Guidance on the consideration of bats in traffic infrastructure projects

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Foreword

The EUROBATS Agreement was set up under The Convention on the Conservation of Migratory Species of Wild Animals, 1979. An Intersessional Working Group (IWG) on the Impact of Roads and other Traffic Infrastructures on Bats was established at the 12th EUROBATS Advisory Committee (AC) Meeting in Budapest, Hungary, 7 – 8 May 2007.

In 2010, the 6th EUROBATS Meeting of Parties, Prague, Czech Republic 20 – 22 September 2010 (MoP 6) requested the Advisory Committee (AC) to develop and publish a EUROBATS booklet highlighting the effects of roads on bats and providing guidance on minimising the impact of traffic infrastructure projects on bats. Resolution 7.9 was passed at the 7th (MoP 7) in Brussels, Belgium 15 – 17 September 2014. This urges Parties and non-party Range States to:

1. Take bats into account during the planning, construction and operation of roads and other infrastructure projects.
2. Ensure that pre-construction strategic and environmental impacts assessment procedures and post-construction monitoring are undertaken and recommend that the data collected are made available for independent scientific analysis.
3. Promote further research into the impact of new and existing roads and other infrastructure on bats and into the effectiveness of mitigation measures.
4. Develop appropriate national or supranational guidelines, drawing on the general guidance to be published by the Advisory Committee.

1. Introduction

1.1 Scope and structure of this guidance document

These guidelines have been produced by the Intersessional Working Group (IWG) on the Impact of Roads and Other Traffic Infrastructures on Bats, part of the EUROBATS Advisory Committee to meet the request under Resolution 7.9. They provide a basis for EUROBATS' Range States to produce their own national guidance, taking into account such factors as the composition and ecology of bat species, topography, climate, construction methods, legislation and planning regimes in their locality.

The document is aimed particularly at those involved in taking decisions about traffic infrastructure that may affect bats, including infrastructure planning and design, bat surveys, impact assessment, designing and monitoring, mitigation, compensation and enhancement. It is relevant to all road and rail projects, be they new construction, improvement or maintenance projects. The guidance will need to be interpreted through other relevant protocols for activities such as tree surveys, structural inspections, and management of the highways' estate.

It is important to note that "guidelines are only guidelines" and no single method or solution will be appropriate or proportionate in every instance. Advice should be sought from qualified specialists and agreed with the relevant advisors on a site-specific basis.

Our understanding of the effects of roads and other developments on bats, and of the effectiveness of mitigation techniques, has increased significantly in recent years, although is still subject to uncertainty. The information in this document is considered to be accurate at the time of publication but will need to be reviewed and updated as new information becomes available.

The decision-making processes for different types of major infrastructure projects have much in common. It is the intention of this document to focus on issues associated with transport projects, both in construction and during operation, rather than on generic issues associated with large infrastructure projects. Information on sources of guidance for generic issues is provided (Section 2.1).

Most research on the effects of transport infrastructure on bats has been carried out in relation to roads. There is limited information on the impact of rail and air transport. Where issues have been identified that are specific to rail or air traffic, these are noted within the relevant section.

Chapters 1- 4 introduce the background, the issues and the evidence base. Chapters 5 - 7 provide the guidance. Technical terms and abbreviations (highlighted in bold and italics) are explained in the Glossary and Abbreviations section.

1.2 Legislative and policy background

All EUROBATS parties have some form of national legislation protecting bats from killing, injury and disturbance and from damage or destruction of roosts, whereas a small number of non-party range states do not. Enforcement of regulations varies greatly between countries.

Bats are reliant on large areas of habitat containing a range of roost sites used for different life stages and in different seasons, as well as foraging grounds and commuting routes that allow them to move between them. Most legislation focusses on protecting bats from deliberate acts resulting in direct injury or killing, or in the destruction of roost sites. Protection of wider habitats is generally more limited.

1.2.1 The Convention on the Conservation of European Wildlife and Habitats, 1979 (Bern Convention)

The Bern Convention[1] requires Members to take appropriate and necessary legislative and administrative measures to ensure the special protection of the wild fauna species specified. All European bat species are listed in Appendix II (Strictly protected fauna species) except *Pipistrellus pipistrellus* which is listed in Appendix III (Protected fauna species

1.2.2 The Convention on the Conservation of Migratory Species of Wild Animals, 1979

The CMS, or Bonn Convention[2] requires Member States to strictly protect these animals, conserve or restore the places where they live, mitigate obstacles to migration and control other factors that might endanger them. It was instigated in recognition of the fact that migratory animals can only be properly protected if conservation activities are carried out over the entire migratory range of the species. All European bat species are listed in Appendix II of the Bonn Convention. The EUROBATS Agreement was set up under this Convention in 1994.

1.2.2.1 EUROBATS Resolution 7.9

This Resolution is concerned specifically with the impact on bat populations of traffic infrastructure (see Forward and Appendix 2).

1.2.2.2 EUROBATS Resolution 8.7

"Notes the growing scientific evidence of bat species changing their range, migration, hibernation and reproductive patterns due to impact of climate change" and advises signatories to

- Ensure that climate change impact on bats is taken into account in land-use planning and impact assessment in future projects evaluation" and
- Ensure habitat availability and connectivity for bats now and in the future by appropriate means of habitat protection, the establishment of ecological networks and adaptive habitat management.[3]

1.2.2.3 EUROBATS Resolution 8.10

Makes recommendations to

"1. Ensure that experts/groups of experts carrying out assessment of projects, plans and programmes on populations of European bats meet the minimum standard of skills, knowledge and experience" as described in the Annex to the Resolution.

2. Ensure that assessment reports of projects are objective and meet appropriate scientific quality standards.
3. Ensure that relevant authorities dealing with these assessments possess the appropriate resources and capacities to be able to assess and evaluate the results of those studies."

1.2.3 The EU Habitats Directive (92/43/EEC)[4].

Specific legislation applies to Member States of the European Union as all European *Chiroptera* species (are listed on Annex IV of the Directive. This requires Member States to take measures to establish a system of strict protection for these species in their natural range. In addition, the rarest species are also listed on Annex II as species of community interest for

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[1] https://www.coe.int/en/web/bern-convention
[2] https://www.cms.int/en/legalinstrument/cms
[3] https://www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP8.Resolution%208.7%20Bats%20and%20Climate%20Change.pdf
[4] http://ec.europa.eu.environment/nature/legislation/habitatsdirective/index_en.htm

which Special Areas of Conservation (SACs) are to be designated. Under Article 6 (3) and (4), schemes that may affect significantly affect SACs require additional consideration, including a greater level of survey intensity and a higher level of confidence in the effectiveness of any proposed mitigation (EC, 2002)[5].

Under Article 12 (4) there is a requirement for Member States to monitor the impact of incidental killing of bats and take further research and conservation measures to ensure that this does not have a significant impact on the species concerned.

This directive is also the EU implementation mechanism of the CMS and the Bern Convention.

1.2.4 The EU Environmental Impacts Directive (EIA)

The EIA Directive (2011/92/EU as amended by 2014/52/EU) provides a process to ensure that plans, programmes and projects likely to have significant effects on the environment are subject to an environmental assessment prior to their approval or authorisation. The process provides a high level of protection of the environment by integrating environmental considerations into the preparation of projects, plans and programmes with a view to reducing their environmental impact.

1.2.5 EU Bats Action Plan

The Action Plan[6] for the Conservation of All Bat Species in the European Union 2018 – 2024 notes two main issues and targets in relation to transport infrastructure within the EU. See the Action Plan for further details. Eurobats is listed as one of the organisations responsible for Action 10.2 and these guidelines have been produced to address that requirement.

