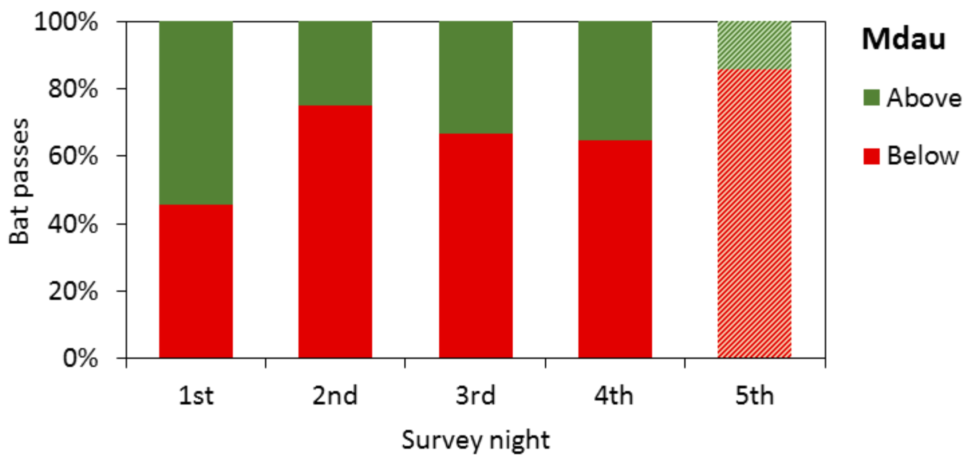

Figure 15 – Percentage of Daubenton's bats (Mdau) passes above and below a height of 4 meters at the control site (N = 231) based on the recordings with ultrasound detectors with synchronised microphones.

Overall, 31% of Daubenton's bats crossed the hop-over gaps above 4 m before the screens were installed (N = 375). During the surveys one and two weeks after the screens were installed 76% of all Daubenton's bats flew over the screens at safe height (N = 360). This overall increase of Daubenton's bats crossing at safe heights was highly significant (χ^2 = 109, P < 0.001), but there was a large variation between sites (46-85%). There was no indication of habituation between the first and the second 'post-construction' surveys for Daubenton's bats at all sites (χ^2 = 15.4, N.S.).

Sufficient numbers for statistical analyses of commuting soprano pipistrelles and western barbastelles were only recorded at one site.

3.2 *Flight patterns and habituation*

Direct observations and IR-video yielded detailed information on the bats' responses to the hop-over screens

On the first night after the screens were installed a relatively large proportion of the bats reacted by turning around, particularly at the Dyrvig site (Table 2). Assessed from the ultrasound recordings the overall activity of Daubenton's bats at this site was highest on the first night after the screens were installed. Some of the bats that did not cross the barriers in their first attempt may have returned and crossed the hop-over gap on a second attempt. There was a significant difference in the responses of Daubenton's bats between sites (χ^2 = 27.5, P < 0.001) and between Daubenton's bats and soprano pipistrelles (Fisher's: P < 0.001).

Table 2 – Behaviour of bats on the first night after installation of the screens based on visual observations only. Mdau: Daubenton's bat, Ppyg: Soprano pipistrelle.

Behaviour	Tuelaa (Mdau) n=34	Dyrvig (Mdau) n=26	Agerup (Mdau) n=29	Knuthenlund (Ppyg) n=39
Over screens	62%	23%	79%	21%
Between screens	21%	19%	0%	3%
Around screens	18%	27%	7%	67%
Turn around	0%	31%	14%	10%

One and two weeks after the screens had been installed the bats showed some habituation to the screens as the number of bats that turned around at the screens was very low (Table 3). However, the screens still had a barrier effect on 4% of the visually observed Daubenton's bats at Agerup and on 8% of the soprano pipistrelles in Knuthenlund.

Estimated from the direct visual observations and IR-videos of the behaviour of 92 Daubenton's bats 7-33% of the bats flew around both screens and up to 7% flew over or around the first screens and in between the screens. Assessed from the visual observations a higher proportion of Daubenton's bats that flew over both screens after 1-2 weeks compared to the first night with screens (χ^2 = 18.0, P < 0.001). No difference in the behavioural response to the screens was observed for Daubenton's bats between sites 1-2 weeks after the screens were installed (Fisher's: N.S.).

