Bat mitigation measures on roads - a guideline. - SafeBatPaths Technical Report SafeBatPaths Technical Report.

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Publication date:
2016

Document version
Også kaldet Forlagets PDF

Citation for published version (APA):
Elmeros, M., Jasja, D., Baagøe, H. J., Garin, I., & Christensen, M. (2016). *Bat mitigation measures on roads - a guideline. - SafeBatPaths Technical Report: SafeBatPaths Technical Report.* . CEDR Transnational Road Research Programme.

CEDR Transnational Road Research Programme
Call 2013: Roads and Wildlife

Funded by Austria, Denmark, Germany, Ireland, Norway, Sweden, The Netherlands and United Kingdom

SafeBatPaths

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

Bat mitigation on roads in Europe – an overview

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CEDR Call 2013: Roads and Wildlife

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Due date of deliverable: 01/06/2016
Actual submission date: 26/08/2016

Start date of project: 01/09/2014 End date of project: 26/08/2016

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Final version, November 2016

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Executive summary

Mitigation of the impact of transport infrastructures on wildlife has become increasingly important over the past decades. Research has shown that transport infrastructures can have detrimental impacts on bats. In order to develop ecologically sustainable transport infrastructures and to comply with legislative obligations to protect bat populations, a variety of actions have been implemented to mitigate and compensate for the effects of roads and traffic during the past decades.

To compile an overview of the status of bat mitigation across Europe, we collected information of bat mitigating measures constructed on roads across Europe along with monitoring and maintenance procedures in the different countries from bat ecologists, consultants and road authorities.

Bat mitigation and compensation

Bat mitigation and compensation measures have been implemented in road schemes in 48% of 29 European countries. The mitigation schemes are most extensive in Germany, France, Ireland, the Netherlands and the United Kingdom. Extensive mitigation schemes have also been applied in more recent road projects in e.g. Poland and Spain.

Measures that have been constructed specifically for bats comprise modified road overbridges, bat gantries, hop-overs, fencing, a small number of tunnels and a wildlife overpass, but most of the recorded bat crossing structures are multispecies or multifunctional passages that have been adapted to also facilitate bat crossings of roads, e.g. oversized culverts for watercourses, large wildlife tunnels and overpasses with dense woody vegetation. Bat boxes have been widely used to attempt to compensate for destroyed roost in trees. Adaptations of existing buildings and bridges to accommodate roosting bats are applied in many countries, but only in low numbers.

The review of bat mitigation on roads across Europe suggests that there is an increasing awareness to integrate mitigation measures in new road schemes in most countries; bat mitigation is planned for new road schemes in countries where such actions have not been applied previously, and more intensive mitigation and monitoring schemes are implemented in the countries where the bat mitigation procedures are well established.

Post-construction monitoring studies indicate that most of the different types of measures may facilitate bats crossings and maintain existing roost sites. The monitoring of a few comprehensive mitigation schemes which include a variety of interventions that targeted different road effects, has shown that it is feasible to neutralise the road impact on threatened bat populations.

Recommendations for road mitigation

- A precautionary approach is advised as the status of bat populations is very sensitive to increased mortality and landscape changes.
- Mitigation strategies should consider several aspects of road effects (e.g. mortality, road permeability, disturbance and barrier effect) and bat ecology (foraging and roost sites) to neutralise road impact.
- Passages and guiding structures should be in place and operative well before existing habitats are destroyed and before the road opens to traffic to allow the bats to habituate to the measures.

- Establish national databases of mitigating and compensatory interventions to promote better convergence and exchange of experiences between projects, and as planning tools for maintenance and monitoring procedures.

Monitoring

Post-construction monitoring programmes have been carried out in most countries, but only UK, Ireland and Germany have systematic appraisal programmes to monitor and assess the performance of bat mitigation interventions.

In all countries, the monitoring are typically performed in the first years after construction of the road and mitigation measures, before the bats may have habituated to the new structures and landscape changes. Most surveys are irregular short-term studies of selected crossing structures. Just two extensive long-term studies in Germany and United Kingdom were identified. However, elaborate short-term monitoring studies and repeated surveys are performed in relation to comprehensive mitigation structures in other countries to assess the functionality of the passages and the temporal development of bats' use of the measures.

Most monitoring primarily aims to document bats' use of the mitigation measures, and only a few programmes have considered the population effects of the mitigation scheme. The above mentioned two German and British long-term monitoring programmes and a handful of other smaller programmes have recorded development in bat numbers in maternity roosts adjacent to the transport infrastructures.

Planning and construction of road schemes span several years and the accumulation of knowledge on the effectiveness of mitigation measures within each country is slow. To promote future development of more effective bat mitigation strategies, more rigorous monitoring methods and publication of the findings is advised.

Recommendations for monitoring

- Study design should be rigorous and quantitative for both pre- and post-construction studies to allow comparison.
- Define target species and goals for the monitoring (use vs. effectiveness).
- Select appropriate, accurate methods and include control sites for effectiveness assessments.
- Regular long-term monitoring and assessment schedules, e.g. every 3-5 years, should be integrated in the general road management plan.
- Monitoring reports should have a clear summary that includes quantitative results, statistical analyses and metrics for the passages.
- Monitoring reports should be publically accessible to increase knowledge exchange between road mitigation schemes, road developers and consultants.

Maintenance

Many of the implemented measures are relatively new and probably need little maintenance at present. However, provisions to ensure the long-term maintenance are required to maintain the effectiveness of the mitigation structure itself and adjacent habitats and landscape elements.

The maintenance requirements vary for the different mitigation structures. E.g. bat boxes may need annual inspections and maintenance actions and often have a short lifetime, and it may be necessary to manage planted vegetation regularly to keep guidance hedgerows intact and maintain the openness of crossing structures, e.g. entrances to underpasses and trees and shrubs at hop-overs. Even small details in the measures and in the surrounding landscape may reduce the functionality and effectiveness of the interventions, e.g. small gaps in guidance structures could divert some bat species onto the road.

An appropriate maintenance strategy should be applied to ensure the long-term ecological effectivity of the mitigation measures. The value of inspections of mitigation measures, subsequent adjustments and general maintenance actions has been demonstrated in the British post operations phase evaluation surveys, and standardised maintenance procedure for fauna passages have successfully been integrated into the general road management in the Netherlands.

Recommendations for maintenance

- Maintenance of bat mitigation interventions should be an integrated part of the general management plan for a road.
- The objectives, target species and maintenance requirements for the mitigation structures should be clearly defined.
- Development of standardised maintenance guidelines and schedules for the measures are advised.

1 Introduction

Bats and roads

Concern for the impacts of road infrastructures on wildlife has led to increasing efforts to mitigate the effects over the last decades (Iuell et al. 2003). Roads may have a range of negative impacts on the wildlife, and as the transport network is continuously expanded and traffic volumes grow, the conflict between wildlife conservation interest and transport infrastructures inevitably increases (Forman & Alexander 1998, van der Ree et al. 2015).

The detrimental effects of roads have primarily been described and researched for non-flying terrestrial mammals, but work on birds and bats show that flying vertebrates are also affected (Abbott et al. 2015). Research over the last decades have documented that bats also are vulnerable to impacts of roads and traffic. Roads and traffic may affect bats directly through vehicle collisions, destruction of roost sites, losses and degradation of foraging habitats, light and noise disturbance (Russell et al. 2009, Berthinussen & Altringham 2012b, Kitzes & Merenlender 2014, Luo et al. 2014, Bunkley & Barber 2015). Indirectly, roads may act as barriers that fragment populations, reduce the genetic diversity within the populations and increase their susceptibility to stochastic events and the probability of extinction (Kerth & Melber 2009, Bennett et al 2013, Fensome & Mathews 2016).

All bat species are affected by roads, but the risk varies between species due to bats' different habitat preferences and flight patterns. The most low-flying, manoeuvrable species that often fly close to or within vegetation, vertical structures or the water in particular are at risk of being killed when crossing roads, e.g. *Myotis, Plecotus* and *Rhinolophus* species (Baagøe 1987, Fensome & Mathews 2016). These species may perceive roads as a barrier that they are reluctant to cross (Kerth & Melber 2009, Bennett et al. 2013). If these species do cross the road, they tend to fly low with a high risk of vehicle-collision (ChiroMed 2014). However, high mortality rates have also been recorded locally for species which normally fly in the open airspace higher above traffic height, e.g. *Nyctalus* species (Lesiński et al. 2011).

Bats' life history traits and ecology makes them highly vulnerable to environmental changes and increased mortality due to e.g. changes in human land use and developments. Bats have a relatively long life expectancy, long pre-reproduction period and a low reproductive rate; adult females for most species produce only one cub in a litter and not all adult females successfully breed every year (Sendor & Simon 2003, Altringham 2011, Chauvenet et al. 2014). Increased mortality rates and lowered reproductive success may have a severe negative effect on the population status of bats (Schorcht et al. 2009, López-Roig & Serra-Cobo 2014). Furthermore, bats utilize seasonally varying resources that are widely dispersed in the landscape compared to similar sized mammals (Robinson & Stebbings 1997, Encarnação et al. 2010). During summer, bats commute several kilometres on a nightly basis between roosting sites and several important foraging habitats, and during autumn and spring bats migrate long distances between summer habitats and winter hibernation sites Hutterer et al. 2008). These complex habitat networks and connectivity across the landscape must be maintained to sustain viable bat populations.

Therefore, bat populations are susceptible to road developments and changes in human land use that increase mortality rates, lower their reproductive success, and fragment the landscape. The recovery of bat populations will also be slow and uncertain in the modified landscapes. A high effectiveness of mitigation interventions must be attained to reduce vehicle-collision risks adequately and to maintain landscape connectivity sufficiently to preserve viable bat populations.

Bat conservation

All European bat species are of conservation concern (Annex B). They are all protected under the Bonn Convention (The Convention on the Conservation of Migratory Species of Wild Animals), the Bern Convention (The Convention on the Conservation of European Wildlife and Natural Habitat) and the EUROBATS Agreement (Agreement on the Conservation of Populations of European Bats), which most European countries have committed to.

In member states of the European Union all bats are also strictly protected by the Habitats Directive (EC Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora), which has been implemented by the member states in their national legislations. The Habitats Directive prohibits deliberate killing and disturbance of bats and their resting and roosting sites. Furthermore, the directive requires development projects to have no detrimental effect on the conservation status of the protected species.
If development projects are likely to affect bats, the impacts should preferably be avoided. If an impact is unavoidable, the impacts should be mitigated by the implementation of mitigating or compensating measures in the project scheme to ensure that the conservation status of bat populations is not adversely affected. Furthermore, the habitat degradation caused by fragmentation and incorporation of ecological connectivity and green infrastructures is emphasized in the strategy for halting loss of biodiversity in the European Union (EU Biodiversity Strategy EC COM, 2011, 244-final).

Bat mitigation on roads

The need to incorporate bat conservation measures in road infrastructure developments has been increasingly acknowledged by road authorities during the past decades in many European countries (e.g. Limpens et al. 2005, Highways Agency 2006, National Roads Authorities 2006, Brinkmann et al. 2008, 2012, Nowicki et al. 2008, 2016, Møller & Baagøe 2011).

A variety of mitigation and compensatory measures to reduce or off-set the adverse effects of roads and traffic on bats has been implemented, including fauna passage, diversion and deterrence and ecological compensation (Table 1). The measures aim to reduce traffic mortality, to increase road permeability and maintain connectivity, or to compensate for roost site destruction or habitat loss and deterioration. Some of the described structures may not only serve as mitigation measures for bats but also have beneficial effect on other wildlife species. Likewise, bats may use fauna passages that have been constructed primarily for other wildlife species. Bats may also use road overbridges and tunnels as passages if human traffic is low during the night.

Bat road mitigation measures have been constructed in many European countries and each country is monitoring some of these mitigation structures. As the planning and construction phases of road projects span years, the accumulation of experience within each individual country can be slow. By combining experiences and expertise accumulated in each country convergence and cost-effective future road mitigation projects for bats can be better achieved.

In the present report we briefly review the mitigation types implemented to reduce the impact of roads on bats, and present an overview of bat mitigating measures constructed on roads, monitoring and maintenance in European countries.