Table 1. Issues and actions from the European Union Action Plan for Bats on bats and transport infrastructure

Issue No.	Issue	Target
10	Large mortality along roads that are built without consideration of local bat issues	A brochure on mitigation measures for road projects is published and a system to monitor road killing is developed in at least 14 Member States by end of 2021.
10.2	Produce technical guidance/best practice to help local authorities and stakeholders to minimise negative impacts during construction phases of new transportation infrastructures.	Guidelines published or a web page produced at the end of 2021.
11	Fragmentation through transportation infrastructures, disappearance of hedgerows or habitat degradation is affecting commuting roads and bat key habitats	Any initiative to reduce fragmentation of EU landscape is supported and a bat indicator is developed to measure fragmentation

[5] http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/natura_2000_assess_en.pdf
[6] https://ec.europa.eu/environment/nature/conservation/species/action_plans/pdf/EU%20Bats%20Action%20Plan.pdf

1.2.6 Infrastructure & Ecology Network Europe (IENE)

IENE was set up in 1996 to promote cross-border cooperation in research, mitigation, planning, design, construction and maintenance in the field of biodiversity and transport infrastructure.

The IENE 2020 International Conference Declaration acknowledges that “the economic, social, and ecological consequences of biodiversity loss and the role of transportation infrastructure is increasingly acknowledged worldwide:

- The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) states that since 1970, transportation infrastructure is an important driver of land use change and associated loss of terrestrial biodiversity https://ipbes.net/global-assessment
- The European Green Deal and the new European Biodiversity Strategy for 2030, adopted by the European Commission in May 2020, stresses the need to develop a resilient Trans-European Nature Network supported by ecological corridors allowing the free flow of genes and individuals https://ec.europa.eu/info/sites/info/files/communication-annex-eu-biodiversity-strategy-2030_en.pdf

The IENE 2022 Conference notes that

- In contrast to Western Europe, the East of Europe now “has the opportunity to develop transport infrastructure that does not cause a devastating and costly fragmentation of nature, making the best use of existing knowledge accumulated over the last decades to become a reference region for overall sustainable development, especially in the critical context of climate change, water shortage, land degradation and biodiversity loss.”

2. Literature Review

2.1 Summary and key references

In 2014 The IWG on the Impact on bats of roads and other traffic infrastructure began to review information on the topic from the EUROBATS range states. It noted that it was only in 1990s that evidence compiled from a range of sources brought the issue of bats as casualties of traffic to the attention of scientists and policy makers (Kiefer et al, 1995). Since then and particularly from 2000 onwards the number of publications reporting bats as traffic casualties steadily increased. Although recognised as an issue globally (Russell et al. 2008), research on the impact of traffic infrastructure on bats initially focused on insectivorous bat species in developed countries (western Europe and North America).

Most records of bat fatalities referred to collisions with motorised vehicles on roads, although there were anecdotal reports of collisions with bicycles, and rare accounts of bats being killed by trains (Kiefer et al, 1995). Some bat collisions with aircraft were recorded as part of aircraft inspections, although European data was not collated or analysed. Most data on bat traffic casualties originated from areas with a well-developed transport infrastructure where there is a long tradition of bat conservation and research, combined with strict nature conservation legislation. Thus, in the review undertaken for EUROBATS in 2014, Germany, France and the United Kingdom contribute approximately 70% of the scientific papers collated for the review, with another 20% from Poland, Portugal, Ukraine, Ireland and the Netherlands.

These publications provided an insight into the most vulnerable bat species and the habitats and time periods that are associated with their increased vulnerability to traffic. In the 1990s attention was focused on bats’ use of transport structures such as bridges and tunnels for roosting (Lustrat & Julien 1993, Walther B. 2002, Ceľuch & Ševčik 2008).

Research effort was also directed towards understanding the threats to foraging and migrating bats, for example the use of the linear landscape features. Limpens & Kapteyn 1991, Blake et al. 1994 More focused field research started after 2000 comprising a range of studies looking at mitigation measures designed to minimize direct collisions of bats and vehicles Limpens & Kapteyn 1991, Blake et al. 1994. In 2003, IENE started to collate information into the Wildlife & Traffic Handbook (see 1.2.6).

About 10 years later, studies started to focus on understanding the different effects of roads on bats, including how bats respond to habitat fragmentation (Melber & Kerth 2010, Berthinussen & Altringham 2011, Stephan 2012, Barataud et al. 2012), and the effects of traffic lighting (Stone et al. 2009) and noise pollution (Schaub et al. 2008, Siemers & Schaub 2010) and latterly attention has been given to the effects of railways on bats (Lüttmann 2012).

These studies have been accompanied by reviews of the associated conservation implications, with guidelines intended to mitigate transport-related impacts (Bickmore 2003, Limpens et al. 2005, Altringham 2008, Brinkmann et al. 2008). Such guidelines have become progressively more precise in relation to what information on bats is needed, including specific methods to adequately assess the environmental impact of road schemes and inform appropriate mitigation measures (SETRA, CETE, 2009, Bundesministerium 2011). Following those, the first publications compiling bat mitigation measures started to appear (O’Connor & Green 2011, Berthinussen & Altringham 2012b). These are extremely valuable for evaluating the investigation methods, the adequacy of the environmental assessment process and the success of any mitigation methods subsequently implemented (Highway Agency 2001, 2006, Limpens et al. 2005, National Road Authority 2006, Nowicki et al. 2008, 2016, Brinkmann *et al.* 2012).

More recently academic research using new technologies and techniques e.g. thermal cameras and acoustic flight path tracking (Koblitz, 2018, Roemer, 2021, Claireau et al 2021) and genetic studies (Claireau 2019) increase our understanding of bat behaviour and impacts of traffic infrastructures and operation on bat populations.

In an era when most scientific results are widely available through the publication process, road mitigation research falls someway behind. There are two main reasons why most research evaluating mitigation success has not been reported in the scientific literature. First, the research is mostly conducted to assess the impacts at specific locations and usually in relation to wildlife crossings: the work therefore lacks the replication required for wider generalisation. The government agencies conducting the work often do not necessarily have an incentive or requirement to publish the work more broadly (Lesbarreres & Fahrig 2012), although this is now encouraged through Eurobats Resolution 7.9 (Appendix 2) and the IENE 2020 Conference Declaration (1.2.6).

Secondly, the scarcity of adequate and well-planned pre-construction survey and comparative post-construction monitoring methodologies and reporting impedes the evidence-based evaluation of the effectiveness of current avoidance, mitigation and compensation measures (Bickmore 2003, Forman et al. 2003, Hinde 2008, Altringham 2008, O'Connor et al. 2011, Berthinussen & Altringham 2012, 2015, Elmeros & Dekker 2016, Elmeros et al. 2016b, van der Ree et al. 2007). Some measures continue to be used or promoted although they not been proven to be effective (Berthinussen & Altringham 2012, 2015, Stone et al. 2013).

A further challenge is in designing studies to understand the risks of mortality through collision, and the effectiveness of mitigation without contributing to that risk. There are some examples of the experimental installation or removal of mitigation measures to study their effects (Christensen et al 2016) but more are needed to safely assess the effectiveness of current and novel mitigation measures.

Until recently, few studies have looked at the impact on bats associated with railways (Borda-de-Água et al, 2017) or air traffic infrastructure (Kelly et al. 2017, Ball et al. 2021). Construction, or upgrading of railway and airport infrastructure occurs less often than road schemes. The scale of such projects should trigger a strict environmental impact assessment process but in practice, these have mostly focussed on mitigating the loss of habitats and roosting locations and less is known about the impacts of the operation of rail and air traffic on bats.

Evidence of impacts of aircraft is limited, and reviews have concluded that there is little economic impact through damage, suggesting that occurrences are infrequent (see Section 4.6, Voigt et al, 2018a). The safety considerations and access restrictions associated with surveying and monitoring near operational railways and airports make this a challenging topic to study.

2.2 Results of EUROBATS questionnaires

EUROBATS range states were consulted by questionnaire on whether they had any evidence of impacts on bats of traffic infrastructure and what actions were being undertaken to address these. Information was requested in 2008 and 2010 and a summary of the results was presented to the 19th Meeting of the EUROBATS Advisory Committee in 2014[7], with a further request for information for a poster presented to the 13th European Bat Research Symposium (Presetnik et al, 2014).