No change in the behavioural responses was detected for the soprano pipistrelles between the first night and 1-2 weeks after the screens had been installed (Fisher's: N.S.). A relatively high proportion of soprano pipistrelles were observed to fly around the screens (67%) even after 1-2 weeks of habituation. These observations differ from the results from the ultrasound survey, which showed that a higher proportion of soprano pipistrelles crossed the hop-over gap at heights above 4 m in the 'post-construction' surveys after 1-2 weeks. The differences between the acoustic survey and the visual observations may indicate that some high-flying bats were not observed during the visual observation and some low-flying bats were not recorded by the ultrasound detectors, e.g. some of those that crossed the hop-over gap at the ends of the screens.

Table 3 – Behaviour of bats after habituation to screens (data from visual observation only). Mdau: Daubenton's bat, Ppyg: Soprano pipistrelle.

	Tuelaa (Mdau)	Dyrvig (Mdau)	Agerup (Mdau)	Knuthenlund (Ppyg)
Behaviour	n=14	n=6	n=72	n=73
Over screens	79%	67%	86%	23%
Between screens	7%	0%	3%	1%
Around screens	14%	33%	7%	67%
Turn around	0%	0%	4%	8%

4 Discussion

4.1 Effectiveness of hop-overs

The present study and Lüttmann (2012, 2013) have shown that the presence of vertical screens in a commuting route changes the average flight height of Daubenton's bats and soprano pipistrelles. Thus, screens at a hop-over site may increase the percentage of individuals of the two species that cross roads at safe height above the traffic.

The proportion of bats that turned back at the screens had declined after 1-2 weeks of habituation. Thus, there is no indication that the 4 m high screens act as a major barrier for Daubenton's bats and soprano pipistrelles. Some of the individuals that failed the first attempt to cross the hop-over gaps may have returned to cross the hop-over. However, Lüttmann (2013) reported a higher number of bats flying along the roads and a decline in the activity of *Myotis* and *Pipistrellus* bats at major roads after installation of long barrier screens.

Berthinussen & Altringham (2015) defined that a mitigation measure should only be characterised as effective if at least 90% of bats are using the structure to cross the road safely and the number of bats crossing the road transect has not declined substantially. If assessed as defined by Berthinussen & Altringham (2015), none of the four tested hop-overs in the present study could be characterized as effective mitigation measures for Daubenton's bats and soprano pipistrelles despite the increase in proportion of bats that crossed the hop-overs safely. Furthermore, we observed different levels of effectiveness between sites for the same species. At one site more than 50% of the Daubenton's bats still crossed the hop-over gaps at heights where they could collide with vehicles. Lüttmann (2013) also observed large variations in flight heights within species at road stretches with barrier screens.

For these reasons, hop-overs cannot be generally recommended as effective mitigation measures for Daubenton's bats, soprano pipistrelles and other species with similar flight behaviours. However, more replicate sites for soprano pipistrelle and western barbastelle are needed to conclude on these species. Hop-overs with different characteristics and designs (e.g. tree heights, gap size, screen length, etc.) might be have higher effectiveness,

Further studies are also needed to develop hop-overs as effective mitigation measures for bat species with different flight patterns, e.g. serotines. Hop-overs are unlikely to be effective mitigation measures for more manoeuvrable and low flying bat species, which must be expected to behave differently in relation to barriers, e.g. lesser horseshoe bats (SWILD & NACHTaktiv 2007). In Europe, this would also include species such as Natterer's bat (*Myotis nattereri*), Geoffroy's bat (*Myotis emarginatus*), Bechstein's bat (*Myoiis bechsteinii*), long-eared bats (*Plecotus* spp.) and horseshoe bats (*Rhinolophus* sp.).
Such research should also ascertain if variations on the screen length and height, screen positioning in relation to landscape elements, manipulation of alternative commuting routes, etc. could improve the effectiveness of hop-overs.

The 90% threshold for bat usage of a mitigation structure to cross the road safely to consider the measure as effective, as defined by Berthinussen & Altringham (2015), may seem to be very high. However, a high usage rate of mitigation measures must be attained to sustain viable bat populations and their access to the widely dispersed resources that the bats utilize in the landscape. All bat species have long life spans and very low reproductive rates, and their population status is highly sensitive to increased mortality rates (Altringham 2011, Chauvenet et al. 2014, Lopez-Roig 2014). Annual adult survival rates in two common European bat species is between 70-90%, while survival rates for younger groups is 10-20% lower (Sendor & Simon 2003, Schorcht et al. 2009).