Table 1 - Types of interventions on road infrastructures in Europe to mitigate and compensate the negative effects on bats.

Measure	Aim	Description
Fauna passages		
Bat gantry	Safer crossing	Light structures build to guide bats across at safe heights to above the traffic
Hop-over	Safer crossing	Tall vegetation and/or screens on either side of a road managed to increase or maintain the bats' flight height across the road to safe heights
Wildlife overpass	Safer crossing	Overpass with vegetation constructed for the fauna. May have multifunctional purposes, e.g. minor roads, pedestrian/cyclist paths.
Modified bridges	Safer crossing	Modifications to road overbridges to improve their suitability as bat passages
Tunnels and culverts	Safer crossing	Tunnels or culvert under roads where it is raised on an embankment. May have multifunctional purposes, e.g. minor roads, pedestrian/cyclist paths and drainage.
Viaducts and river bridges	Safer crossing	Road bridge across rivers and valleys to maintain landscape corridors in the valley. Can have multifunctional purposes, e.g. minor roads and agricultural tracks.
Diversion, deterrence and other interventions		
Treelines, hedgerows and fences	Guide to safer crossing points	Hedgerows, treelines or fences constructed to divert bats to safer crossing points.
Screens	Prevent crossing	Barrier screens and fences to prevent road crossing or guide bats to cross at a higher altitude.
Lighting	Prevent crossing	Strong lights used to deter bats away from the road and divert bats to safer crossing site.
	Enhance use of passage	Restriction of lighting in multifunctional passages to enhance their suitability as a bat crossing structure.
	Reduce disturbance and mortality risk	Adaptation of the light source and light spectrum to reduce disturbance of bats and reduce attraction of insects to street light.
Noise	Prevent crossing	Adaptation of the road surface to deter the bats from crossing when the collision risk is high.
	Reduce disturbance	Adaptation of asphalt on roads surfaces or noise screens to reduce noise pollution.
Ecological compensation		
Artificial roost sites and enhancement of existing sites	Compensation for roost site losses	Installation of artificial roost sites, adaptation of existing structures, translocation of tree trunks with existing roosts, artificial holes in trees, tree retention.
Habitat enhancement	Compensation for habitat losses or degradation	Creation of new feeding habitats or improvement of habitat quality of existing bat habitats

2 Bat mitigation types

Bats readily cross over roads and fences are not often obstacles for most species. At sites where many bats cross a road, special structures may facilitate safe passage to reduce traffic mortality risk and increase road permeability at the site, e.g. underpasses and overpasses. Other interventions can also reduce the potential impact of transport infrastructures, e.g. planting of trees and hedges to guide bats to safer crossing structures, noise and light management, artificial roost sites, and general habitat improvement such as tree planting and pond creation.

The descriptions of the various mitigation and compensation measures below refer to the intended aims for each type of measure. There is a large species-specific variation between bats in their flight and echolocation behaviour, typical flight height in relation to vegetation and structures and habitat use. Consequently, the use of the mitigation measures and their effectiveness varies widely between bat species.

The described measures are not necessarily documented to be effective and recommendable for bat mitigation or compensation. Empirical data on the effectiveness of most of the measures is limited. Berthinussen et al. (2013) and Møller et al. (2016) have reviewed the evidence of bats' use and the effectiveness of the different types of measures and methods. Measures that have not been documented to be effective should be regarded as experimental interventions. If such undocumented measures are planned in a road project, they should be monitored methodically to determine their effectiveness.

2.1 Fauna passages

2.1.1 Bat gantries

Bat gantries (alternatively called 'bat bridges') are light structures spanning the roads (Highways Agency 2006). Bat gantries are constructed at sites where roads have severed bat commuting routes, e.g. forest edges and hedgerows. The gantries aim to guide the bats across the road above the traffic to reduce road mortality rates and maintain landscape connectivity. The structure is supposed to provide echoes for the commuting bats thereby encouraging them to maintain the flight height over the roads.

The gantries are typically constructed with steel wires or ropes, nets or light lattice metal constructions erected on poles on either side of the road. Some gantries are constructed as more closed structures resembling small bridges. The gantries are typically constructed where the roads are built level with the surrounding terrain or in cuttings below the terrain. To enhance the use of gantries, guidance structures such as shrubs, treelines or temporary fences, can be installed between the bat gantry and the adjacent bat flight paths and habitats.

The effectiveness of wire gantries is questionable. Studies have shown that the effectiveness of wire gantries and other open-structures gantries is low (Berthinussen et al. 2012a, 2015, Cichocki 2015). Only a very small proportion of bats crossed the road in the proximity of the gantries. Bats approaching the road do not change their flight path or height to follow the gantries to cross the road.

Installation of numerous large spheres with multiple reflective surfaces on the wires may provide the commuting bats with stronger echoes and increase bats' use of wire gantries

(Pouchelle 2016). Wire gantries with large spheres installed at short distances on the wires have been proposed as a temporary measure during until a wildlife overpass has been completed at the site between two woodlots.

2.1.2 Hop-overs

Hop-overs have been advocated as a simple method to guide bats safely across roads (e.g. Limpens et al. 2005, Stratmann 2006). The aim of hop-overs is to maintain existing bat commuting routes and to increase or keep the bats at height above the traffic when they cross the road. A hop-over consist of tall trees, preferably deciduous trees, close to the road margins on either side of a road to narrow the gap in the commuting route which is created by the road. The branches of the trees should preferably overhang and meet over the road to create a continuous canopy.

Small, low-flying bats species tend to cross a gap in the vegetation functioning as a commuting route at low height and experience a high collision risk. The tall vegetation at the hop-over site is expected to encourage the bats to increase and maintain their flight height over the road whereby the likelihood of vehicle-collisions is reduced. Ramps or embankments on the road verges leading up to the hop-over may enhance the effective height of the measure.

Hop-overs are best used on narrow roads that are in level with surrounding terrain or in cuttings below the terrain. Intersections of commuting routes by wider motorways or dual carriageways can be difficult to mitigate with hop-overs. Planting tall trees or other structures on the central reservation may help to reduce the gab size and encourage the bats to maintain the flight height across the road lanes at both sides of the central reservation.

The detailed structure of hop-overs may dependent on the target species and the site settings. If dense vegetation near the roads cannot be established e.g. due to traffic safety concerns, some bat species might be brought up to safer heights further from the road by removing undergrowth and lower branches of the trees whilst retaining a closed crown layer. This approach may work for species that typically fly at low-medium heights along vegetation, e.g. *Eptesicus* and *Pipistrellus* bats. However, other more clutter-adapted species (specialist species that may hunt within the foliage) may lower the flight height in the commuting route where the undergrowth and lower branches has been removed, increasing the risk for vehicle collision.

At hop-overs for semi clutter-adapted species, e.g. some *Myotis* species, planting of dense thicket close to the road margins to force the bats to fly above the traffic. Highly clutter-adapted, manoeuvrable species as *Rhinolophus* bats, *Plecotus* bats and some *Myotis* species can fly through relative dense vegetation. For these species, it has been advocated to install barrier screens along the road to force the bats to increase their flight before crossing the road. However, experimental work with *Rhinolophus hipposideros* has shown that instead of increasing flight height, most bats flew along the screens only to cross the road at low height at the end of the screens, or the bats descended to low height after crossing the first screen (SWILD & NACHTaktiv 2007). Similar behaviours have been observed for less manoeuvrable species (*Myotis daubentonii* and *Pipistrellus pygmeaus*), and the variation in effectiveness for each species between sites can be large (Christensen et al. 2016). A hop-over may potentially increase collision risk at a site, if the bats forage over road sections sheltered by the woody vegetation.

The vegetation structures and settings that are characterised as a hop-over are not consistent between studies. In some studies any severed hedgerow is described as a hop-over, while other authors characterise a similar setting as an unmitigated road severance of a commuting route. The vegetation should be planted and maintained as a bat mitigation intervention. A detailed maintenance plan for the vegetation and regular trimming is important to preserve the functionality of hop-overs.

2.1.3 Wildlife overpasses and landscape bridges

Wildlife overpasses and landscape bridges (alternatively called 'green bridges', 'environmental bridges' 'landscape bridges' or 'ecoducts') are large structures over roads that have been designed and constructed specifically for wildlife to increase road permeability and landscape connectivity (Iuell et al. 2003). Wildlife overpasses have a layer of top-soil and vegetation. Trees and shrubs are usually planted along the edges of the bridge and on the approach ramps to provide guidance structures and cover for wildlife. Fences are often installed on both sides to protect the wildlife from light and noise disturbance from the traffic below the overpass.

Due to their large size, wildlife overpasses can maintain connectivity across the roads for a wide range of species and habitats. Wildlife overpasses and landscape bridges have primarily been built for large mammals, e.g. ungulates and carnivores, but overpasses in forested areas are also used by bats. Wildlife overpasses can be effective as road crossing structures for bats providing that the vegetation and nearby habitats are adapted to the bats' needs (Bach & Müller-Stieß 2005, Berthinussen & Altringham 2015).

Bat activity over wildlife overpasses is correlated to occurrence of trees and shrubs on the bridge and the connectivity of the vegetation to bat habitats in the vicinity of the structure ((Bach & Müller-Stieß 2005). Usage of new wildlife overpasses by clutter-adapted bat species is low before the vegetation has developed, but if the structures are located on a traditional commuting route *Pipistrellus* species and aerial hawking species may use structures with undeveloped vegetation (Stephan & Bettendorf 2011, Lambrechts et al. 2014, Ransmayr 2014b).

Wildlife overpasses may carry agricultural access roads, forest tracks or pedestrian pathways, but human traffic on the overpass must be low during the night. Furthermore, human activity and disturbance, e.g. build-up areas and lighting, adjacent to the structure must be low.

2.1.4 Modified bridges and other technical structures

Bats sometimes use overbridges built for other purposes than bat crossings to cross roads, e.g. bridges for minor road, cyclist and pedestrian paths, and road sign gantries. The usage by bats of such structures is generally low and incidental (Bach et al. 2004, Abbott et al. 2012a, Berthinussen & Altringham 2015). However, large numbers of bats have been observed to use such structures regularly if they were positioned exactly on traditional bat commuting routes and the structures are well connected to adjacent hedgerows and woodlands (Ransmayr et al. 2014b, Cichocki 2015, V. Loehr, pers.comm.).

Although these structures are constructed for purposes other than bat mitigation, they may provide additional safe crossing points for bats. To enhance bats' use of existing bridges and other technical structures a number of modifications have been tested.

Panels installed on the side of overbridges may give better echoes for bats than normal fences and facilitate bat crossings along the structures. The panels may also reduce the disturbance from street lights, light and noise from the vehicles on the larger road below the modified overbridges. Such experimental modifications have resulted in increased usage of overbridges as passages for bats, particularly by *Rhinolophidae* spp. and *Myotis myotis* (Burette 2013, ChiroMed 2014, L. Arthur pers. comm.)

Overbridges with wide green verges on one or both sides can enhance the permeability of the traffic infrastructures for bats (NACHTaktiv & SWILD 2014). Green verges planted with shrubs and small trees on the overbridges can maintain or link traditional bat flight paths. The verges may also facilitate road crossings for other small wildlife species. Night time traffic intensity on the roads on adapted overbridges should be low to avoid collision risk on the bridge, and the structures should be unlit.

2.1.5 Culverts and tunnels

Culverts and tunnels are relatively small underpasses which are typically constructed where the roads are built on an embankment (Iuell et al. 2003). Tunnels and culverts with dry banks on one or both sides of a river are sometimes constructed to facilitate wildlife passages for mainly small and medium sized species to reduce road mortality numbers and increase road permeability.

Bats may use wildlife tunnels and culverts to cross safely under roads (Bach et al 2004, Berthinussen et al. 2012b). Bats may also make use of tunnels and culverts that have been constructed for other purposes than wildlife such as road tunnels, pedestrian paths and railways. Bats may use underpasses if they are constructed on existing bat flight paths and human traffic at night is low.