7 https://www.eurobats.org/sites/default/files/documents/pdf/Advisory_Committee/Doc_StC9_AC19_14_IWGReportRoadsandTraffic_incl_Annexes.pdf

Information on bat mortality resulting from road and rail traffic collisions was collated from the questionnaires and from more than 200 literature sources relating exclusively to EUROBATS range states. However, there are likely to be additional data on the subject in other sources, notably environmental impact assessments. Most road planning is under national, federal or local government regulation and the supporting information, although public, is usually contained in reports (‘grey literature’) that are not always easily accessible. Some of this work has been reported in conference proceedings available on the internet (e.g., International Conference on Ecology and Transportation (ICOET, formerly ICOWET), but most has not been published in the primary literature. Information on air traffic collisions was not included in the questionnaire but was later requested by the IWG.

More than 25 countries reported at least anecdotal knowledge of bat traffic casualties. Most of the reported casualties arose from road traffic (30 species), although rail (6 species) and air traffic (5 species) fatalities may be underestimated. From approximately 1,400 specific accounts of bat casualties, it is evident that not only low-flying bat species such as *Rhinolophus* and *Myotis* species, but bats flying in middle or higher airspace, like *Pipistrellus* and *Nyctalus* species, are affected (see Figure 1.) In view of this, it was concluded that *all* European bat species should be treated as potential traffic casualties. Studies also showed that in different environments there are marked differences in the of composition of bat species that become traffic victims. It was not clear whether this was a consequence of the local frequency of different bat species or particular environmental factors in the study areas.

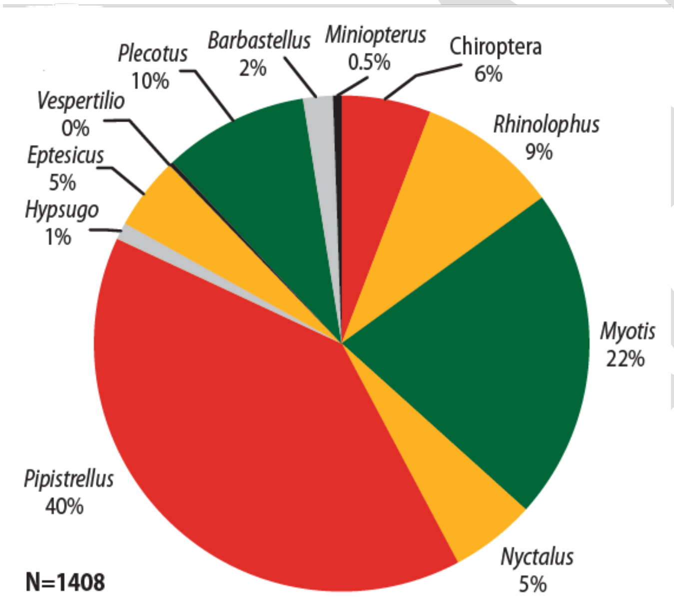


Figure 1. *Percentage of bat traffic casualties by genus based on data collated for EUROBATS literature review (Presetnik et al. 2014).*

Table 2. Bat species recorded as casualties from road, rail and air traffic collated by country[8] to 2020 from literature review (2.1) and responses to EUROBATS questionnaires (2.2)

Family and species	**State**	**Transport type**		
Rhinolophidae		road	rail	air
Rhinolophus blasii	ME	+		
Rhinolophus euryale	FR, GR, IT	+		
Rhinolophus ferrumequinum	AM, BG, DE, FR, IT, HU, PT	+		
Rhinolophus hipposideros	BA, CH, DE, ES, FR, GB, IT, HU, ME, PL, PT, RS, SK, SI, UA	+		
Rhinolophus mehelyi	PT, TN	+		
Vespertilionidae				
Barbastella barbastellus	CH, DE, ESP, FR, GB, PL, PT, SK, SI, UA	+		
Eptesicus nilssonii	DE, NO, SK	+		
Eptesicus serotinus	CZ, DE, ES, FR, HRV, HU, PL, PT*	+	+	
Hypsugo savii	ES, FR, IT, TR	+		+
Myotis alcathoe	CZ	+		
Myotis bechsteinii	DE, FR, GB, PT, SK, TR	+		+
Myotis blythii / oxygnathus	AM, ESP, FR, PT**	+		
Myotis brandtii	CZ, DE, PL	+		
Myotis capaccinii	ES, GR, IT, ME,	+		
Myotis dasycneme	PL	+		
Myotis daubentonii	CZ, DE, ES, FR, GB, IT, NO, PL, PT, SI	+		
Myotis emarginatus	CZ, ES, FR, GR	+		
Myotis escaleri	ES, PT	+		
Myotis myotis	DE, FR, PL, SK, PT**	+	+	
Myotis mystacinus	DE, FR, IE, GB, IT, ME, NO, PL, PT, SI, UA	+		
Myotis nattereri	CZ, DE, FR, GB, IE, IT, HU, PL, PT, UA	+		+
Nyctalus lasiopterus	DE, FR	+		
Nyctalus leisleri	CZ, DE, FR, GB, IE, IT, PL, PT, SI	+		+
Nyctalus noctula	CZ, DE, FR, GB, HU, PL, RS, SK, UA	+		+
Pipistrellus kuhlii	DZ, ES, FR, GR, IQ, IT, KW, ME, PT, SMR, SI, SY, TR, UA	+		+
Pipistrellus nathusii	CZ, DE, FR, ME, PL, RS, UA	+		+
Pipistrellus pipistrellus	AM, CZ, DE, ES, FR, GB, HU, IT, IE, PL, PT, SK, UA	+	+	+
Pipistrellus pygmaeus	CZ, FR, GB, IE, ME, NR, PT, SI	+		+
Plecotus sp				+
Plecotus auritus	DE, FR, G, IE, IT, NR, PL, UA	+		
Plecotus austriacus	DE, ES, FR, IT, PL, SVK	+		
Plecotus macrobullaris	BA, IT	+		
Vespertilio murinus	DE, HU	+		+
Miniopterus schreibersii	AL, AM, DE, ES, FR, PL, PT	+		
Molossidae				
Tadarida teniotis	IT			+

PT = species given as* Eptesicus serotinus/isabellinus *PT** = species given as M. myotis/M. blythii*
AL = Albania, AM = Armenia, BG = Bulgaria, BA = Bosnia and Herzegovina, CH = Switzerland, CZ = Czech Republic, DE = Germany, DZ = Algeria, ES = Spain, FR = France, GB = Great Britain, GR = Greece, HU = Hungary, HR = Croatia, IE = Ireland, IQ = Iraq, IT = Italy, KW =

[8] http://www.nationsonline.org/oneworld/country_code_list.htm

Kuwait, ME = Montenegro, NO = Norway, PL = Poland, PT = Portugal, RS = Serbia, SK = Slovakia, SM – San Marino, SI = Slovenia, SYR – Syria, TN = Tunisia, TR = Turkey, UA = Ukraine

3. Why consider the impact of traffic infrastructure on bats?

This Chapter provides a general summary of bat ecology relevant to impacts associated with traffic infrastructure. More detailed information on the natural history of bats and species accounts of European bat species can be found in the EU Bats Action Plan (See 1.2.4).

3.1 European bat species

Fifty-two bat species from five families occur within the area covered by the EUROBATS Agreement[9,10]. All are dependent on insect prey caught in flight or gleaned from vegetation or other surfaces, except for *Rousettus aegyptiacus,* the only fruit bat species occurring in the EUROBATS area. Two bat species are known to take larger prey: *M. capaccinii* can catch small fish and *N. lasiopterus* occasionally preys on small migrating songbirds (Kyheröinen et al, 2019).