The level of effectiveness of a mitigation measure, that is required to reduce mortality risk sufficiently to protect the status of bat populations, probably varies between species, population status, habitat use, and human land use and road traffic intensity. At roads with a low traffic intensity, and hence a lower probability of vehicle-collisions per bat road crossing, a usage rage lower than 90% might be sustainable for a bat population. A lower effectiveness of the mitigation measures and a larger mortality rate for local population in the vicinity of roads might also be sustainable for common species with large, potential source populations. If an infrastructure project is planned in areas with rare species, small vulnerable populations, or occurrence of species with a fragmented distribution, special consideration should be given and a more precautionary approach must also be applied.

It is a complex task to estimate sustainable traffic-related mortality rates and acceptable fragmentation effects of roads for bat populations, and to define universal criteria for the effectiveness of mitigation structures. Unfortunately, a general lack of empirical data on demographic rates, population dynamics and road effects on bats hampers the application of predictive population and landscape modelling to explicitly predict the effects of roads and mitigation measures on bat populations, and to define effectiveness criteria for mitigation measures. Hence, to comply with the conservation concerns for bats in Europe, a precautionary approach must be applied when assessing the effects of roads and the effectiveness of bat mitigation measures.

4.2 Change of commuting route

The present study focused on the behaviour of bats crossing a hop-over gap in a commuting route at the experimental site, but we also assessed the use of potential alternative commuting routes at the sites. At the Dyrvig site (Figure 20) we noticed that some bats changed commuting route during the study period. Whether they changed the route as a reaction to the barrier in the original commuting route at the hop-over, or the change was a result of the natural variability on bats' use of the landscape during the season is not known.

Many bat species are very conservative and show a high fidelity to their commuting routes. However, bats also quickly find and adopt new commuting routes if conditions on the original routes change. Thus, if a mitigation measure, e.g. screens, increases the barrier effect of the road, the mitigation at a site may just relocate the conflict site.

Bats' use of the landscape varies though the active part of the year according to their needs of roost sites and foraging areas. This variability and plasticity in landscape use by bats stresses the importance of thorough studies very early in the road planning phase (2-3 years) and repeated surveys during the seasons when bats are active.

Pre-construction surveys should not only include mapping of important commuting routes at a very early stage. It should also include experiments with e.g. portable screens to test if the location of potential hop-overs may have the required effectiveness, securing safe pathways for commuting bats at the site.

4.3 Small roads versus large roads

In the present study, we only tested hop-over sections with 8-10 metres between the barrier screens. This represents the situation with hop-overs at minor roads. Larger multi-lane roads may have a more detrimental impact on bat populations. We expect that large roads, forming larger gaps in the commuting routes, will reduce the proportion of bats flying over the second screen and increase the number of bats that descend to lower flight height between the screens, as observed for lesser horseshoe bats (SWILD & NACHTaktiv 2007). This behaviour is probably species dependant, with a greater risk for all clutter-adapted and manoeuvrable species that generally fly low over open stretches e.g. some *Myotis* sp. *Plecotus* sp., *Rhinolophus* sp., than for semi-clutter adapted species, e.g. *Pipistrellus* species, and aerial hawking species as *Nyctalus* species.

For multi-lane roads, it has been suggested to install additional screens on the central reservation to force the bats to maintain the flight heights. The proportion of *Myotis* and *Pipistrellus* bats that crossed multi-lane roads did not differ between road sections with and without a screen in the central reservation (Lüttmann 2013). Unfortunately, flight heights for bats at sites with and without screens at the central reservations were not reported. Light and noise pollution on major roads with heavy traffic loads may affect the effectiveness of simple mitigation structures as hop-overs negatively and increase the barrier effect of the roads (Stone et al. 2009, Siemers & Schaub 2011, Luo et al. 2015).

Conclusions and perspectives

The experimental field study simulated a hop-over at a road severance of a commuting route for bats. We simulated a hop-over by installing 4 m high and 20 m long vertical screens as artificial barriers in natural open gaps in bat commuting routes at four sites. The flight heights and behaviours at the hop-over sites were recorded for two nights before, the first night with screens, and one and two weeks later.