Culverts and tunnels are typically less spacious than open-span bridges and are not suitable as passageways for a comparable wide range of bat species (Abbott et al 2012a, 2012b). Tunnels and culverts are primarily used by clutter-adapted species which normally fly close to vegetation, vertical structures or the water. The larger the size of tunnels and culverts, the wider a range of species may use the underpasses. The height of the underpasses is often limited by the height of the road embankment.

To ensure functionality and effectiveness for bats the underpasses should be designed to conform to local vegetation, topography, and the bats' habitat use. The tunnels and culverts should be situated in the existing bat commuting routes. The vegetation up to the entrance should connect with existing vegetation or landscape features along the commuting routes so that the bats should not alter their flight paths to fly though the underpasses.

Bats' use of multifunctional tunnels and culverts is hampered by artificial lighting in the underpasses or near the entrances. Restricting or modifying the lighting in and around the underpasses to create a dark corridor through the underpass could increase their functionality as bat passages.

2.1.6 Viaducts and river bridges

Viaducts or river bridges are long, elevated bridges (alternatively called 'open-span bridges' or 'fly-overs') that carry an infrastructure across river valleys, lowlands with wetland or canyons (Iuell et al. 2003). The dimensions vary extensively from short, relatively low river bridges across small river valleys, long structures with relatively low clearance across wetlands to high structures in canyons in mountainous areas. Large viaducts are usually not constructed to mitigate road effects on wildlife and the environment, but due to the large span and clearance, they can function well as passage structures for many wildlife species. Viaducts may inflict a minimum disturbance to the habitats and vegetation types and structures under and adjacent to the structure, and preserve existing wildlife corridors under the bridge.

The use and effectiveness of large viaducts as passageways for bats has not been examined in many studies, but it is assumed to be high for many species. Viaducts with high clearance may provide optimal opportunities for a large range of functionally diverse bat species to cross under the structure. Bats' use of short and low open-span bridges may be restricted for open-air species as with tunnels and culverts, but the effectiveness of river bridges is higher than tunnels and culverts (Abbott et al. 2012a). To lower road-kill rates, low river bridges can be combined with screens along the road margins to increase the proportion of bats that fly under the road or over the road at height above the traffic (Cichocki 2015).

As viaducts and river bridges minimize the disturbance to habitats and wildlife corridors in the valleys, they are preferable to infrastructures on embankments across the valleys and lowlands.

2.2 Other measures to divert, deter and reduce barrier effect

A variety of other interventions have been implemented to reduce the detrimental effects of roads on bats, e.g. reducing habitat degradation and fragmentation due to light and noise pollution, and measures that aim to reduce road mortalities or to divert bats to safe crossing sites.
Measures that deter or divert bats away from the road may reduce traffic mortalities, but if successful, increase the barrier effect of the infrastructure. Therefore, they should only be used in combination with measures that provide safe crossing sites for the bats. Noise barrier screens installed to reduce disturbance of humans may also function as barriers and guidance structures for bats.

2.2.1 Artificial lighting

Artificial lighting may cause strong avoidance behaviour by bats (Blake et al.1994, Stone et al. 2015, Rowse et al. 2016). The light can induce barriers in commuting routes, degrade foraging habitats and cause bats to abandon the roost sites. Bats may avoid lit areas to reduce the predation risk. The effects of lights vary between species, with light intensity and spectral content. In particular slow-flying, clutter-adapted species from the *Rhinolophus*, *Plecotus* and *Myotis* genera are most photophobic (Kuijper et al. 2008, Stone et al. 2009), while other species seem to be less sensitive to lights, e.g. *Pipistrellus*, *Eptersicus* and *Nyctalus* bats. This latter group of bats are often observed foraging on the abundant insect aggregations around street lights (Blake et al. 1994, Rydell & Baagøe 1996).

Several interventions to manage artificial lighting schemes have been tested to mitigate road impacts: deterrence with light, modification of light spectrum or intensity, reduced light spill into bat habitats, dynamic lighting systems, part-night street lighting, and restricted lightings in multifunctional passages.

Light deterrence

Strong white lights have been employed to reduce road mortalities of bats. The strong lights were placed on the road verges to deter the bats from attempting to cross the road at the site (Wray et al. 2006, Pickard 2014).
The avoidance behaviour may also guide the bats to safe crossing sites by installing strong street lights at road sections next to fauna passages for bats and under wildlife overpass to prevent foraging activity close to the road surface under the bridge (Nowicki et al. 2016).
Strong avoidance of bats to artificial lights has been well described, but the effectiveness of light as a deterrence to reduce road mortalities has not been documented.

Adaptation of light spectrum

Amber coloured light is less visible and more tolerable to bats than white light (Limpens et al. 2012, Rowse et al. 2016). Street lights with narrowband LED amber spectrum have been installed as mitigation to reduce the impact of light pollution and the barrier effect of lit roads (Fure 2012, V. Loehr pers. comm.).
Insects are attracted to lights emitting an ultraviolet component (Rowse et al. 2016). Some bat species will opportunistically forage on the insects attracted to the street lights putting the bats at high risk of collisions with vehicles (Blake et al. 1994). Street lights with a low UV-spectral component have been installed roads as a road mitigation measure to reduce the mortality risk for bats (G. Apoznański, pers. comm.).
The effectiveness of amber coloured lights to reduce the barrier effect of roads and low-UV lighting to reduction in traffic mortalities of bats has not been documented.

Reducing general light pollution

Light spill from roads into adjacent habitats may degrade their quality for bats. Light pollution can be reduced by low level, directional lighting focusing it towards the road surface only, or by reducing light intensity. Simple measures such as installing hoods or cowls on lamps may further minimise the spillage of light into areas used by bats.
Managing the period with artificial lighting has also been suggested as an option to reduce the light disturbance of bats. Dynamic lighting systems controlled by motion sensors may reduce light disturbance to periods when pedestrians or cyclists are present on a road or a path. Part-night lightning has also been proposed as a management option to mitigate road impacts on bats (Day et al. 2016). To be effective, the part-night lighting schemes should maintain dark conditions during the peak activity periods of the bats at dusk and dawn.

Restricting lighting in potential crossing structures could increase their effectiveness as passages for bats, e.g. tunnels, culverts and overbridges for pedestrians and cyclists. The light disturbance and the lit area in the passage could be reduced by reducing light intensity in the passages, by installing the lights on short poles or on the handrails, and by directing and focusing the light to create a dark corridor thorough the underpasses (Fure 2012, V. Loehr pers. comm.). Amber lights in multifunctional passages may also cause less avoidance behaviours by bats.

2.2.2 Noise

Road traffic is an important source of noise pollution, and traffic noise reduces foraging efficiency for bats (Schaub et al. 2008, Siemers & Schaub 2011, Luo et al. 2015). The search time to catch a prey for gleaning bats is more than twice as long when the bats are exposed to noise equivalent to the traffic noise levels more than 500m from roads (Bunkley & Barber

2015). The traffic noise does not mask the echoes from the prey for echolocating bats, but the noise seems to act as an aversive stimulus that causes an avoidance response by bats (Luo et al. 2015). Hibernating bats are sensitive to noise disturbances, and they may also respond to traffic noise (Luo et al. 2014).

Reducing noise pollution

Noise reduction should be considered when large roads are located near important roosting habitats and fauna passages to enhance their effectiveness for bats. Reduction of traffic noise disturbance can be achieved with noise abatement asphalt and noise barrier screens (Almenar & Ciscar 2012, Cichocki 2015).
Barrier screens installed at road sections over underpasses may simultaneously reduce the noise and light disturbance of bats and other wildlife in the corridor towards the passages. The screens may also increase flight height for those bats that attempt to cross over the roads up above traffic height. Noise abatement is intuitively beneficial for bats but the effectiveness has not been evaluated.

Noise deterrence

The avoidance behaviour of bats to sonic and ultrasonic noises has been used to deter bats from roosting sites in buildings and on wind turbines.
An audible warning system aiming to deter bats away from roads when the collision risk is high has been tested on road sections with a high number of crossing *Rhinolophus ferrumequinum* (ChiroMed 2014). The audible warning system comprises of short sections of asphalt which generate near-ultrasonic noise when a vehicle passes. The length of the specially coated stretch, the distance between these stretches and bat crossing site, and the speed of the approaching vehicle determine the time provided for the bats to respond.
The initial results of the systems are promising, but the audible warning system has not been thoroughly evaluated to assess the methods effectiveness, potential differences between species, vehicle speeds and habituation.

2.2.3 Hedgerows, treelines and fences

Many bat species often use linear and longitudinal landscape elements such as hedgerows, trees, rivers or streams, stone walls and forest edges as flight paths. Woodland species and small low- and medium flying generalist species are more dependent on such features than large fast-flying bat species.

Planting of new hedgerow and treelines have been suggested as a method to divert bats away from unmitigated road sections and guide the bats towards safe crossing sites (Limpens et al. 2005, Billington 2013, NACHTactiv & SWILD 2014). Linking fauna passages and existing commuting routes and habitats with new corridor habitats may also create a funnelling effect and increase the effectiveness of the passages.

Barrier screens and fences are also installed to discourage bats from crossing over the road at sections over an underpass or at road sections adjacent to safe crossing points.

2.3 Ecological mitigation

Inevitably the negative impacts on bats and their habitats sometimes cannot be avoided or mitigated despite precautionary planning. Where valuable habitats and roost sites for bats are lost or degraded as a result of road development, ecological compensation could then be implemented to balance the impact at landscape or population scale. General habitat improvement and roosting conditions may also improve the overall resilience of bat populations to unmitigated effects of the road, e.g. mortality and landscape fragmentation.

2.3.1 Artificial roost sites and enhancement of existing sites

The availability of roosts can be a limiting factor in bat conservation. Optimal roosts provide shelter and optimal microclimatic conditions to reduce individual metabolic costs, harbouring hibernation and nursery colonies and may protect the bats from predators. Road developments often result in the destruction of trees and buildings used by bats as roost sites. Most bats show high fidelity to roost sites, and destruction of breeding and hibernation can pose a threat to local bat populations. Suitable microclimatic conditions are difficult to recreate in alternative roost sites, and it may take years for the bats to locate the new roost sites. Preservation and renovation of existing roost site structures near road infrastructures is advantageous to new installations.

Bat boxes

Installing bat boxes in trees and buildings is a quick, low-cost measure which has often been promoted as a method to compensate for roost site destruction (Korsten 2012, Rueegger 2016). There are numerous different models of bat boxes, but all box types are primarily used as temporary roost site. It often takes several years before they are regularly occupied and bat boxes are rarely used as maternity roosts or for hibernation. Most boxes needs to be maintained annually and renewed after a few years. Given the general low occupation rate and the low usage of bat boxes as maternity roost and hibernacula, bat boxes cannot be recommended as a compensatory measure (Nowicki et al. 2016, Rueegger 2016).

Bat houses, bridges and underground sites

Human-made structures can provide suitable roosting conditions for cave-roosting bat species, e.g. buildings, bridges and artificial underground sites such as tunnels and ice cellars (Marnell & Presetnik 2010). Construction of new roost structures and improvement conditions in existing roost structures may compensate for roost sites losses or increase the resilience of the populations. Careful management of internal microclimate conditions (temperature and humidity) and access routes (e.g. reduce predation risk and light disturbance) at existing roost sites may successfully improve roost site quality and increase colony size. Due to their larger size the climate inside is typically more stable than in the small bat boxes.

Bridges can be important roost structures for many bat species (e.g. Billington & Norman 1997, Pysarczuk & Reiter 2008). Small numbers of bats may roost in crevices in both old and modern bridges, but large maternity roosts and hibernacula are sometimes found in the abutment of large bridges. Occurrence of bat roost sites should be considered when renovating bridges. Maternity roosts and hibernacula in bridges have successfully been preserved during renovations of bridges (e.g. Sunier & Magnin 1997, Beck & Schelbert 1999). Roosting conditions were preserved or improved by maintaining access, retrofitting roost chambers with rough walls and managing humidity and air flow. Roost sites could be integrated in the design of new bridges near important bat habitats. Underground chambers and tunnels could be constructed in the earthwork of bridges and wildlife overpasses (Nowicki et al. 2016).

Preservation and renovation of existing roost site structures is advantageous to new installations and may have immediate effects. Purpose-built roost sites in new buildings, bridges and underground sites have obviously beneficial effects for bats as long-term compensation measures.