Thirty-two bat species have been recorded as casualties of road or rail traffic in the EUROBATS area (see Table 2), including 27 of the 43 Vespertilionid species present and all five Rhinolophidae. The sole species in the family Molossidae has been recorded as a casualty of air traffic. To date, there have been no reports of casualties from the families Emballonuridae and Pteropodidae, though these families are also only represented by one species each in the EUROBATS area. Thus, most bat species are considered susceptible to collision impacts, however some are more vulnerable than others.

3.2 Bat ecology

Bats are relatively long-lived animals for their size, with a lifespan often of over 10 years, or even over 20 years but have low reproductive rates (e.g. Barclay and Harder 2003, Wilkinson and South, 2002, Barclay et al, 2004, Dietz et al, 2009). Females from a colony gather in maternity roosts before parturition and during the lactation period, with fertile females giving birth to a single young per year (occasionally twins). The energy demands of pregnant and lactating females are extremely high. Both mothers and the juvenile bats need access to productive feeding areas within a few hundred meters of the maternal roosting site to meet this requirement and for the young to survive their first crucial months. The **core sustenance zone** for a colony is defined as "the area surrounding a communal bat roost within which habitat availability and quality will have a significant influence on the resilience and conservation status of the colony using the roost" (Collins, 2016).

Hibernating bats can congregate in large numbers in favoured sites, but also hibernate singly or in small numbers. Decreased breeding success or survival (through disturbance at roosts, sub-optimal conditions in roosts or habitat) may take some years to become apparent. While roosting in large congregations has advantages, it also increases vulnerability and as species with low fecundity, bats cannot quickly replace any losses. Bats are thus vulnerable to

9 https://www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP8.Resolution%208.2%20Amendment%20of%20the%20Annex%20to%20the%20Agreement_0.pdf

10 *Plecotus gaisleri* has since been added to the Eurobats list https://www.eurobats.org/node/2601

disturbance, particularly at critical times, to damage and loss of roosting sites and to intentional or incidental killing, hence their protected status in many countries.

Bats are unusually mobile and typically have large home ranges compared with other small mammals. This leads to many chances for interaction with transport infrastructure. Long-distance ***migration*** and dispersal are known in several species. For example, noctules *Nyctalus* spp. and Nathusius’ pipistrelle *P. nathusii* may travel 1,000km between winter and summer habitats and roosts (Hutterer et al., 2005). Even relatively sedentary species can travel many kilometres between ***roost sites***, ***mating or swarming sites*** and ***foraging areas***, distances which may increase during dispersal (see Kyheröinen et al. 2019). Natterer’s bats *M. nattereri* have been recorded travelling 60 km to swarming sites in the UK (Rivers et al, 2006).

Insectivorous bats use echolocation to navigate and to find their prey. Some species (e.g., trawling *M. daubentonii* and *M. dasycneme*) have specialised in certain prey types and consequently use particular habitat types predominantly for foraging, whilst others (e.g., some *Pipistrellus* and *Eptesicus species*) are more generalist (see Kyheröinen et al. 2019). Whatever their preference, all bat species utilise a variety of habitats and habitat features as they cross large areas of the landscape to reach favoured foraging sites or roosts. Consequently, they are influenced by a wider range of environmental factors than many other similar-sized mammals (Altringham 2011).

A large proportion of insectivorous bat flights occur at a height of less than 4m above the ground putting them in the same zone as road and rail traffic Bats fly at low speeds (<20 km/h) and weigh between 4 – 30g so are vulnerable to being drawn into the slipstream of passing vehicles (Berthinussen & Altringham, 2012b).

Figure 2. *R. hipposideros* road casualty. Photograph by Monika Podgorelec

3.3 Flight characteristics and foraging strategies

Bat species can be split into functional groups according to their flight characteristics and preferred foraging habitats. Echolocation call type and wing morphology (wing aspect ratio) are good predictors of the foraging strategies of a species (Norberg, Rayner 1987, Roemer et al, 2019). For simplicity, this document uses three broad groups though recognises that species do not fit neatly into categories and that individual species have differing levels of specialisation and vary in the plasticity of their echolocation calls (Holderied & von Helversen, 2003, Denzinger & Schnitzler 2013).

- **Clutter adapted species** includes the woodland specialists such as *Rhinolophus*, *Plecotus* and some of the *Myotis* species that forage in **complex** environments with dense foliage. They typically have broad wings, are highly manoeuvrable, low-flying, slow-flying and tend to rely on ***short-range echolocation (SRE).*** They have discriminating close-range sensory perception, allowing capture of prey close to foliage or water substrates. Species with lower intensity calls navigate by using acoustic cues from the landscape, closely following features such as hedgerows, tree lines, fences, forest edges and water courses (Kyheröinen et al, 2019).
- At the other end of the spectrum are the ***open airspace adapted species*** e.g., *Nyctalus* and *Tadarida* species that catch insects in mid-air by aerial hawking and use ***long-range echolocation (LRE)*** calls (Schnitzler and Kalko 2001). Their long, narrow wings are adapted for fast, energy-efficient flight over long distances.
- A third functional group are the ***open/edge adapted species*** e.g., *Pipistrellus* and *Eptesicus* species*,* and certain *Myotis* species which habitually forage in both open airspace and woodland edge habitats, sometimes referred to as ***mid-range echolocators (MRE).***

The **clutter and open/edge adapted** species in particular benefit from the ***edge effect*** (Brigham et al., 1997; Verboom and Spoelstra, 1999), i.e., a concentration of insects in or near trees associated with linear or edge habitats that provides a source of prey and a sheltered environment for foraging and commuting.

Flight characteristics can be useful for a general description of the types of risk to which different bat species are most vulnerable, and therefore which types of mitigation measures may be most effective in mitigating risk (Abbott et al, 2012 b, Bhardwaj et al 2017). For example, the disruption or removal of habitat features used as navigation aids for **clutter adapted species** may reduce their access to foraging resources (Kyheröinen *et al*, 2019). In addition, as these species spend more time flying low to the ground, especially when crossing open areas, they are therefore very susceptible to collision with road and rail traffic (Richarz, 2000, Bickmore, 2003).

Open airspace adapted species do not avoid roads but do not necessarily fly over them at a safe height. High mortality rates have also been recorded locally for bat species that normally fly above traffic height, e.g. *Nyctalus* species in forested areas where commuting routes coincide with roads (Lesiński et al. 2011). The risk to a species at a given location will be influenced by the landscape, topography and habitat and the ability of the species to utilise these.

High altitude flight behaviour, i.e., flight well above the landscape topography and vegetation, poses a risk to bats from collision with air traffic (see Section 4.6.3). Twenty-one European bat species exhibit high altitude flight behaviour (Voigt *et al*, 2018a). *Tadarida teniotis* tracked using Global Positioning System (GPS) were recorded at over 1,600 metres. In contrast to other bat species *T. teniotis* is the only bat species in our data collation where collision mortality has been recorded only through collision with aircraft and not with road or rail traffic (see Table 2).

Figure 3. *Flight style and habitat use by insectivorous bats. From Elmeros (2018)*

Assigning species to functional groups may be useful to some extent if there is a lack of published evidence about the flight characteristics or foraging behaviour of a species or about its behaviour in the habitat at the study site. However, the extent to which understanding / information is transferable between species and locations is variable, depending on whether the species are generalists of have specific requirements (Bhardwaj et al, 2017).

NB. The risks of this approach need to be recognized and acknowledged. Research and monitoring should be undertaken to support and verify the assumptions wherever possible.

4. How traffic infrastructure affects bats

Changes in habitat size, quality and connectivity, together with disturbance and pollution affect the ability of an area to support bats and to facilitate movement between bat populations of a bat species. Impacts may be short term and reduced through effective mitigation. Some impacts persist or increase in the long term, exacerbated by cumulative effects and the inability of bat populations to recover quickly.