The hop-overs with barrier screens increased the proportion of Daubenton´s bats and soprano pipistrelles that crossed the hop-over site at heights above 4 m, but no increase was observed for western barbastelles. At the different study sites 46-85% of individual Daubenton´s bats flew over both screens. When screens were installed 61% of soprano pipistrelles crossed the open gap at heights above 4 m. More than 85% of western barbastelle crossed the hop-over site above 4 m both before and after the screens were installed. Commuting soprano pipistrelles and western barbastelles were only recorded at one site.

The present study showed that hop-overs have some potential for reducing the risk of bat-vehicle collision, but hop-overs cannot be generally recommended as the effectiveness is low at some sites. At one site more than 50% of individual bats still crossed the hop-over gaps in hazardous heights after one and two weeks after the screens were installed. Some individuals also appeared to switch to alternative commuting routes which should then be mitigated if needed. Which usage rate of mitigation measures is needed to reduce mortality risk sufficiently at each site to protect the local bat populations will vary between species, population status and traffic intensity, but a high effectiveness of the measures should be attained to sustain viable bat populations.

The results presented here only represent the species included in this study, and possibly for other species with very similar flight behaviours, e.g. the common pipistrelle that has very similar flight behaviour to the soprano pipistrelle. Other species may behave differently. Further studies on the behaviour of more bat species at hop-over structures are needed.

Further research is also needed concerning the effectiveness of hop-overs with different characteristics and designs, e.g. denser tree canopy overhanging the road, longer or higher screens, wider gaps (i.e. broader roads), and on the effects of light and noise pollution from the road on the bat behaviour at the mitigation structures.

Bats may switch to alternative commuting routes if conditions in the preferred route change. Consequently, hop-over or other mitigation structures should be constructed at all potential commuting routes and alternative unmitigated commuting routes must be manages to discourage the bats from using them. Further experiments with more complex study designs are needed to test if careful adjustments and management of local conditions may increase the effectiveness of hop-overs. This should include testing screen lengths, alternative screen positions, closure of alternative commuting routes, etc.

We suggest that such further experiments should be made at potential bat-critical road constructions sites by using temporal screens at a very early stage (two or more years before start of construction work) in order to give sufficient time to study the behaviour of the particular bat species in question. We suggest that such tests are made by using temporary portable screens as in this study. Such screens can easily be manipulated to simulate different situations.

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6 References

Abbott I, Melber M, Altringham J, Berthinussen A, Boonman M & Stone E 2015. Bats and roads. In: van der Ree R, Smidt DJ & Grilo C (eds.). Handbook of road ecology. Wiley Blackwell, pp. 290-299.

Altringham JD 2011. Bats: from evolution to conservation. Oxford University Press, Oxford.

Baagøe HJ 1987. The Scandinavian bat fauna: adaptive wing morphology and free flight in the field. In: Fenton MB, Racey P & Rayner JMV (eds.). Recent advances in the study of bats. Cambridge University Press. Cambridge, pp. 57-74.

Berthinussen A, Richardson OC & Altringham JD 2013. Bat conservation. Global evidence for the effects of interventions. Synopses of Conservation Evidence 5. Pelagic Publishing.

Berthinussen A & Altringham JD 2015. Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructures. Defra Research Project WC1060.

Brinkmann R, Biedermann M, Bontadina F, Dietz M, Hintemann G, Karst I, Schmidt C, Schorcht W 2012 Planung und Gestaltung von Querungshilfen für Fledermäuse – Eine Arbeitshilfe für Straßenbauvorhaben im Freistaat Sachsen. Staatsministerium für Wirtschaft, Arbeit und Verkehr, Freistaat Sachsen, Dresden.

Chauvenet ALM, Hutson AM, Smith GC & Aegerter JN 2014. Demographic variation in the U.K. serotine bat: filling gaps in knowledge for management. Ecology and Evolution 4, pp. 3820-3829.

ChiroMed 2014. Technical Guide No. 1. Systems to help with the crossing of roads. Camargue Regional Nature Park. Available from: www.lifechiromed.fr [10/01/2016]

Fensome, AG & Mathews F 2016. Roads and bats: a meta-analysis and review of the evidence on vehicle collisions and barrier effects. - Mammal Review online, doi: 10.1111/mam.12072.