Enhancing occurrence of natural roost sites

Forestry and arboricultural procedures often lead to a loss of tree roosts for bats. Large, old trees with cavities or a potential for developing cavities are rare in managed woods. Tree retention and advancement of cavity development in large trees have been suggested as long-term strategy to compensate for roost site losses. Large broadleaved trees with cavities and trees with a high potential for natural cavities should be protected in a forest to secure a continuous recruitment of roost sites for bats and retain a more diverse forest structure. Natural cavities in trees develop very slowly. Cutting slits, drilling holes or enlarging natural hollows in trees could be applied to advance the development of potential roost sites.

2.3.2 Habitat improvement

Habitat creation and enhancement schemes are the only method to balance the effects of destruction and degradation of important bat habitats.

Compensatory measures to generate alternative feeding habitats with large volumes of insect food resources for the bats may include enhancement or creation of ponds and wetlands, planting of trees, hedgerows and woodlands, and modified management of grasslands and general land use. A more bat-friendly management may include simple actions such as allowing plants to flower before cutting, and the planting of flowering, insect-rich shrubs and trees. Creation and enhancements of linear corridor habitats may be located to increase connectivity between existing potential bat habitat patches in the landscape and to reduce the barrier effects of the road.

Habitat improvements are obviously positive interventions for the carrying capacity of bats in an area, but the scale of habitat compensation that is needed to compensate for the road impact is unknown. Enhanced and newly created habitat will take years to develop into high quality bat habitats and for the bats to find the new feeding grounds or roosting areas.

3 Bat mitigation on roads in Europe

3.1 Methods

The awareness of the detrimental effects that roads may have on bats and the conflict between bat conservation and transport infrastructures has increased significantly over the past decades. In order to develop more ecologically sustainable transport infrastructures, mitigation measures for bats have been integrated in road development projects in many countries.

A questionnaire survey and literature review was conducted to collect up-to-date information on bat mitigation measures and other potential beneficial road structures on roads across Europe. The survey included information on fauna passages and other mitigating measures constructed for bats primarily, multi-species fauna passages used by bats, multifunctional passages and technical road structures that might function as bat passages on roads.

The questionnaire also addressed monitoring and maintenance procedures, costs and risks associated with maintenance. The questionnaire was distributed to NRAs, bat researchers, consultants and organisations, e.g. representatives and experts in the Agreement on the Conservation of Populations of European Bats (EUROBATS), and BatLife-Europe.

The information on bat mitigation measures collected through the questionnaire was supplemented with a literature search in electronic reference databases. The literature review is conducted using the Web of Science, Scopus citation index, Google Scholar and Researchgate, and by scanning specialist bat journals, the web and reports.

We received information on bat mitigation measures from 30 countries. The alternative literature sources provided no information on bat mitigation measures in the remaining countries (Albania, Croatia, Finland and Lithuania).

Hedgerows, treelines, etc. severed by roads as hop-overs were only recorded as bat mitigation interventions if the vegetation had been managed or screens had been installed or any other measures had been adapted to increase the bats flight altitude across the road gap.

Structures (underpasses, road bridges and other structures) that had been constructed for other purposes than to facilitate bats' crossing of roads were not recorded as mitigation measures for bats even though the structures had been monitored and shown to function as passageways for bats. Finally, artificial roost site installations, enhancements or restorations of bat habitats were only recorded if they part of a road mitigation scheme.

3.2 Results

Bat mitigation and compensation measures have been implemented in road infrastructure schemes in approximately half of the European countries; in 14 of the 29 countries (figure 1). The mitigation efforts for bats are most widely established in Germany, France, the Netherlands and United Kingdom (table 2 and 3). Extensive mitigation schemes have also been applied in Ireland over the past two decades, and in more recent road development projects in Poland and Spain.

Bat gantries, hop-overs, modifications of overbridges, and a few tunnels and an overpass were constructed specifically for bats. Most other registered bat crossing structures were multifunctional passages which were adapted to improve their functionality for bats, e.g. oversized culverts for watercourses or enlarged multi-species tunnels. Diversion of bats to crossing structures by planting of guidance structures is practiced in most countries where bats are considered in road schemes.

Bat box schemes are widely used to compensate for destroyed roosts in trees. Adaptations of buildings and bridges to accommodate roosting bats are applied in many countries, but only in low numbers in each country compared to the use of bat boxes.

There is an increasing awareness of the need to integrate mitigation measures for bats in new road schemes in some of the countries where bat mitigation has not been applied. In some of these countries bat mitigation schemes are projected in new road developments, bat behaviour near roads is researched, usage of technical road structures and fauna passages constructed for other species by bats is surveyed, and national guidelines on bats and roads are in progress.

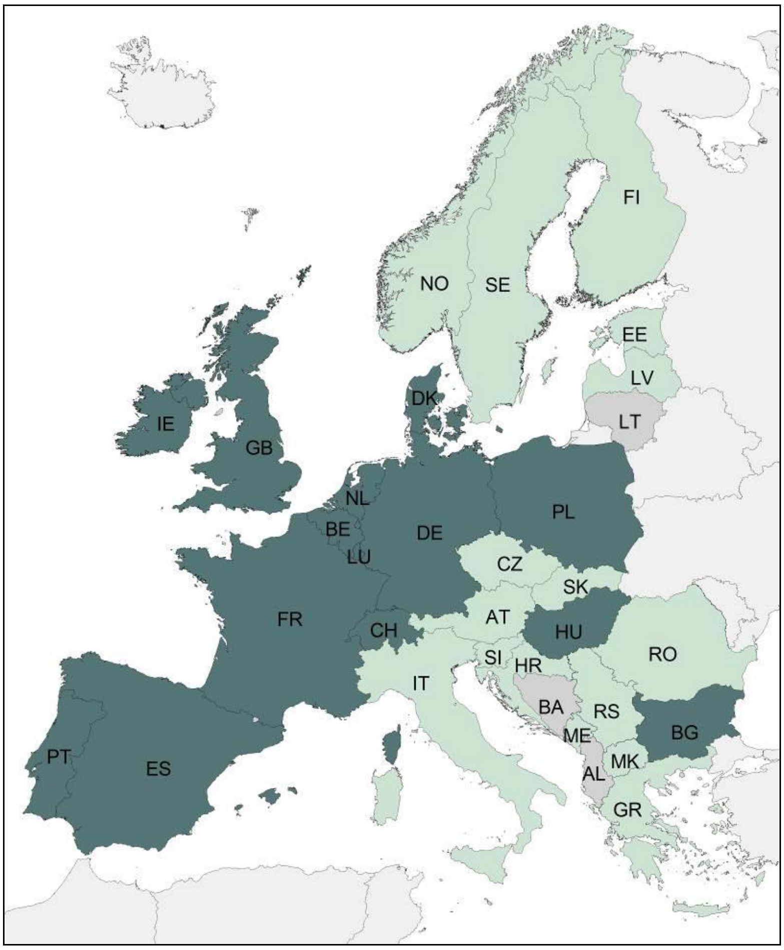

Figure 1 – Application of bat mitigation measure on roads. Dark blue: bat mitigation measures implemented on road schemes. Light blue: no bat mitigation measures in relation to roads. Grey: no information.

Table 2 - Interventions aiming to increase road permeability and reduce mortality for bats on road infrastructures that have been implemented in European countries. Some of the measures aim to mitigate road effects for a wider range of wildlife species. Brackets indicate that the structure is projected or under construction.

	Wildlife overpasses	Modified bridges	Bat gantries	Hop-overs	Viaducts & river bridges	Tunnels & Culverts	Hedgerows and treelines	Barrier screens	Light management	Noise management
Belgium	X					X				
Bulgaria							X			
Denmark						X		X		
France	X	X	X	X	X	X	X	X	X	X
Germany	X	X	X	X	X	X	X	X	X	
Hungary								X		
Ireland	(X)				X	X	X			
Luxembourg	(X)									
Netherlands	X		X	X	X	X	X	X	X	
Poland	X		X		X	X	X	X	X	
Portugal								X	X	
Spain	X					X	X	X	X	X
Switzerland						X		X		
United Kingdom	X	X	X	X	X	X	X	X	X	

Table 3 - Ecological compensation measures for bats on road infrastructures implemented in European countries.

	Bat boxes	Bat houses and under-ground sites	Tree trunk translocation	Tree retention	Modification of existing roosts	Roosting structures in bridges	Habitat enhancement
Belgium		X					
Denmark	X		X	X			
France	X	X			X	X	X
Germany	X	X			X	X	X
Hungary	X						
Ireland	X	X					X
Netherlands	X	X	X		X	X	X
Portugal	X					X	
Switzerland	X					X	
United Kingdom	X	X		X	X	X	X

3.2.1 *Austria*

Bat mitigation and compensation	None
Monitoring	Two recent surveys of bats use of road overbridges, a wildlife overpass, and river underpasses Regional survey of bat roosting in bridges
Maintenance	Not applicable

Bat mitigation and compensation

No specific bat mitigating measures have been implemented on roads in Austria (E. Hahn, pers. comm.). Several wildlife overpasses constructed for larger terrestrial mammal, viaduct bridges and river tunnels offers bats safe crossing points on major roads (e.g. Ransmayr et al. 2014a, 2014b).

Monitoring

Bats' use of road overbridges, underpasses and a new wildlife overpasses built for other purposes than facilitating safe crossings for bats was studied by Ransmayr et al. (2014a, 2014b).

The use of road bridges as roosting sites have been recorded in some regions of Austria (Freitag & Friedrich 1996, Pysarczuk 2004, Pysarczuk & Reiter 2008). *Rhinolophus hipposideros* and *Myotis daubentonii* maternity roosts were recorded in the bridges.

3.2.2 *Belgium*

Bat mitigation and compensation	Wildlife overpasses primarily constructed for other species, but also bats Tunnel for bats and other small mammals Artificial underground sites constructed in relation to a road and an overpass
Monitoring	Repeated surveys of bat use of wildlife overpasses over several years
Maintenance	No information

Bat mitigation and compensation

Four multi-species wildlife overpasses constructed across the motorways and a national road to provide safe passageways for bats and other wildlife species (Lambrechts et al. 2007, 2008, Moelants et al. 2012, Emond et al. 2015). An underground roost sites for bats is integrated in one of the wildlife overpasses.

Two multispecies underpasses for bats and other small mammals, and an underground roost site have been constructed under the bypass road near Couvin (T. Kervyn pers. comm.).

A defragmentation programme for the Sonian Forest near Brussels is presently in development (Kuijsters et al. 2014, www.sonianforest.be). The programme will include a wildlife overpass, four gantries and three underpasses to provide safe passageways for wildlife species including bats.

Monitoring

A series of repeated surveys has recorded bat on the two wildlife overpasses over several years (Lambrechts et al. 2007, 2008, 2010, 2011, 2013, 2014). Bats' use of the overpass at E19 has been surveyed once (Emond et al. 2015).

Willems (2014) surveyed bat activity in relation to roads and watercourses in southern Limbourg. The study recorded bats use of underpasses for roads, watercourses and cyclist and road overbridges.

3.2.3 Bulgaria

Bat mitigation and compensation	Planting of trees to divert bats to a safe crossing site
Monitoring	None
Maintenance	Not applicable

Guidelines for impact assessment of development projects on bats, including of road infrastructures, and mitigation measures have been published by the National Museum of Natural History at the Bulgarian Academy of Science, the Romanian Bat Protection Association and the Dutch Mammal Study and Protection Society (Petrov 2008).

Bat habitats and mitigation of effects of roads are considered in the planning process for new road projects. The main strategy is avoiding important bat sites (A. Hubancheva, pers. comm.).

The only example of bat mitigation intervention in relation to road development was planting of trees and shrubs to divert the bats to safer crossing points which were not purpose-built for bats. Unfortunately, all the planted saplings have since died.

3.2.4 Croatia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific mitigating measures for bats have been constructed on roads in Croatia (D. Hamidović, pers. comm.).

Many wildlife overpasses constructed for larger terrestrial mammal and viaduct bridges in mountainous areas also provide bats with safe crossing points on new motorways in Croatia.