Impacts on bats can be separated into two main types – firstly **through impacts on habitats used by bats** (4.1 – 4.5) and secondly **direct mortality through collision** (4.6).
Figure 3 Bat habitat use a) before and b) after construction of new road [Graphic to insert]

4.1 Changes in abundance and species diversity

Roads have been shown to adversely affect both bat activity and species diversity across the globe (e.g. Kitzes & Merenlender, 2014, Berthinussen and Altringham, 2012, Medinas et al, 2016).

The size and shape of the area affected by the infrastructure and its traffic - the ***road-effect zone*** (Forman & Deblinger, 2000). are determined by features of the built structure (the road or railway), traffic, the landscape, climate, the sensitivity of the species and the ecological processes affected (e.g., hydrology). Further research is needed to assess the extent of ***effect zones*** of rail and air transport infrastructure and would require landscape-scale survey and monitoring (e.g. see 5.5.3), since most work to date has focused only on the area of the infrastructure or immediately adjacent habitat and not the surrounding landscape.

Despite the inherent difficulties of separating the effects of roads from other factors, transect studies have demonstrated that the **road-effect zone** extends into the wider landscape and varies by species. For example,

- a decline in *P. pipistrellus* activity, and in species diversity, was recorded for at least 1.6km either side of a major road in the UK (Berthinussen & Altringham, 2011).
- a significant negative effect of major roads on bat activity was observed up to 5km from the road in France. The effect was most noticeable for clutter-adapted species, (*Myotis* spp., *Rhinolophus hipposideros*) and open/edge adapted species *E. serotinus* and *P. pipistrellus,* but less so on high-flying open adapted species (Claireau et al, 2019).
- a study in Portugal showed that even roads with low and medium levels of traffic can have a negative effect bat activity up to about 300m from roads in woodlands or more than 500m in open field habitat.
- The effects varied seasonally and by species and by habitat. Impacts were less noticeable in the mating and swarming periods. The activity of ***clutter adapted***, and ***open/edge adapted species*** was found to be negatively affected by proximity to roads, although activity increased for ***open airspace adapted / LRE species*** and road verges can provided important foraging areas for some species where good quality habitat is otherwise lacking (Medinas et al, 2016).
- *Myotis* species avoided an area 10 – 25m from a high-speed railway line located in woodland even when trains were not passing through (Lüttman 2012a).
- activity fell by ≥ 30–50% each time a train passed for at least two minutes, at wooded rail-side sites in the UK (Jerem & Mathews 2021).

4.2 Loss of habitats and roosts

The creation of new road surfaces removes significant areas of available roosting, commuting and foraging habitat, e.g., 7 hectares for every 10 kilometres of 7-metre wide, two-lane road, with further habitat lost to roadside hard shoulders, verges, junctions, service areas etc (Berthinussen & Altringham, 2015). Any one area may fulfil a range of ecological functions (foraging, commuting, roosting, mating) for the resident and migratory species that use it. Even a small decrease in foraging potential may have long-term effects such as reducing the biological fitness of individuals which in turn may affect populations.

Linear infrastructure projects can alter the topography of a large area by the removal of land, and dissection of landscape and habitat features and affects the hydrology of the surrounding habitat. Cuttings may increase soil erosion and drain aquifers; embankments may change the water regime producing either drier or wetter conditions (IENE, 2022).

As a generality, a mosaic of natural or semi-natural connected habitats including riparian and wetlands habitats and woodlands provides a rich source of insect prey and important foraging and commuting habitats for many bat species; loss of, or reduction in quality of such habitats, or in connectivity between them will be detrimental.

Foraging and commuting strategies vary greatly by species, by season and regionally depending on climate, topography and habitat. Thus, the assessment of the value of an area for bats must consider the suite of species using the area and their requirements in that locality throughout the seasons.

Loss of roost sites, especially in the areas where they are scarce, would generally have a more significant impact but the impact varies by species, e.g. *P. pipistrellus* bats in the UK found alternative roost sites following exclusion from a maternity roost (Stone *et al*, 2015a) in contrast to *M. nattereri* (Zeale *et al,* 2016). Forest stands with a high ratio of old trees and deadwood provide a choice of roosts, vital for some of the rarer bat species (Boye & Dietz. 2005). There is detailed information on the roosting and foraging preferences of bat species in the EUROBATS area in Dietz et al (2009) and Kyheröinen et al, (2019) Eurobats Publication Series no. 9. (See also 7.5).

Roosts are often protected from destruction by legislation and the provision of replacement roosts is required as part of the mitigation and compensation process. The extent of roost loss due to developments is difficult to quantify as some bat species typically move roosts frequently and do not always leave evidence of use. Monitoring of mitigation often lacks the rigour and time needed to demonstrate the effectiveness of different types of mitigation for different species (e.g. Collins et al, 2020).

Roost in natural features (trees, rock features) require more effort to locate and their importance is likely to be underestimated (Andrew and Gardener, 2015). Traffic infrastructure projects can affect large areas of undisturbed habitat of high value to biodiversity that cannot be directly replicated by mitigation. (Reference)

4.3 Habitat fragmentation, the barrier effect and collision risk

Habitat fragmentation and changes in management practices can reduce the ability of an area to support bats. Even if the habitat quality is not altered, bats may be reluctant to travel across the new infrastructure to access roosts or foraging areas, thus severance of flightpaths and commuting routes by roads is a key concern for the conservation of bat populations (Bach et al 2004, Schorcht et al 2008, O'Connor et al. 2011).

Habitat fragmentation can significantly increase isolation of more sedentary bat species and reducing gene flow between populations, leading to genetic drift and inbreeding (Meyer et al. 2009). The effects may be significant for species with small and fragmented populations but may not be evident unless they are studied at a large scale, e.g. a study in the UK found that there is a separation in populations of *M. bechsteinii* that approximately aligns with the M4 motorway Wright et al (2018). A study in France found that the presence of major roads has a negative effect on the genetic structure of *R. hipposideros* in roosts either side of them that cannot be explained by geographic distance alone (Claireau, 2018).

Vegetation structure and vehicle presence influences bat behaviour in deciding whether to cross a road or to turn back. Some species will make large detours to avoid gaps in otherwise continuous corridors, expending more energy as a result (e.g. Kerth and Melber, 2009, Bennett and Zurche, 2013).

Vegetation along road verges may facilitate commuting and can provide protection, foraging habitat and greater insect availability, leading to increased bat activity (Verboom and Huitema, 1997, Avila-Flores & Fenton, 2005) (Medinas et al 2019; Roemer 2020). Tree rows alongside roads probably allow bats to benefit from the **edge effect** without having to fly directly above the road, contrarily to forest landscapes with hard edges, which act as conduits (Kalcounis-Rueppell et al., 2013).

In the Mediterranean region of France, tall and large trees along roads led to higher bat densities, and a higher proportion of bats flying in the collision risk zone compared to roads with sparse tree lines (Roemer et al, 2020). However, contrary to expectations, most of the time bats flew parallel to the road axis, even in the presence of perpendicular tree rows. Where woodland or trees rows follow the same alignment as the road, bats probably use the vegetation as shelter from the wind and rain, or to forage on insects abundant near the foliage.

In areas without trees, flights parallel to roads might be interpreted as bats foraging along road verges, as these are usually more productive in insects than the surrounding agricultural areas (Villemey et al., 2018). It is possible that this result is dependent on the context of the study where tree rows perpendicular to the roads were always associated with small temporary streams in otherwise very dry surrounding habitat (Roemer, 2020- check).

A study in southern Portugal found that bat activity patterns changed from year to year due to increasing water stress that affected vegetation growth and insect abundance, hence foraging activity and that the higher mortality was associated with prime foraging habitats and proximity to roosts (Medinas et al 2013, 2021). Remote sensing data could be used to help predict risk (see also 4.6.2 and Case Study). Further research is needed to determine if similar changes in bat activity patterns occur in different habitats and climate zones. Pre-construction surveys undertaken over a number of years should give a more reliable estimate of risk.