Highways Agency 2001. Nature conservation advice in relation to bats: design manual for roads and bridges. Highways Agency.

Highways Agency 2006. Best practice in enhancement of highway design for bats. Highways Agency and Bat Conservation Trust.

Limpens HJGA, Twisk P & Veenbaas G 2005. Bats and road construction. Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, Delft & Vereniging voor Zoogrierkunde en Zoogdierbescherming, Arnhem, the Netherlands.

López-Roig M & Serra-Cobo J 2014. Impact of human disturbance, density, and environmental conditions on the survival probability of pipistrelle bat (*Pipistrellus pipistrellus*). Population Ecology 56, pp. 471-480.

Lüttmann J 2012. Are barrier fences effective mitigating measures to reduce road traffic bat mortality and movement barrier effects? In: Safeguarding Ecological Functions Across

Transport Infrastructure, Proceeding of the IENE 2012 International Conference, 21-24 October 2012, Berlin-Potsdam, Germany, p. 108.

Lüttmann J 2013. Beeinflussen Querungshilfen und Schutzzäune das Querungsverhalten von Fledermäusen. Poster on the Landschaftstagung der Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), June 6.-7. 2013, Biberach an der Riß, Germany.

Møller, JD & Baagøe HJ 2011. En vejledning: Flagermus og større veje, registrering af flagermus og vurdering af afværgeforanstaltninger.Rapport 382-2011. Vejdirektoratet.

National Roads Authority 2006. Best practice guidelines for the conservation of bats in the planning of national road schemes. Technical handbook, National Road Authority, Dublin, Ireland.

Nowicki F, Dadu L, Carsignol J, Bretaud J-F & Bielsa S 2008. Routes et chiroptères. État des connaissances. Service d'Etudes Techniques des Routes et Autoroutes, Bagneux, France.

Nowicki F, Authur L, Dorey J, Rauel V & Rousselle K 2016. *Guide méthodologique. Chiroptères et infrastructures de transport.* Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (CEDEMA).

Russell AL, Butchkoski CM, Saidak L & McCracken GF 2009. Road-killed bats, highway design, and the commuting ecology of bats. Endangered Species Research 8, pp. 49–60.

Schorcht W, Bontadina F & Schaub M 2009. Variation of adult survival drives population dynamics in a migrating forest bat. Journal of Animal Ecology 78, pp.1182–1190.

Sendor T & Simon M 2003. Population dynamics of the pipistrelle bat: effects of sex, age and winter weather on seasonal survival. Journal of Animal Ecology 72, pp.308–320.

Siemers BM & Schaub A 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society B 2262, pp.1-7.

Stone EL, Jones G & Harris S 2009. Street lighting disturbs commuting bats. Current Biology 19, pp.1123–1127.

SWILD & NACHTaktiv 2007. Schadensbegrenzung für die Kleine Hufeisennase an Straßen - Experimente zur Wirksamkeit von Schutzzäunen. Unveröffentlichter Bericht im Auftrag der DEGES, Berlin.