3.2.5 Czech Republic

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific mitigating measures for bats have been implemented on road infrastructures in the Czech Republic (M. Andreas, pers. comm.).

Many fauna passages constructed for larger terrestrial mammals on new motorways in recent years may also benefit bats.

3.2.6 Denmark

Bat mitigation and compensation	Artificial roost sites, tree trunk translocation, screens on road over river culvert
Monitoring	Short-term studies of bat usage of wildlife overpasses primarily constructed for other species Research study of effectiveness of culverts and occupancy rate of bat boxes
Maintenance	No information

The Danish Road Directorate published guidelines on bat mitigation on road infrastructures in 2011 (Møller & Baagøe 2011).

Bat mitigation and compensation

No specific bat passages have been constructed at roads in Denmark, but measures to deter and compensate for potential roost loss have been applied.

Short barrier screens have been installed over a low river culvert in a motorway improvement project (M. Ujvári, pers. comm.).
A single roosting structure was installed in the ceiling of a long, oversized culvert for a watercourse where a motorway crosses a river valley on an embankment (Jeppesen et al. 1998). The culvert was constructed as fauna passage for medium-sized mammals. Bat boxes have been provided as replacement roost sites on two road and a railway schemes which are presently in development (Christensen 2015).
Tree trunks with existing roosts or natural cavities were relocated to preserve potential roost sites in a new motorway development project (JD Møller, pers. comm.). Translocation of tree trunks is planned for another two road development schemes (M. Ujvári, pers. comm.).
Tree retention in forest to conserve potential suitable large trees as roost sites has been implemented as compensation for destroyed large trees with potential roosts sites in relation to a railway development project (M. Ujvári, pers. comm.).

Monitoring

Two short-term studies have examined bats' use of wildlife overpasses and the effectiveness of river culverts as passages for bats. Bat activity was recorded on three narrow wildlife overpasses, which had been constructed for medium-sized and large mammals (Elmeros et al. 2011). The effectiveness of two box culverts for watercourses under an old motorway as bat passageways was examined acoustically and by direct observation (Møller et al. 2014). The underpasses were not constructed to facilitate bats a safe crossing corridors and no pre-construction data were available for comparison.

The occupation rates of bat boxes put up in relation to two road projects was monitored 2013 and 2014 (Christensen 2015). Five different box types and the occupancy rate in relation to distance to roads were assessed.

3.2.7 Estonia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No special mitigation measures have been targeted for bats in Estonia (V. Lükk, pers. comm.). A wildlife overpass for large mammals and bats, guiding fences and vegetation as well as an artificial underground roost site were projected for new national road which was assessed as a major barrier for bats. The project was cancelled late in the planning phase.

3.2.8 Finland

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

Bats are surveyed in bigger road projects, but no mitigation measures have been constructed for bats in Finland (E.-M. Kyheröinen, pers. comm.). Bats have been monitored for several years after the construction on a recent road improvement project to assess impact of the road.

3.2.9 France

Bat mitigation and compensation	Viaduct bridges, underpasses, modified road bridges, bat gantries, hop-overs, plantings, noise barriers screens, light adaptation, acoustic warning system, artificial over- and underground roosting sites, enhancement of buildings for roosts and habitat improvement, plus several wildlife overpasses
Monitoring	Mainly short-term surveys of bats' use of single mitigation and compensation measures. Bat mitigation measures monitored in Bourges over several years. A two-year monitoring project of new mitigation measures on A89. This study is to be continued.
Maintenance	No information

SETRA published guidelines and a critical evaluation of bat mitigation measures on roads in 2008 (Nowicki et al. 2008). Updated guidelines were published by CEREMA in 2016 (Nowicki et al. 2016).

Bat mitigation and compensation

Numerous road schemes have included tunnels and culverts as crossing structures for multiple species including bats (Nowicki et al. 2016, S. Roué and O. Tasse, pers. comm.). Many wildlife overpasses constructed primarily for large mammals and viaducts also function as safe bat crossing sites. Some overbridges for minor road or agricultural tracks have been adapted to enhance their use as crossing structures for bats over both motorways and railways. Adaptations to the overbridges include narrow green verges and screens on the sides of the bridge or installation of panels or a dense railing (Burette 2013, ChiroMed 2014).

Three bat gantries are constructed on the A65 and A89 motorways (Naturalia Environnement & FRAPNA 2015, M. Gest pers. comm.). The mitigation schemes on those roads also include hop-overs comprising of earth ramps and vegetation (Naturalia Environnement & FRAPNA 2015, Nowicki et al. 2016). An experimental audible warning system have been created to deter bats from crossing the road when there is a high risk of vehicle collisions at two sites (ChiroMed 2014).

Hedgerows and trees are regularly planted to divert bats to safe crossing and link fauna passages to existing bat commuting routs (Nowicki et al. 2016, O. Tasse, pers. comm.).. Planting of forests and creations of wetlands is also implemented as replacement of lost and degraded habitats.

Noise and barrier screens are often installed on road sections over underpasses to reduce noise disturbance in the corridor leading up to the underpass. Disturbance of bat habitats from street lighting are mitigated by installation of directional lighting, reduced number of lamps on the road and modification of the light spectrum. Vegetation has also been used to screen light from industrial areas (Nowicki et al. 2016, S. Roué, pers. comm.).

Implemented bat interventions in road and railway schemes have also included enhancements of roosting conditions in existing buildings, adaptations to bridge structures to function as roosting sties for bat, and the creation of bat house and underground roost sites and hibernacula e.g. in bridge abutment. Bat boxes have been widely used to provide additional roosting structures in bridges and underpasses. Bat boxes are not generally recommended as compensation for destroyed roost sites during construction (Nowicki et al. 2016).

Temporary fences are erected to maintain bat flight paths during construction phase and until planted hedgerows/treelines have developed. A simple temporary gantry has been installed across a road cutting until the planned overpass has been constructed (Pouchelle 2016).

Several mitigating interventions for bats have been implemented in recent developments of high-speed railway lines.

Monitoring

Many short-term studies have examined the performance of individual crossing structures in France.

Bats' use of mitigation measures have been monitored irregularly in specific surveys, e.g.:
Eighteen crossing points (ten overpasses, seven underpasses and a large river bridge) on motorways and county roads were monitored over three years to assess the effectiveness of these structures and investigate the behaviour of bats in the vicinity of infrastructures (Cavailhes & Tapiero 2012).
Arthur et al. (2010) recorded bats' use of a wildlife overpass, culverts, road tunnel and hedgerows/treelines.
Biotope (2009, 2010 in litt. Nowicki et al. 2016) surveyed more than 85 underpasses (comprising small culverts to river bridges), and LPO (La Ligue de protection des oiseaux) recorded the effects of erecting fences along the road over a small underpass. In a series of studies Arthur and co-workers have monitored the development of bats' use of a modified

road overbridge and connecting fences and hedgerows near Bourges (Lemaire et al 2006, Arthur et al. 2010, Burette 2013).

The bat activity and use of mitigation measures on the A89 motorway have been surveyed over two years (Naturalia Environnement & FRAPNA 2015, 2016). Further studies of the effectiveness of the measures are in progress (F. Claireau, pers. comm.).

Two studies have described bat flight patterns and use of a permanent and a temporary gantry (Tasse & Pouchelle 2014, Pouchelle 2016), and ChiroMed (2014) carried out a short-term study of bats behaviour at two road sections with two experimental installations (an audible warning system and a modified bridge) and at a river bridge.

Usage of bridges as roosting sites by bats has been recorded in many regional studies (e.g. Rolandez & Pont 1986, Ouvrard et al. 2006, Cornut & Firard-Claudon 2013). Recommendation to protect bats in bridges during renovation and installation of bat boxes in bridges has been described by Chamarat (1999), Lemaire & Arthur (2002) and Ouvrard (2013).

Monitoring reports are often confidential and have not published by the developer in France.

3.2.10 Germany

Bat mitigation and compensation	Many multifunctional overpasses, viaducts and smaller underpasses for bats. Focussed bat mitigation: modified bridges, noise, light and barriers screens, bat gantries, hop-overs, adaptations to buildings and bridges with roosts and artificial underground roost site, planting and habitat improvements
Monitoring	Long-term monitoring of a comprehensive mitigation scheme in an area with *Rhinolophus hipposideros* population Systematic evaluations of mitigation schemes on new major roads. Early systematic studies of bats' use of wildlife overpasses and underpasses.
Maintenance	No information

Guidelines for road development and protection of bats were published in 2008 by the state of Sachsen (Brinkmann et al. 2008). These guidelines have since been updated with new knowledge (Brinkmann et al. 2012). Other states have published separate guidelines on bat mitigation and road (e.g. Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein 2011).

Bundesministers für Verkehr initiated a comprehensive research project on quantification and management of traffic-related effects on pat populations in 2004 (Siemers et al. 2007, Kerth & Melber 2009, Siemers & Schaub 2011, Lüttmann et al. 2014).

Bat mitigation and compensation

A comprehensive mitigation scheme has been implemented on the BAB17 and S170n roads in Sachsen to protect a *Rhinolophus hipposideros* population. The mitigation scheme includes a wildlife overpass, six modified bridges, a river bridge, six culverts, barrier fences, light deterrence near overpasses, extensive planting of hedgerows and adaptation to existing buildings with roosts.

Generally, tunnels, culverts and small river bridge are constructed or adapted to accommodate bats on numerous road schemes if relevant, e.g. nine multispecies tunnels have been installed on a 2 km long stretch of motorway between two Natura2000 designated forests on the BAB4 (Dietz et al 2016). The mitigation on that section also included a wildlife overpass and 350 m fences intended as a hop-over.

Overall, more than 60 wildlife overpasses have been constructed across Germany. These overpasses are planted with woody vegetation and if located near forest and other bat habitats, the overpasses will facilitate bats to cross safely over the infrastructures (Bach & Müller-Stieß 2005). Two bat gantries have been constructed over a local road in Baden-Württemberg (http://www.badische-zeitung.de, 25/07/2014).

Fences and screens are widely used on road sections to prevent bats' access to the road, as guidance crossing sites or to function as hop-overs. Planted hedgerows and trees are regularly used to guide bats to safe crossing sites as well. Screens on the central reservation are installed on some sections of wide motorways when the screens are aimed to function as a hop-over (Lüttmann 2012, 2013). Opaque noise barrier screens are used to prevent light spillage to neighbouring habitats.

Fences screens are erected on roads over existing and new underpasses as an encouragement for the bats to fly under the road or high above the traffic. The fences on the underpasses are typically 3 m high and extend 20 m from the outer edges of the underpass (C. Steck, pers. comm.).

Modifications and adaptations to buildings with existing roosts and replacement underground roost sites have been implemented as replacement roosts in relation to a few road developments, (e.g. http://www.saarland.de, 20/02/2014). Adaptations and enhancements of roosting conditions in bridges during maintenance and renovations are well-established intervention to protect bat populations (e.g. Häussler et al. 1997, Hartman & Herold 2010, Harrje 2015).

Monitoring

A long-term monitoring project was implemented to monitor the performance of a comprehensive mitigation scheme on BAB17 (10 years) and S170n (7 years) (NACHTactive & SWILD 2006, 2014). The monitoring programme comprised of permanent acoustical recording from April to October in some mitigation structures, and intensive monitoring of some structures to understand bat flight behaviour near passages with thermographic cameras and ultrasound detectors. Concurrently, the colony size in the maternity roosts and six reference colonies are monitored annually (NACHTactive & SWILD 2014). Comprehensive pre-construction studies including radio-tracking studies were carried out to identify foraging habitats and flight routes near and across the projected road corridors.

Many major road projects are monitored one, four and seven years after construction (U.Tegethof and J. Lüttmann, pers. comm.). The methods typically include acoustic monitoring at fauna passages, radio-telemetry studies and occasionally mist netting to identify occurrence of cryptic bat species.
An extensive monitoring programme was initiated in 2015 on a new section of BAB4 (Dietz et al. 2016). The monitoring included mist netting, automatic acoustic recordings in crossing structures, acoustic and visual observations of bats crossing the road and radio-telemetry to describe crossing patterns. The survey is to be repeated on the fourth and the seventh years after the motorway was opening to traffic.