In a forested area in Sweden, a motorway and a railway running in parallel acted as barriers for two bat species *M. mystacinus* and *M. brandtii*). However, a green bridge and an underpass were used by the bats to cross and to forage (Kammonen 2015). Another study also found that railway verges had a negative effect on specialist *Myotis* species but did not significantly influence foraging/commuting activity of more generalist bat species (Vandevelde et al, 2014).

The presence of favourable habitat close to roads, notably woodland, is linked with significantly reduced barrier effects especially for clutter and edge-adapted species, but this comes at the cost of a heightened risk of collision (Fensome & Mathews, 2016) (see 4.6). Collision risk is increased when traffic infrastructure is located close to bat roosting, commuting and foraging habitats.

<u>Collision risk</u>

The relationship between barrier effect and collision risk
Habitat features close to the road (hedgerows, treelines, woodland edge etc)

- reduce the barrier effect of roads and railways,
- provide productive edge habitat,
- provide linear features for navigating / commuting

but also - encourage activity close to the road - and therefore increases collision risk,

- for clutter-adapted species that fly low to the ground when flying over open areas
- for edge-adapted species flying parallel to the road
- even for open-adapted species, depending on habitat (e.g., continuous forest) and topography (e.g., roads on hillsides)

Clutter-adapted SRE species bats are more likely to be killed if they do cross a road or railway because of their low flight than are edge / open adapted MRE species, but they are also less likely to fly close to the traffic zone. Hence clutter-adapted/SRE bats' greater avoidance has some protective effect but at the expense of effectively reducing the habitat available to them through the barrier effect (Roemer et al 2021). Clutter-adapted SRE species are also less likely than MRE to fly within the road zone if a vehicle is passing by (Roemer et al 2021).

High mortality rates have also been recorded locally for bat species that normally fly higher above traffic height, e.g., *Nyctalus* species in forested areas, where commuting routes overlap with roads (Lesiński et al. 2011).

A study in a limestone gorge in Bulgaria (a European biodiversity hotspot) found that higher numbers of bat casualties occurred on road segments close to bat roosts and on segments with bridges (Stoianova et al. 2021).

4.4 Air traffic infrastructure and aerial habitats

Airports and their associated hard landscaping infrastructure (terminal buildings, runways, access roads, hotels, parking areas) have a similar footprint to shopping centre or housing estate developments though the pattern of noise and light pollution will be temporally and spatially different (see 4.5). Urban and military areas with high levels of aerial traffic may act as barriers for bats leading to fragmentation of aerial habitat (Voigt et al 2018). However, the presence of agricultural and semi-natural habitats close to airfields can attract wildlife (DeVault et al. 2017).

Aerial habitats are potentially subject to functional fragmentation due to physical barriers (e.g., tall structures) and disturbance caused by noise and light pollution. Despite this, bat collisions with aircraft do occur during aircraft landing and take-off phases indicating that bats do not completely avoid even busy airfields (see 4.6.3).

Aerial habitats do not have the same recognition or protection as terrestrial and aquatic habitats (Davy et al 2017), despite their importance to many organisms including bats and their prey.
Voigt et al (2018a) described three aerial zones of relevance to bats–

- Zone 1 - from ground level to 50m above ground level - used by all bat species, includes roosts and may include the forest canopy,
- Zone 2 - the air column between 50 – 1000m above ground level and which is included in the activity range of most high-flying bat species (including *Nyctalus* species)
- Zone 3 - from 1000m to 3500, used by very high-flying bat species (*Tadarida* species).

4.5 Pollution

Pollution from lighting, noise or chemical compounds may significantly increase the barrier effect and have negative impacts on habitat quality during both the construction and operational phases.

4.5.1 Lighting

Although artificial light may not present a physical obstacle, it may nonetheless reduce the availability of habitat when bats avoid large areas and commuting routes illuminated by artificial light at night ***alan*** (Rowse et al. 2016, Pauwels et al 2021). Vehicle headlights also affect bat commuting and foraging activity (Azam et al., 2016; Hale et al., 2015; Stone et al., 2009), also effectively resulting in habitat loss (Azam et al., 2018).

Recent declines in insects in Europe and the subsequent negative impact on insectivores can, in part, be linked to the increasing use of artificial light at night (Van Langevelde et al, 2018) Voigt et al (2021). Increasing urbanisation and the effects of artificial light may change bat communities at a landscape scale, with “light opportunistic” species expected to become more prevalent but overall, a reduction in bat abundance and species diversity (Van Langevelde et al, 2018, Voigt et al 2021). Road lighting deters light averse, clutter adapted species from approaching roads (Stone et al, 2009) and may reduce their use of potential commuting or foraging habitat (Stone et al 2015, Mathews et al 2015, Voigt et al 2021). The presence of a streetlight irrespective of its characteristics had an impact on the activity of 10 of the 15 bat species studied by Pauwels et al (2021).

A thorough review and guidance on the subject can be found in EUROBATS publication series No 8 *Guidelines for consideration of bats in lighting projects* (Voigt et al, 2018), (see also 6.4.1).

4.5.2 Noise

Bat abundance and species diversity are lower closer to roads (see 4.3.1); traffic noise may account for part of this effect. Published studies indicate that bats’ responses to noise vary by species, location and activity, however there is insufficient evidence to determine the levels at which noise causes disturbance to bats, i.e. affects their behaviour. A review by Bentley and Reason (2020) noted that studies on the topic tend to use weighted (decibel) noise level measurements that are applicable to the human hearing range, but which underemphasise the effects of high frequency sounds. It was not possible to compare the results of the studies reviewed because data on noise levels measurements was not reported in a consistent way.

4.5.2.1 Roosting bats

There is anecdotal information of bats roosting near to noisy environments, in tunnels under roads, bridges above major roads and a railway tunnel (e.g. Billington, 2013, cited in Reason & Bentley, 2020) suggesting that bats may tolerate, or become habituated to background noise, or to occasional very loud noises close to roosts.

It is possible that persistent loud noise (and vibration) from drilling, blasting and pile-driving during the construction stage could disturb bats in roosts close proximity to the work.

4.5.2.2 Foraging and commuting activity

Vehicle noise appears to reduce foraging efficiency for some species (Siemers & Schaub, 2011). Background noise overlaps with bats’ echolocation calls (acoustic masking), or reduces the attention given to catching prey, or at the extreme, bats may simply avoid areas perceived as being noisy. For example, the foraging efficiency of *M. daubentonii* decreased when vehicle noise masked their echolocation calls, leading to the avoidance of roadside habitat. However, the impact of noise can also depend on the habitat context, and more research is needed to better understand its extent (Luo et al. 2015).

Species that rely on sounds to find prey (e.g., *M. myotis*, *M. blythii*, *M. bechsteinii* and *Plecotus* species) are particularly vulnerable although these effects are short range – possibly up to 60 metres (Schaub et al., 2008). A study using recorded road noise played back to free ranging wild bats found that noise in the sonic spectrum had a negative impact on species from functional species groups utilising different types of echolocation call (*R. ferrumequinum*, *N. noctula*, *Myotis* spp and *Pipistrellus* spp) up to at least 20m away (Finch et al, 2020).

Road noise at speeds above 75 km/h is primarily generated by contact between the tyres and the surface of the road, rather than from engine sound (The Highway Agency, 2011). For this reason, the transition to electric vehicles may reduce road noise within urban environments but is unlikely to make a significant difference on most roads (Finch et al, 2020).

4.5.2.3 Railways

Traffic levels are lower and disturbance less frequent on railways than major roads, e.g. train noise on a busy rail line in the UK was detectable over a much shorter distance compared to road noise (Altringham, 2012). However, in another study activity of the two most common species in the area (*P. pygmaeus* and *P. pipistrellus)* fell by ≥ 30–50% for at least 2 minutes each time a train passed. Consequently, activity was reduced for at least one-fifth of the time at the sites with median rail traffic, and at least two-thirds of the time at the busiest site (Jerem and Mathews, 2021).