Annex A: Overview of survey sites, dates and times

Site	Position/team	Date	Start time	Close time	Sunset
Site 1 - Tuelaa	**55 26'N 11 36'E**				
Survey 1 - Before	MFC	10.06.2015	21:22	23:48	21:50
Survey 2 - Before	MFC/ETF	16.06.2015	21:26	00:18	21:58
Survey 3 - Screen setup	MFC/ETF	25.06.2015	23:08	00:35	22:00
Survey 4 - After	MFC/ETF	30.06.2015	22:11	23:58	21:59
Survey 5 - After	MFC	06.07.2015	22:26	00:50	21:56
Site 2 - Dyrvig	**55 52'N 8 44'E**				
Survey 1 - Before	MFC/ELM	09.07.2015	21:47	00:03	22:08
Survey 2 - Before	MFC/ELM	10.07.2015	22:26	00:07	22:07
Survey 3 - Screen setup	EFT/ELM	14.07.2015	21:34	00:18	22:01
Survey 4 - After	ETF/ELM/HJB ao.	21.07.2015	22:16	23:55	21:52
Survey 5 - After	ETF/ELM	28.07.2015	21:53	23:52	21:40
Survey 6 - After	ETF/ELM	06.08.2015	22:10	00:08	21:22
Survey 7 - After	MFC/ELM	11.08.2015	21:11	23:09	21:11
Site 3 - Agerup	**56 46'N 11 36'E**				
Survey 1 - Before	MFC/HJB	12.07.2015	21:57	00:04	21:46
Survey 2 - Before	MFC/Aske	13.07.2015	21:57	23:34	21:45
Survey 3 - Screen setup	MFC/ETF/HJB	15.07.2015	22:01	23:52	21:43
Survey 4 - After	MFC	26.07.2015	21:00	23:12	21:27
Survey 5 - After	MFC/ETF	30.07.2015	21:17	23:09	21:20
Site 4 - Knuthenlund	**54 51'N 11 21'E**				
Survey 1 - Before	MFC/HJB	13.08.2015	20:58	23:20	20:53
Survey 2 - Before	MFC/ETF	16.08.2015	20:48	22:43	20:46
Survey 3 - Screen setup	MFC/HJB/ETF	20.08.2015	21:10	22:54	20:37
Survey 4 - After	MFC	26.08.2015	20:51	22:42	20:23
Survey 5 - After	MFC	03.09.2015	19:45	21:35	20:03
Control - Skjoldnæsholm	**55 32'N 11 51'E**				
Survey 1 - Control	MFC/HJB	08.07.2015	21:44	23:24	21:54
Survey 2 - Control	ELM/HJB	23.07.2015	21:50	00:15	21:35
Survey 3 - Control	MFC/ETF	10.08.2015	21:16	22:42	21:00
Survey 4 - Control	MFC	27.08.2015	20:01	21:42	20:20
Survey 5 - Control	MFC/ETF	17.09.2015	19:48	20:59	19:26

Annex B: Weather information for the survey dates

Site	Dato	Start Temp.	Close Temp.	Humidity (DMI)	Average Wind (DMI)	Wind Direction (DMI)
Site 1 - Tuelaa						
Survey 1 - Before	10.06.2015	22	18	81	5	WMW
Survey 2 - Before	16.06.2015	22	14	68	5	WNW
Survey 3 - Screen setup	25.06.2015	18	16	77	5	W
Survey 4 - After	30.06.2015	22	18	76	4	WNW
Survey 5 - After	06.07.2015	22	20	77	2	ENE
Site 2 - Dyrvig						
Survey 1 - Before	09.07.2015	12	12	82	10	WNW
Survey 2 - Before	10.07.2015	9	9	74	9	WNW
Survey 3 - Screen setup	14.07.2015	20	17	82	5	W
Survey 4 - After	21.07.2015	21	20	90	5	SW
Survey 5 - After	28.07.2015	20	18	93	3	N
Survey 6 - After	06.08.2015	20	18	85	4	SE
Survey 7 - After	11.08.2015	19	18	80	4	SW
Site 3 - Agerup						
Survey 1 - Before	12.07.2015	21	19	84	3	SW
Survey 2 - Before	13.07.2015	18	18	82	4	W
Survey 3 - Screen setup	15.07.2015	20	18	70	5	WNW
Survey 4 - After	26.07.2015	19	16	75	8	W
Survey 5 - After	30.07.2015	19	17	87	5	W
Site 4 - Knuthenlund						
Survey 1 - Before	13.08.2015	20	21	77	3	ENE
Survey 2 - Before	16.08.2015	22	21	84	4	ENE
Survey 3 - Screen setup	20.08.2015	19	18	70	4	ENE
Survey 4 - After	26.08.2015	21	20	82	5	S
Survey 5 - After	03.09.2015	16	13	77	4	S
Control - Skjoldnæsholm						
Survey 1 - Control	08.07.2015	21	19	83	8	SW
Survey 2 - Control	23.07.2015	17	15	70	5	W
Survey 3 - Control	10.08.2015	21	20	72	3	ENE
Survey 4 - Control	27.08.2015	20	19	84	5	SSW
Survey 5 - Control	17.09.2015	19	19	84	7	S

Temperatures were measured on the site. Data on humidity and wind were extracted from the Danish Meteorological Institute (DMI) regional weather database (http://www.dmi.dk/vejr/arkiver/vejrarkiv/).