Further post-construction studies are on-going at a wildlife overpass and reference sites on BAB27, and road overbridges and multifunctional underpasses on BAB5 (L. Bach and C. Steck, pers. comm.). Monitored with acoustic detectors and night vision devises once a month from May to September. Mist netting is.

Some of the first studies that examined bats' use of wildlife overpasses, tunnels and road overbridges were performed by Bach et al. (2004) and Bach & Müller-Stieß (2005) on passage structures constructed to facilitate safe crossings for other wildlife species than bats.

Several research studies and student studies on bat behaviour, effects of roads and fauna passages and other potential crossing constructions have been carried out (Lüttmann et al. 2001, Kerth & Melber 2009, Furthmann 2014, Biedermann et al. 2015, Locke 2015)

There are numerous studies on bats use of bridges as roost sites (e.g. Koettnitz & Heuser 1994, Walter 2001). Guidelines for protection of roost sites for bats when renovating bats have been published by Dietz (2001). Considerations to conservation of bats during bridge maintenance and renovations are well-established (e.g. Häussler et al. 1997, Hartman & Herold 2010, Harrje 2015).

Many monitoring reports are confidential and have not published by the developer in Germany.

3.2.11 Greece

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific bat mitigating measures have been implemented on road infrastructures in Greece (E. Papadatou and L. Georgiadis, pers. comm.).

3.2.12 Hungary

Bat mitigation and compensation	Screens and artificial roosting sites
Monitoring	None
Maintenance	No information

Screens have been installed on many motorway stretches targeted at restricting birds' access to the road. These screens are also promoted as mitigating measures for bats to reduce collision risk (Z. Bihari, pers. comm.). Bat boxes have been installed in a road bridge on new motorways.

Wildlife overpasses and underpasses constructed for larger terrestrial mammals on new motorways in recent years may also benefit bats.

3.2.13 Ireland

Bat mitigation and compensation	River bridges, tunnels and culverts, planting hedgerows/treelines, artificial roost sites and improvement of existing roosting buildings and habitat enhancement. A wildlife overpass for bats is under construction
Monitoring	Detailed research study on bats use of multifunctional and technical road structures as crossing structures Monitoring of colony size in bat house Several regional surveys of bat roosting in bridges
Maintenance	No information on crossing structures

The Irish National Road Authority (now Transport Infrastructure Ireland) published two guideline documents on bats in 2006 on road development and bat mitigation (National Roads Authority 2006a, 2006b, 2008).

Bat mitigation and compensation

Two large underpasses to facilitate safe crossings for bats have been constructed under the M6 motorway (www.rpsgroup.com). A wildlife overpass purpose-built to maintain landscape connectivity for *Rhinolophus hipposideros* is presently under construction on the N17/N18 motorway (O’Malley pers. comm.).

Two buildings have been renovated and adapted specifically to create optimal roosting conditions for *Rhinolophus hipposideros* on the N18 road scheme (Abbott 2012, O’Malley pers. comm.). The buildings were modified to replace a building that housed a breeding roost, which had to be demolished (National Roads Authority 2008, Abbott 2012). Along selected sections of the same road scheme, hedgerows and trees were planted as new flight corridors to connect suitable habitats and divert the bats away from the road.

Bat boxes have been installed in the vicinity of several road development schemes to provide replacement roosts where trees have been removed (Aughney 2008b, Abbott 2012). For some projects the bat boxes mentioned in the environmental impact statement appear not to have been erected (Abbott 2012).

Temporary gantries were created at crossing points for *Rhinolophus hipposideros* as mitigation for a single carriageway road widening scheme (Highways Agency 2006). The gantries were intended as temporary measure until road side trees had created a closed canopy cover over the road.

Monitoring

Bat behaviour on potential crossing structures (underpasses constructed for drainage, river bridges, road overbridges and severed hedgerows) was studied on the M18 motorway (Abbott et al. 2012a, Abbott et al. 2012b).

Colony size is monitored in the buildings specially adapted and preserved as *Rhinolophus hipposideros* roost sites on the N18 road scheme (Abbott 2012, O’Malley pers. comm.).

Bat Conservation Ireland inspected bat boxes for 2-6 years in five road schemes where bat boxes were implemented to mitigate the impact of the road construction (Aughney 2008b).

Several regional studies of bridges usage by bats as roost sites have been completed (Smiddy 1991, Shiel 1999, Keeley 2003, 2007, Aughney 2008a, Dixon et al.2008, Masterson et al. 2008). The surveyed bridges were primarily old bridges on small roads.

3.2.14 Italy

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No bat mitigating measures have been adopted on roads specifically in Italy (A. Alonzi, pers. comm.).

3.2.15 Latvia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No mitigating measures have been implemented on roads specifically for bats in the Latvia (G. Pētersons, pers. comm.).

3.2.16 Luxembourg

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific bat mitigating measures have been implemented on roads in Luxembourg at present (G Biver, pers. comm.). A wildlife overpass aimed at maintaining landscape connectivity for bats and European wildcats is projected for a new road and railway infrastructure scheme.

3.2.17 Macedonia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific mitigating measures for bats have been applied on roads in the Macedonia (M. Branko, pers. comm.).

3.2.18 Netherlands

Bat mitigation and compensation	Hop-overs, a gantry, adaptations of underpasses, plantings, modification of street lighting, light and barriers screens, adaptations to underpasses, underground sites and a bridge to accommodate roosting bats and habitat enhancement. Many wildlife overpasses constructed for other species.
Monitoring	Several short-term evaluations of performance of single mitigation measures. Research and student studies of bats 'use of structures constructed for other purposes than wildlife mitigation and evaluations of specific measures, e.g. light adaptations
Maintenance	Dedicated maintenance handbook for fauna passages and wildlife guidance vegetation.

The Ministry of Infrastructure and the Environment published guidelines for bats and roads in collaboration with the Dutch Mammal Society in 2005 (Limpens et al. 2005).

Bat mitigation and compensation

Numerous wildlife overpasses (+40) have been constructed across major road and railways in the Netherlands. The primary aim for these overpasses is to defragment the landscape for other wildlife species, but the overpasses also facilitate bats to cross safely over the infrastructures.

Other bat crossing structures employed on roads include small river bridge, adaptations of tunnels and culverts and a single experimental bat gantry (V. Loehr and H. Limpens, pers. comm.). At many road severances, large trees close to the road are protected during the construction phase to function as hop-over. New hedgerows and treelines are regularly planted to divert bats to safe crossing sites or to function as hop-overs. If possible, trees are maintained on the central reservation on wide dual-lane roads to encourage the bats to maintain the flight height. Alternatively, poles are erected on the central reservation.

Adaptations of street lighting have been widely implemented as a mitigation measure in several road projects to reduce light spillage to reduce disturbance of bat flight corridors and foraging habitats (V. Loehr, pers. comm.):
- directional lighting in multifunctional passages to increase their potential as crossing structures for bats,
- reducing the height of the lighting poles near crossing sites,
- temporary lighting and hoods on the lamps to direct light during the construction phase,
- use of amber coloured street lighting,
- dynamic lighting systems which only switch on when there is bicycles or pedestrians on the road,
- noise barriers with an opaque lower half to block light pollution from vehicles in adjacent bat foraging habitats.

Bat boxes and other artificial roost sites have been erected as compensation for roost site losses during road development or to provide additional resting sites (P. Twisk and V. Loehr, pers. comm.). Adaptations to accommodate bats have been installed in underpasses and manholes in road constructions to improve their functionality as roosting sites for bats. A new bridge across a canal has been specifically designed to provide ample cavities and crevices for roosting bats (http://www.dearchitect.nl/projecten/2015/detail/vlotwateringbrug/vlotwateringbrug.html). New feeding habitats or improvement of existing habitats are also integrated in road development schemes.

Temporary screens have been used in some road developments to maintain bat flight paths and divert bats to safe crossing sites (http://www.dewoudklank.nl, V. Loehr, pers. comm.).

Monitoring

Many studies have examined bat use of mitigation measures and other road structures constructed for other purposes and species, e.g. multifunctional underpasses and wildlife overpasses (e.g. Schut et al. 2011, Emond et al. 2014a, 2014b, 2014c, 2015, Prescher 2014). Most of these studies have been short-term descriptive surveys, but some mitigation schemes have been repeatedly surveyed to monitor the development of their performance (e.g. Brekelmans et al. 2011).

A bat box scheme on the N59 has been monitored systematically since it was established (2004/2005) (P. Twisk, pers. comm.), and the development of colony sizes in some artificial underground hibernacula constructed to compensate for a new motorway has been monitored annually from 2003-2010 (Heijligers 2011). Occupancy of other artificial roost sites and resting sites in road infrastructures is recorded on an irregularly basis.

Maintenance

The Dutch roads agency has developed specific maintenance handbook for fauna passages and guidance vegetation based on the intended ecological functionality (Ouden & Piepers 2008, Wansink et al. 2013), as well as other technical structures which potential mitigate road effects on bats (V. Loehr, pers. comm.). The handbook provides specific maintenance actions and inspection schedules.
The actual maintenance is outsourced to contractors. Maintenance of individual measures aimed at bats is not differentiated in these tenders.

3.2.19 Norway

Bat mitigation and compensation	None
Monitoring	Monitoring of roosting numbers during road development
Maintenance	Not applicable

No specific mitigating measures for bats have been constructed on roads in the Norway (J. van der Kooij and T.C. Michaelsen, pers. comm.).

A single project studying the effects of road development on bats has been reported. The study examined the occurrence of hibernating bats in a cave system while two new road tunnels were blasted through the same mountain (van der Kooij et al. 2011).

3.2.20 Poland

Bat mitigation and compensation	Bat gantries, fences, and barrier screens, plantings and adaptation of street lighting. Many multi-species over- and underpasses in bat habitats.
Monitoring	A 3-year study of bats use of gantries, other fauna passages, multi-functional and road overbridges and tunnels. A small study of bats use of bat gantries on another road Several regional survey of bat roosting in bridges
Maintenance	No specific information on bat mitigation measures

Bat mitigation and compensation

Lattice bat gantries have been constructed on two expressways S5 and S8 (Czerniak et al. 2013, J. Wojtowicz and G. Łutczyk, pers. comm.). A comprehensive wildlife mitigation scheme, including bat gantries, has been implemented on the A2 motorway traversing a forest area near a large hibernaculum (Cichocki 2015). The mitigation scheme includes several wildlife overpasses, tunnels, culverts and viaducts for larger mammals and bats.

Barrier screens have been installed on many sections of new motorways to reduce bats and birds the mortality risk. Screens are obligatory on road sections above culverts and river bridges where the watercourse function as bat commuting route (J. Cichocki, pers. comm.).

Specific street lighting with a low UV-content is installed on several roads. The aim is to reduce attraction of insects which would indirectly reduce bat mortality risk for species that may forage on the insect aggregations over the roads (G. Apoznański, pers. comm.).

Mitigation measures including wildlife overpasses and underpasses, including for bats, and barrier screens and a hop-over exclusively for bats are planned on developments of expressways (S3, S6, S7 and S19) and the A1 motorways.

Monitoring

A 3-year monitoring project has been conducted on the A2 motorway. Bat observations were conducted at the three gantries, at wildlife overpasses and tunnels for larger mammals, culverts and road/railway bridges (Cichocki 2015).

The effects of screens specially built as barriers for bats as well as acoustic screens to reduce noise pollution for humans are monitored on the A2 motorway and the S3 expressway (J. Cichocki, pers. comm.).

Czerniak et al. (2013) studied bat activity and flight routes near three newly installed bat gantries during one season on the S3 expressway.

Several smaller regional studies have examined occurrence of bats roosting in bridges (e.g. Ignaczak & Manias 2004, Gottfried & Gottfried 2014, Wojtaszyn et al. 2015).

Maintenance

The maintenance of roads including maintenance of bat mitigation structures is outsourced to subcontractors. There is no specific information on maintenance costs or procedures on bat mitigation measures specifically. Presently, the structures are all very new and still under warranty.