4.5.3 Chemical pollution

Pollutants have impacts at the level of individual animals, populations and affect the wider environment. Emissions from road vehicle exhausts is the most important source of chemical pollutants, e.g. carbon monoxide, nitrogen oxides, sulphur dioxide, hydrocarbons including polycyclic aromatic hydrocarbons (PAH) and dioxins (IENE, 2022). Emissions are lower at railways than roads because many trains have electric engines (Santos et al, 2017).

Contamination of run-off water from roads with hydrocarbons and heavy metals (e.g. lead, zinc, copper and cadmium) could potentially affect bats by reducing the availability of insect prey or possibly by chemical poisoning, however this requires more research (Nowicki et al, 2008).

Chemical pollution can also be introduced through road and rail maintenance practices, such as the application of herbicides on road and rail verges, and de-icing (sodium and chloride) (Forman et al. 2003).

4.6 Collisions

Impacts of mortality

Grilo et al (2020) estimated that 194 million birds and 29 million mammals may be killed each year on European roads including an estimated mortality rate for the soprano pipistrelle bat *P pygmaeus* of 1.76 individuals per km per year. Using modelling based on species life traits, they concluded that the species whose long-term persistence was threatened by road mortality may not be the species with the highest levels of roadkill, nor were they always necessarily considered to be species considered as high conservation priority. Collision mortality has a greater impact on the likely persistence of populations of species (such as bats) that have higher mobility, larger home ranges, lower reproductive rates and late maturity age (Rytwinski and Fahrig 2012, Grilo et al 2020).

As with other small animals, collisions with vehicles, even at low speeds, are most likely to be fatal to bats. However, in contrast to small terrestrial mammals or birds that produce multiple young in a breeding season, bat populations cannot quickly replace losses (Berthinussen & Altringham 2012b). Mortality of individual animals through collision with vehicles can be significant if extrapolated over a large area, or if losses are high at a specific location. The major driver for bat population dynamics seems to be adult, and in particular female, survival thus even slight additional mortality may be threatening to bat populations. Annual mortality of 5% of a colony would be unsustainable and is possible since a large proportion of the colony may be concentrated in a relatively small area at certain times of the year (Schorcht *et al*. 2009).

During the late spring and early summer pregnant and lactating females need to forage earlier and for longer, they make regular returns to the roost to feed young and are heavier and less manoeuvrable and all these factors increase their exposure to traffic and susceptibility to collisions (Medinas et al., 2012). Juveniles are more likely to be casualties than adults because of their reduced manoeuvrability and slower flight (Medinas et al, 2012, Fensome and Mathews, 2016), and especially where maternity roosts are near to a transport route.

Peaks in bat collision mortality occur in summer and autumn (Fensome & Mathews, 2016) and can be explained by a seasonal increase in bat activity combined with and an increase in bat populations as the young of the year start to fly (Roemer et al, 2021). In one long term study of a road scheme, the first casualties of the season occurred in early August when an increase in traffic volume coincided with the key bat emergence period (the three hours after sunset) and with the first flights of the young of that year (Pickard, 2014). The volume of traffic is positively correlated with mortality rates in 22 or 64 studies across taxonomic groups studied [Reference].

Evidence of mortality
Unlike larger mammal species that are commonly killed on roads such as deer and badgers, bat traffic casualties are unlikely to be found without targeted survey work. Bat carers occasionally receive injured or dead bats that have been hit by cars and there is anecdotal evidence of collisions noticed by drivers but most evidence has resulted from systematic surveys of road verges (e.g. Lesinski, 2007, Pickard, 2014). However, even systematic studies are problematic as such small corpses may be thrown some distance from the road, remain stuck to the vehicle, disappear because of the repeating crushing by vehicles, or be removed by scavengers (Santos et al, 2011). Slater (2002) experimented by artificially baiting roads and concluded that estimates derived from car-based surveys underestimated mortality rates by 12 - 16 times. Even where carcasses remain in situ, casualty figures based on carcass searches are likely to significantly underestimate mortality; in studies of the effectiveness of carcass searches for bats killed by wind turbines, surveyors found only between 14% and 20% of carcasses that had been placed in the search zone (Arnett, 2006 and Mathews et al, 2013). Small corpses were, on average, removed by scavengers within 30 minutes in the hours just before and after dawn.

Bat carcasses (and those of lizards) had the lowest persistence time after being killed by a vehicle (<1 day) compared to other taxa (1-2 days for small herpetofauna, mammal and bird species, up to >7 days for large carnivores) (Santos et al 2011). Carcasses were predicted to disappear more quickly if they are smaller (under 20g), occurring in paved lanes, and in wetter or warmer conditions and on roads with lower traffic levels (< 1000 vehicles/day), allowing easier access for scavengers. Lower traffic levels and a smaller contact area on railways may allow carcasses to may persist longer because of lower traffic levels, although this can allow more removal by scavengers (Barrientos 2017?).

Collinson et al (2014) reviewed studies on vertebrate roadkill and undertook experimental trials to design a reliable and cost-effective protocol for assessing multi-taxa roadkill (Amphibia, Reptilia, Aves, and Mammalia). They recommend categorising the study area by species diversity level (high, intermediate, or low) for data to be comparative longitudinally at the same site, and with other sites for future roadkill detection research. Adequate sampling was defined as the point where the estimated richness was equal to or less than the richness observed by daily sampling. Mammals required the greatest sampling effort: as an example, to sample mammal species in an area of low species richness, sampling for duration of 61 days over a distance of 100 km, or 40 days over 125 kms would be required. Detection rated decreased significantly at speeds above 50km per hour (Collinson et al 2014).

They proposed a protocol based on experimental trials using driven transects to detect two sizes of simulated roadkill. The smaller size was based on a small rodent (*Tatera leucogaster*), that is much larger than most of the European bat species - approximately 70g (Stuart & Stuart, 1993) compared to *P. pipistrellus* c 5g, or *M. myotis* c 25g (Dietz et al, 2009). The protocol is applicable for multi-taxa surveys but has some limitations regarding its applicability to bat species. However, it does include further searches on-foot to look for roadkill that may have been missed or to target specific locations where small-bodied species may occur. Other studies also found more carcasses using on-foot surveys than when driving (Slater 2002, Guinard et al, 2012). Experienced field workers found more than new recruits, and substantially more are found if a trained dog is used (Barrientos et al, 2018). See also 5.4.4.

4.6.1 Road traffic casualties

Patterns of bat casualties are not equally distributed in space, nor in time. Higher bat mortality rates have been found where bat flightpaths cross roads in high quality habitat and close to foraging locations, such as riparian habitats and water bodies (Medinas et al., 2013; Gaisler et al. 2009; Ikovic et al., 2014; Lesinski, 2007; Lesinski et al., 2010; Secco et al., 2017). Berthinussen and Altringham (2012) found a positive correlation between the height of the roadside cutting and the height at which bats flew across the road, but the effects are species-specific. Deeper cuttings also mean wider gaps for bats to cross.

Locations where clusters of casualties are recorded may be reported as roadkill hotspots, though the location of roadkill hotspots on existing roads may change over time if there has been previous high mortality in the area. Per capita road mortality, (i.e. the chance of an individual in the population being killed) may be a more reliable indicator of locations with a higher need of mitigation (Zimmerman Teixeira et al, 2017). Collision patterns are often described annually (Fensome and Mathews, 2016) without consideration or analysis of inter-annual variations in locations or species affected (Malo et al., 2004; Skorka et al., 2015), e.g see Case studies below. See also 5.4.4.

Case studies

Southern Portugal

Daily casualty surveys were undertaken along a 51-km-long transect on different types of operational roads.

From analysis of surveys between March 16 - October 31, 2009. (Medinas et al 2012)

- A total of 154 casualties of 11 species were found.
- The two most common species in the study area, *Pipistrellus kuhlii* and *P. pygmaeus* comprised 72 % of the specimens collected.
- Casualties of rare species and threatened species were also collected, including *Miniopterus schreibersii, R. ferrumequinum, R. hipposideros, Barbastella barbastellus and Nyctalus leisleri*
- Two-thirds of the total mortality occurred between mid-July and late September, peaking in the second half of August.
- Significantly more casualties were found in high quality habitat (associated with woodland and water).