3.2.21 Portugal

Bat mitigation and compensation	Barrier screens, lighting restrictions, alternative roost sites and adaptations of bridges for bats
Monitoring	A survey of bat roosting in non-fauna tunnels
Maintenance	No information

Information on roads, bat mitigation measures and monitoring was provided by P. Barros, P. Gonçalves and C.G. Silva (pers. comm.).

Bat mitigation and compensation

The occurrence of bat roosting sites is detailed search along a corridor parallel to planned infrastructures. If bat roosts are recorded, barrier screens along the road, lighting restriction and fences on cave entrances are installed to reduce disturbance from the road and prevent human entrance to cave. Culverts on new roads near bat roosts are recommended to be minimum 3m in diameter to function as underpasses for bats. Alternative artificial roosting sites and adaptation of bridges for bats, tree planting and creating of alternative feeding sites have been suggested on some projects.

Monitoring

Barros (2014) studied usage of five underpasses constructed for farm-access under a national single-carriageway road. The underpasses were constructed eight years prior to the study.

Occurrence of bat roosts in bridges has been recorded by e.g. Rainho et al. (1998), Alves et al. (2008), Reis & Rufino (2012 and Amorim et al. (2013). Overall, 17 species have been registered to use bridges, including large colonies of *Tadarida teniotis*, *Pipistrellus* and *Eptesicus* species.

3.2.22 Romania

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

Guidelines on bats and impact assessments of development projects, including road infrastructures, and mitigation measures for bats were published by the Romanian Bats Protection Association in collaboration with the Dutch Society for the Study and Conservation of Mammals (Jére et al. 2008).

No specific bat mitigating measures have been constructed on roads in the Romania (A. Szodoray-Paradi, pers. comm.).

3.2.23 Serbia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

Guidelines on bats and impact assessments of development projects, including road infrastructures, and mitigation measures for bats were published in 2011 by the Wildlife Conservation Society “MUSTELA”, Natural History Museum and Ministry of Environment, Mining and Spatial Planning developed in collaboration with the Dutch Mammal Study and Protection Society (Paunović et al. 2011).

No specific mitigating measures for bats have been constructed on roads in the Serbia (B. Karapandza pers. comm.).

3.2.24 Slovakia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific mitigating measures for bats have been implemented on roads in Slovakia (P. Backor, pers. comm.). Wildlife overpasses constructed for larger terrestrial mammal on new motorways may provide safe crossing points for bats. Ceľuch & Ševčík (2008) studied road bridges as bat roosting sites in Slovakia.

3.2.25 Slovenia

Bat mitigation and compensation	None
Monitoring	None
Maintenance	Not applicable

No specific bat mitigating measures have been constructed on roads in the Slovenia (P. Presetnik and LS Pavlovič, pers. comm.).

Several wildlife overpasses constructed for larger terrestrial mammal, viaduct bridges and tunnels in mountainous areas may provide bats with safe crossing points on new motorways in Slovenia.

3.2.26 Spain

Bat mitigation and compensation	Overpasses, tunnels, viaduct, planting, fences, light restriction, noise screens and abatement asphalt
Monitoring	Detailed study of effectiveness of mitigation scheme on a motorway and a high-speed railway and monitoring of colony size in nearby caves Study of bat activity on wildlife overpasses
Maintenance	No information

Bat mitigation and compensation

There are only a few new, but very elaborate mitigation schemes specifically for bats. Other non-bat wildlife mitigation interventions, e.g. overpasses, are also beneficial for bats.

An elaborate mitigation scheme has been employed at the A-7 motorway near Alcoy where the road passes close to a large cave used by for four bat species. The mitigation scheme includes three narrow overpasses, a wire-mesh totally enclosing the road over ca. 250 m stretch, a multifunctional road underpass, a culvert, noise abatement asphalt, noise screens and planting of trees has been installed to mitigate the potential negative impact on roosting bats (Almenar & Alcayde 2011, Almenar & Ciscar 2012). Street lighting is reduced or eliminated near the overpasses to enhance their effectiveness as passageways for bats.

A 5-meter high and 110m long wire fence has been installed between two tunnel entrances on a high-speed railway track at a site in Andalucía near a cave with >2000 roosting bats (Flaquer et al. 2010). The fencing aims to prevent bats from crossing the railway at low altitudes and to divert bats to the tunnel entrances or a road underpass in the railway embankment.

Monitoring

The bat mitigation scheme on the A-7 motorway was monitored in 2011 and 2012 before and after the motorway was opened to traffic (Almenar & Alcayde 2011, Almenar & Ciscar 2012). Bat activity was monitored acoustically, with infrared cameras, radio-telemetry supplemented with road-kill surveys. Bat numbers was monitored by emergence counts from a local roost cave.

Flaquer et al. (2010) studied the effectiveness of wire fences on a high-speed railway and a road underpass under the railway embankment in 2009 and 2010. Bat numbers in the nearby cave is monitored to assess effects on population size.

Rosell et al. (2015, 2016) studied of bat activity at two wildlife overpasses and at a reference site in a wood clearing nearby.

In a research project, a colony of *Tadarida teniotis* roosting in a bridge was monitored for 13 years by Ibañez & Pérez-Jordá (1998).

3.2.27 Sweden

Bat mitigation and compensation	None
Monitoring	One recent research study of bats in relation to a motorway
Maintenance	Not applicable

No specific bat mitigating measures have been constructed on road infrastructures in Sweden (J. de Jong and A. Sjölund, pers. comm.).

The behaviour and habitat use by *Myotis brandtii* and *Myotis mystacinus* near a motorway in Central Sweden were studied acoustically and by radio-tracking (de Jong 2016). The study also recorded the bats' use of an overpass and road-underpasses.

3.2.28 Switzerland

Bat mitigation and compensation	River culvert, planting / management of vegetation, light restrictions, bat boxes, and protection and enhancement of roosting conditions in bridges
Monitoring	Emergence counts of bats in artificial roost sites on an irregular basis Monitoring of colony size, and microclimatic conditions following adaptation of bridge to bats.
Maintenance	No information

A guideline for road and bat mitigation is in progress in Switzerland (F. Bontadina, pers. comm.).

Bat mitigation and compensation

Bat boxes schemes or other artificial roost sites in bridges are used to compensate for potential impact of several road constructions (Beck & Schelbert 1999, C. Brossard and M. Flubacher, pers. comm.). The first once was initiated in 1996, but most are from the last decade.

A drainage culvert under a railway embankment has been scaled up to function as a passageway for bats. Hedgerows along the stream have been planted to guide the bats to the underpass (M. Flubacher, pers. comm.).

During renovation of a viaduct bridge at (Pont de Corbières) in Kanton Fribourg a breeding colony of *Myotis myotis* was recorded (Sunier & Magnin 1997). The bridge structure was adapted to preserve and enhance the roosting conditions.

Light pollution from roads is considered when new lamps are installed, and street lighting is adapted to reduce spillage into neighbouring habitats (C. Eicher pers. comm.).

Monitoring

The successes of some bat box schemes and of many of the bridges with artificial roost sites are monitored by emergence counts on irregular basis (e.g. Beck & Schelbert 1999).

The temperature, humidity and colony size was monitored for 4 years following the adaptation of a bridge structure to preserve the breeding colony in Pont de Corbères (Sunier & Magnin 1997).

Magnin (2007) recorded the occurrence of bats using a large modern viaduct bridge. The presence of five species was recorded.

3.2.29 United Kingdom

Bat mitigation and compensation	Two overpasses for bats, several bat gantries, tunnels and culverts, river bridges, barrier screens, modification to an overbridge, hop-over, planting, light restrictions, bat boxes, bat house and underground sites, adaptation of buildings with roosts and habitat improvement
Monitoring	Systematic evaluations of bat use of selected mitigation and compensation measures in major road schemes Long-term monitoring of a comprehensive mitigation scheme for a *Rhinolophus hipposideros* population Irregular surveys of use of crossing structures on minor roads Robust scientific studies of effectiveness of selected mitigation measures and road and railway effects on landscape scale
Maintenance	No information

The first set of design guidelines for bat conservation and mitigation interventions were released by the Highways Agency in an Interim Advice Note HA80/99 (Highways Agency 1999). Updated best practice recommendations and guidelines have since been published as the knowledge on bat biology, road effects and mitigation techniques improved (Highways Agency 2006, 2008, O'Connor & Green 2011).

A DEFRA (Department for Environment, Food & Rural Affairs) funded research project has recently developed and evaluated methods to monitor the effectiveness of mitigation measures and the effects of transport infrastructures on bats on landscape scale (Berthinussen & Altringham 2015).

Bat mitigation and compensation

Bat mitigation measures have been implemented in numerous road development schemes in United Kingdom in the past two decades (e.g. O'Connor & Green 2011, Highways England 2015 and individual road scheme evaluation reports). Most of the mitigation schemes include extensive use of bat boxes and planting of trees and hedgerows.

Provision of alternative roost sites to replace roosts where trees and other structures have been removed, have also included bat bricks in river bridges, cavities in bridge abutments, bat house, underground hibernation chambers and roosting sites, installation of heaters in existing roosts and removal of lighting on roost entrances in buildings.

Habitat enhancement measures are implemented in many road schemes for the benefit of bats and other species, e.g. creation of ponds, wetlands and species rich meadows as feeding habitats for bats. As part of road mitigation schemes grasslands are protected from future development projects to preserve feeding habitats, and management strategies for grasslands have been adapted to improve their value as feeding habitats for bats, e.g. allow plants to flower before cutting. Flowering shrubs and tree plants are also planted to enhance food resources for bats.

Tunnels, culverts and adaptations of multifunctional underpasses to accommodate bats are regularly installed, and bat gantries have been applied in eleven major road schemes and three local road projects. Two wildlife overpasses for bats and small number of modified bridges (adapted with panels, raised parapet on the railing or a single row of shrubs on both sides of an agricultural access road) have been prepared for bats (Pickard 2014, Bethinussen & Altringham 2015, Highways England 2015).

Light deterrence has been used along the A487 road in Wales and on the underside of the overpass at A21 in Kent (Pickard 2014). The overpass also carries a minor road which is closed during night. Light strategies at the entrance and in underpasses are allied to enhance their functionality as crossing sites for bats.

Woven wooden fencing is erected outside the entrance of underpasses to guide bats into tunnels and around the entrance as encouragement for the bats to use the underpass in some projects. Gilles have been installed in some underpasses to stop humans accessing other than for maintenance.

Temporary fences are regularly erected to maintain bat flight paths during construction phase and to guide bats to new safe crossing structures until planted hedgerows and treelines have developed (O'Connor & Green 2011, Pickard 2014). Simple temporary rope gantries have been reported from two road schemes (O'Connor & Green 2011).

During construction lighting strategies during construction are implement to minimise light spillage into areas used by bats (low level, directional lights and hoods or cowls on lamps), especially near roost areas and flight routes.

Monitoring

Bat mitigation and compensation measures are systematically monitored on major road schemes in England as part of the post operational project evaluation (POPE) (reviewed in O'Connor & Green 2011, Highways England 2015). The objective of POPE is to identify to which extent the impacts of road schemes, including bat mitigation measures, have materialised and improve future road schemes and assessment methods. In some road schemes bats use of selected crossing structures and bat boxes occupancy are monitored over 2-5 years (O'Connor & Green 2011, Highways England 2015). Surveys of bat activity at crossing structures were typically performed as acoustic surveys and direct observations. Extensive monitoring programmes have been implemented on road schemes in Wales (Billington 2013, Pickard 2014).

The monitoring have resulted in modifications to some mitigation measures to enhance their functionality for bats, e.g. bat house improvement and low level directional lighting and black painted underpass ceiling. Repeated surveys and extended monitoring (10 and 15 years) have been suggested to evaluate the long-term successes of the bat mitigation measure (Highways England 2015).

An comprehensive long-term post-construction monitoring scheme (2001-2013) was implemented to evaluate the performance and develop the mitigation scheme installed along A487 Llanwnda to Llanllyfni improvement which affects a Natura2000 area designated to protect one of the largest known colonies *Rhinolophus hipposideros* in UK (summarised in

Billington 2013, Pickard 2014). Based on the monitoring, a series of improvements and measures has been applied to reduce the risk of effects of the road. The monitoring comprised counts of *Rhinolophus hipposideros* numbers in 18 roosts, road mortalities, radio-tracking studies and monitoring of crossing sites. Road mortality was surveyed most years as daily dawn surveys from August until the first period with cold spells. Road crossing surveys were carried out between April-October with surveyors along the edge of the road. Surveyors equipped with ultrasound detectors typically observed bats for three hours after dusk. Some pre-sawn surveys were also carried out. Automatic acoustic monitoring was also used in a couple of underpasses to record bat crossings for a complete night. Radio-tracking was done in 2001, 2002 and 2004 to gain information on the foraging areas, flight routes and roosting sites of the bats.

Monitoring of the A465 and another A487 improvement scheme also considered population effects by monitoring numbers of *Rhinolophus hipposideros* bats in nearby maternity roosts (O´Connor & Green 2011).

Short surveys of individual mitigation structures have been carried out on smaller road schemes (e.g. Wray et al. 2006).

Parallel to these road scheme evaluation surveys, more robust scientific studies of the effectiveness of mitigation measures and the effects of transport infrastructures has been carried out (Berthinussen & Altringham 2012a, 2012b, Berthinussen & Altringham 2015).

Bats usage of primarily old bridges as roosting sites has been recorded in regional surveys (e.g. Roberts 1988, Billington & Norman 1997). Billington & Norman (1997) also included guidelines for assessment of bridges' potential as roosting structure. Monitoring guidelines and guidelines for maintenance or renovation of bridges taking the protection of bats colonies during into considerations have been published in Mitchell-Jones & McLeich (2004) and Bat Conservation Trust (2012).

4 Conclusions and Perspectives

Bat mitigation

Bat mitigation actions have been implemented on roads in 48% of 29 European countries. Germany, France, Ireland, the Netherlands and United Kingdom publish specific guidelines for bats and roads more than a decade ago, and implementation of bat mitigation is most widely applied in these countries. Extensive mitigation schemes have also been applied in more recent road projects in e.g. Poland and Spain.

There is an increasing awareness to integrate mitigation measures in new road schemes in most countries; bat mitigation is planned for new road schemes in countries where such actions have not been applied previously, and more intensive mitigation and monitoring schemes are implemented in the countries where the bat mitigation procedures are well established.

Measures that have been constructed specifically for bats comprise modified road overbridges, bat gantries, hop-overs, fencing, a small number of tunnels and a wildlife overpass, but most of the recorded bat crossing structures are multispecies or multifunctional passages that have been adapted also to facilitate bat crossings of roads, e.g. oversized culverts for watercourses, large wildlife tunnels and overpasses with dense woody vegetation. Bat boxes are widely used to compensate for destroyed roost trees in many countries. Adaptations of existing buildings and large bridges to accommodate roosting bats or purpose-built bat houses or caves are applied in some countries, but only in low numbers for very rare species.

Post-construction studies indicate that most of the mitigation actions may facilitate bat crossings and maintain existing roost sites. Long-term monitoring studies of a few comprehensive mitigation schemes have shown that it is feasible to neutralise the road impact on threatened bat populations.

Recommendations for road mitigation

- A precautionary approach is advised as the status of bat populations is very sensitive to increased mortality and landscape changes.
- Mitigation strategies should consider several aspects of road effects (mortality, road permeability, disturbance, barrier effect, degradation of habitat quality and roost site availability) to neutralise road impacts.
- Passages should conform to the local landscape and existing flight paths.
- Passages and guiding structures should be in place and operative well before existing habitats are destroyed and before the road opens to traffic to allow the bats to habituate to the measures.
- Establishing national databases of mitigating and compensatory interventions to promote better convergence and exchange of experiences between projects, and use as planning tools for maintenance and monitoring procedures.

Monitoring

Regular monitoring of mitigation measures is important to evaluate the performance of the structures and to accumulate knowledge to develop more effective mitigation strategies for future road projects. Post-construction studies are carried out in most countries to monitor and assess the performance of mitigation interventions, but most systematically in Germany, Ireland and the United Kingdom.

The majority of post- construction surveys in all countries are irregular short-term studies of selected measures. The surveys are often carried out shortly after road construction, i.e. before the bats may have fully habituated to the new structures and landscape changes, and before the planted vegetation have matured to effectively link traditional bat flight paths and fauna passages as intended. Two extensive long-term studies of comprehensive mitigation schemes have been performed in Germany and United Kingdom. Elaborate short-term studies are performed in e.g. Germany, the Netherlands and Spain. Some of these surveys have been or are scheduled to be repeated after 3-5 years.

Most post-construction surveys aim to record bats' use of mitigation structures. Only a few monitoring programmes consider population effects of the road and mitigation schemes. The two above mentioned German and British long-term studies and some smaller monitoring projects in United Kingdom and Ireland aiming to protect *Rhinolophus hipposideros* populations recorded bat numbers in maternity roosts adjacent to the road schemes. Numbers of roosting bats have also been monitored in large roost caves in Spain to assess the effects of nearby transport infrastructures.

Planning and construction of road schemes span several years and the accumulation of knowledge on the effectiveness of mitigation measures within each country is slow. Pre- and post-construction reports are confidential in some countries. This confidentiality prevents the exchange of experiences among projects.

Most bat pre-construction surveys of road development projects and post-construction studies of bat mitigation measures are descriptive and lack adequately robust study designs to enable assessments of effects of roads and mitigation schemes on bat populations. More rigorous monitoring methods and the publication of the findings in scientific papers should be promoted to ensure future development of effective bat mitigations.

Recommendations for monitoring

- Study design should be rigorous and quantitative for both pre- and post-construction studies to allow comparison.
- Define target species and goals for the monitoring (use vs. effectiveness).
- Select appropriate, accurate methods and include control sites for effectiveness assessments.
- Regular long-term monitoring and assessment schedules, e.g. every 3-5 years, should be integrated in the general road management plan.
- Monitoring reports should have a clear summary that includes quantitative results, statistical analyses and metrics for the passages.
- Monitoring reports should be publically accessible to increase knowledge exchange between road mitigation schemes, road developers and consultants.

Maintenance

The functionality of mitigation measures depends on their maintenance status. We received very little information on maintenance procedures and costs for bat mitigation measures. Maintenance of individual structures or functional groups of measures are not separated from other tasks, and the maintenance might be outsourced to contractors. Some new mitigation structures are still under warranty of the developer. The Dutch road agency seems to be the only road authority with dedicated maintenance procedures for fauna passages. The Dutch maintenance handbook provides functional goals for the passages, timing and frequency of inspection and maintenance task.

Many of the implemented measures on roads in Europe are relatively new and probably need little maintenance at present, but provisions should be made for the long-term maintenance of the measures. This is necessary to maintain long-term ecological functionality and effectiveness, and should include both the mitigation structure itself, adjacent bat habitats and essential landscape elements, e.g. guidance vegetation.

The maintenance requirements of the different types of mitigation structures vary. Annual inspections and maintenance actions are needed for some types of bat boxes which also have a short lifetime. It will be necessary to manage planted vegetation to keep guidance hedgerows intact and to maintain the openness of crossing structures, e.g. entrances to underpasses. Even small details in the measures and in the surrounding landscape may reduce bats' use of mitigation structures, e.g. gaps in guidance structures that could divert bats onto the road.

An appropriate maintenance strategy should be applied to ensure the long-term effectiveness of the mitigation measures. The value of inspections of mitigation measure, subsequent adjustments and general maintenance actions has been demonstrated in the UK, and standardised maintenance procedure for fauna passages have successfully been integrated into the general road management in the Netherlands.

Recommendations for maintenance

- Maintenance of bat mitigation interventions should be an integrated part of the general management plan for a road.
- The objectives, target species and maintenance requirements for the mitigation structures should be clearly defined.
- Development of standardised maintenance guidelines and schedules for the measures are advised.

5 Acknowledgements

The research presented in this report was carried out as part of the CEDR Transnational Road Research Programme on Wildlife & Roads. The funding for the research was provided by the national road administrations in Austria, Denmark, Germany, Ireland, Norway, Sweden, The Netherlands and United Kingdom. We thank CEDR for the support, advice and comments to the project and the report.

We express our sincere gratitude to the many bat and road expert throughout Europe (Annex A) who contributed to the project by responding to our questionnaires, provided us with information on bat mitigation measure, monitoring and maintenance procedures in their countries. EUROBATS kindly circulated our request for information on their network of bat experts.

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Annex B: European bat species

European bat species, their European and global red list status (Temple & Terry 2007, www.iucnredlist.org 2016) and their protection in the European Union by the Habitat Directive in the countries surveyed for road mitigation actions. LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered, DD: Data Deficient.

Latin name	Common name	IUCN Red list category Europe	IUCN Red list category Global	EU Habitat Directive Annex
Rousettus aegyptiacus	Egyptian fruit bat		LC	II + IV
Rhinolophus hipposideros	Lesser horseshoe bat	NT	LC	II + IV
Rhinolophus ferrumequinum	Greater horseshoe bat	NT	LC	II + IV
Rhinolophus euryale	Mediterranean horseshoe bat	VU	NT	II + IV
Rhinolophus mehelyi	Mehely's horseshoe bat	VU	VU	II + IV
Rhinolophus blasii	Blasius's horseshoe bat	VU	LC	II + IV
Myotis daubentonii	Daubenton's bat	LC	LC	IV
Myotis dasycneme	Pond bat	NT	NT	II + IV
Myotis capaccinii	Long-fingered bat	VU	VU	II + IV
Myotis brandtii	Brandt's bat	LC	LC	IV
Myotis mystacinus	Whiskered bat	LC	LC	IV
Myotis aurascens	Steppe whiskered bat	LC	LC	IV
Myotis alcathoe	Alcathoe bat	DD	DD	IV
Myotis nipalensis	Asiatic whiskered bat		LC	IV
Myotis nattereri	Natterer's bat	LC	LC	IV
Myotis escalerai	Iberian Natterer’s bat			IV
Myotis emarginatus	Geoffroy's bat	LC	LC	II + IV
Myotis bechsteinii	Bechstein's bat	VU	NT	II + IV
Myotis myotis	Greater mouse-eared bat	LC	LC	II + IV
Myotis blythii	Lesser mouse-eared bat	NT	LC	II + IV
Myotis punicus	Maghreb mouse-eared bat	NT	DD	IV
Nyctalus noctula	Common noctule	LC	LC	IV
Nyctalus lasiopterus	Greater noctule	DD	VU	IV
Nyctalus leisleri	Leisler's bat	LC	LC	IV
Nyctalus azoreum	Azores noctule	EN	VU	IV
Pipistrellus pipistrellus	Common pipistrelle	LC	LC	IV
Pipistrellus pygmaeus	Soprano pipistrelle	LC	LC	IV
Pipistrellus hanaki	Hanak's Pipistrelle		DD	IV
Pipistrellus nathusii	Nathusius's pipistrelle	LC	LC	IV
Pipistrellus kuhlii	Kuhl's pipistrelle	LC	LC	IV
Pipistrellus maderensis	Madeira pipistrelle	EN	EN	IV

Latin name	Common name	IUCN Red list category Europe	IUCN Red list category Global	EU Habitat Directive Annex
Hypsugo savii	Savi's pipistrelle	LC	LC	IV
Vespertilio murinus	Parti-coloured bat	LC	LC	IV
Eptesicus serotinus	Serotine	LC	LC	IV
Eptesicus nilssonii	Northern bat	LC	LC	IV
Eptesicus isabellinus	Isabelline serotine		LC	IV
Eptesicus bottae	Botta's serotine		LC	IV
Barbastella barbastellus	Barbastelle	VU	NT	II + IV
Plecotus auritus	Brown long-eared bat	LC	LC	IV
Plecotus macrobullaris	Alpine long-eared bat	NT	LC	IV
Plecotus sardus	Sardinian long-eared bat	VU	VU	IV
Plecotus austriacus	Grey long-eared bat	LC	LC	IV
Plecotus kolombatovici	Balkan long-eared bat	NT	LC	IV
Plecotus teneriffae	Canary long-eared bat	EN	VU	IV
Miniopterus schreibersii	Schreiber's bent-winged bat	NT	NT	II + IV
Tadarida teniotis	European free-tailed bat	LC	LC	IV