From analysis of surveys between 2009 - 2011. (Medinas et al 2021)

- A total of 509 casualties at 86 statistically significant roadkill hotspots, accounting for 61% of casualties and 12% of the road network.
- The location of hotspots changed from year to year. 17% of the road network length was consistent from year to year. 43% of hotspots disappeared and 40% of new segments were classed as hotspots.
- Changes in the location of hotspots was associated with increasing water stress on the surrounding habitat, less vegetation growth and a presumed reduction in insect prey affecting bat activity at the locations.

Road casualty case studies

Wales, UK

A casualty survey programme was started on a new road scheme because of concerns about possible impacts on a maternity and hibernation roost of several hundred lesser horseshoe bats *R. hipposideros* 1.4km from the scheme.

- Daily dawn surveys were carried out between August to November/December 2001 – 2012 (except 2006 and 2011) on a 4km section of road.
- The carriageway and verges (up to 50m from the road) were inspected within an hour and half of dawn.
- A total of 67 bats were found – 42 x *R. hipposideros*, 7 x *Myotis brandtii/mystacinus*, 7 x *P. pipistrellus*, 6 x *Plecotus auritus*, 3 x *M. nattereri* and 2 x *P. pygmaeus*.
- *R. hipposideros* was the only species recorded as casualties in each year of the surveys up to 2010.
  (Pickard, 2014).

4.6.2 Rail traffic collisions

Studies of bat collisions with road traffic demonstrated the difficulty in detecting bat casualties, suggesting that mortality through rail collisions may be high but overlooked (Borda-de-Água, 2017). Data on rail traffic casualties is more limited, but one study suggests that the lower volume of rail traffic at night decreases the risk by two-thirds compared to the risk posed by road traffic at night (Pakula & Furmankiewicz, 2021). The study used bat behaviour observations (bat detectors and thermal imaging cameras) to determine species identification and flight height along electrified railway lines in Poland and undertook carcass surveys using human teams and a search dog. One bat carcass was found compared to 40 carcasses of other mammals, birds and amphibians. The bat, a male *P. pipistrellus* was found immediately after two trains passed simultaneously. The collision occurred in a tunnel where the bat had no chance of escaping. Bat behaviour was influenced by species and by habitat: bats flew in the collision risk zone more often in urban habitats than in forest or water habitats. *Eptesicus* and *Pipistrellus* bat species were observed to fly more often in the collision risk zone (Pakula & Furmankiewicz, 2021). In this study the edge of the surrounding vegetation (forest and bushes) is at least 10 metres from the track.

Overhead power lines (catenary) above the track of electrified railways represent an additional source of potential impacts (Santos et al 2017).

4.6.3 Air traffic collisions

Research on bat collisions with aircraft is limited and to date most published studies have analysed data involving US and Australian aircraft, with the exception one study from the Republic of Ireland (Kelly et al 2017). These studies have focussed on safety concerns and the potential economic impact of damage to aircraft from wildlife collisions.

A recent review (Ball et al, 2020) found that while avian strikes were the most common wildlife strikes, mammal species accounted for 3-10% of recorded wildlife strikes. The composition of *Chiroptera* species involved varied regionally, e.g. 4 families in Australia and 5 families in the USA. However, bats were not identified to species level in 17% of instances in that study.

The number of bat collisions is not known but is likely to be underestimated. One study found that the number of wildlife carcasses found during runway checks at a commercial airport suggested that pilots reported only one quarter of all wildlife strikes (Linnell et al. 1999). Information is sometimes provided on when and where strikes occurred, but in most cases, it is not known. The remains of an African fruit bat persisted on an aircraft that flew from Africa to the UK and to Israel before the remains (and the damage to the aircraft) were discovered (Leader et al. 2006). Smaller carcasses that do not result in damage are highly likely to go unnoticed and unreported, although the partial remains of a female *Mops condylurus* were found in the landing gear of a plane at the airport at Geneva, Switzerland on plane flying from Togo or Benin, via Paris.

Reporting of airstrikes is mandatory within the European Union (EU) but is not consistent and information is incomplete, e.g. in Germany only mammals the size of a rabbit or larger are reported (Ball et al. 2021). Standardised reporting could produce more useful data (see 5.4.6, 5.5.4) and improve management strategies to reduce the risk of damage to aircraft and wildlife mortality.

4.6.3.1 US aircraft data

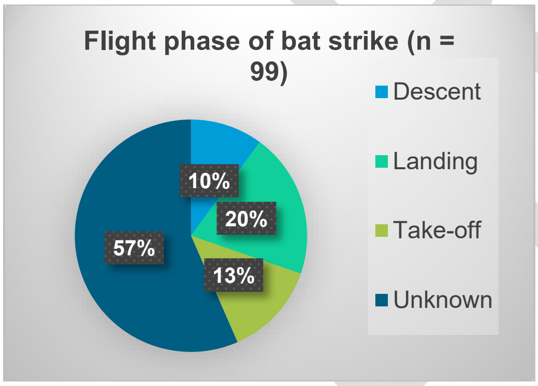
An analysis of wildlife collisions with US Air Force aircraft between 1997 – 2007 from 21 countries revealed that. twenty-five bat species were recorded as casualties worldwide with the most common being *Tadarida brasiliensis* (Peurach et al. 2009). Four of the 6 most commonly identified species are migratory species. The sixth most commonly identified species was *P. kuhlii* (n = 17) from collisions in the Middle East. Over 57% of strikes occurred from August to October. Over 12% were reported at >300m above ground level. Most damage resulted from a small number of collisions. Two strikes involved more than one species of bat. 19 of the strikes were reported to occur during the day and two of these involved both birds and bats, possibly from daytime flights of migratory species.

Washburn et al (2014) analysed data on wildlife strikes involving US military helicopters deployed in combat and non-combat missions outside the USA between 1994 – 2011. The majority of the 701 strikes were birds (69 species) but 18 involved bats. Four occurred on or over the airfield and 14 off the airfield. Nine bat casualties were identified to species and comprised *P. kuhlii, (4), Rhinopoma microphyllum (3), T. teniotis* and *P.pipistrellus (1)*. Most occurred in Afghanistan with just two in Iraq. Only one strike was reported to be "damaging" to the aircraft.

A collation of data on 417 reported bat collisions with US civil aircraft between 1990 – 2010 found that 10 bat species were recorded, although most (68.9%) victims were not identified to species (Biondi et al. 2013). The greatest incident rate occurred at dusk (57.3%), most during the landing phase (85%), then at take-off (11.2%) Bat strikes were considered to be low risk and have minimal economic effect civil aircraft.

4.6.3.2 European air traffic data
Data provided by the UK Civil Aviation Authority (CAA) and the French Service technique de l'Aviation civile (STAC) covering the periods 2009 – 2019 and 1999 – 2019 respectively, have enabled a preliminary analysis for flights within the EUROBATS area. This resulted in 94 reported strike events including 38 (by STAC) from 12 airports within France and two each in Switzerland and Germany. The UK CAA reported 56 strike events from 27 UK airports, three in Spain, two in Italy, and one each in Portugal, Switzerland and Turkey.

In most cases evidence of strikes was found during routine inspections of the runway, or of the aircraft on the ground and it is not known when the strike occurred. In one notable exception, the flight crew were aware of the strike event and noted that it occurred at an altitude of 1800m. Bat remains were found attached to the plane after landing. Where carcasses were found and identified the species affected were *Pipistrellus* species (10), P. *pipistrellus* (1), *P. nathusii* (1), *N. noctula* (4), *N. leisleri* (1), *Plecotus* species (1), *Tadarida* sp. (1). In 14 cases, the report indicated that more than one bat was struck, and in one (unconfirmed) case more than 11 bats were reportedly involved.



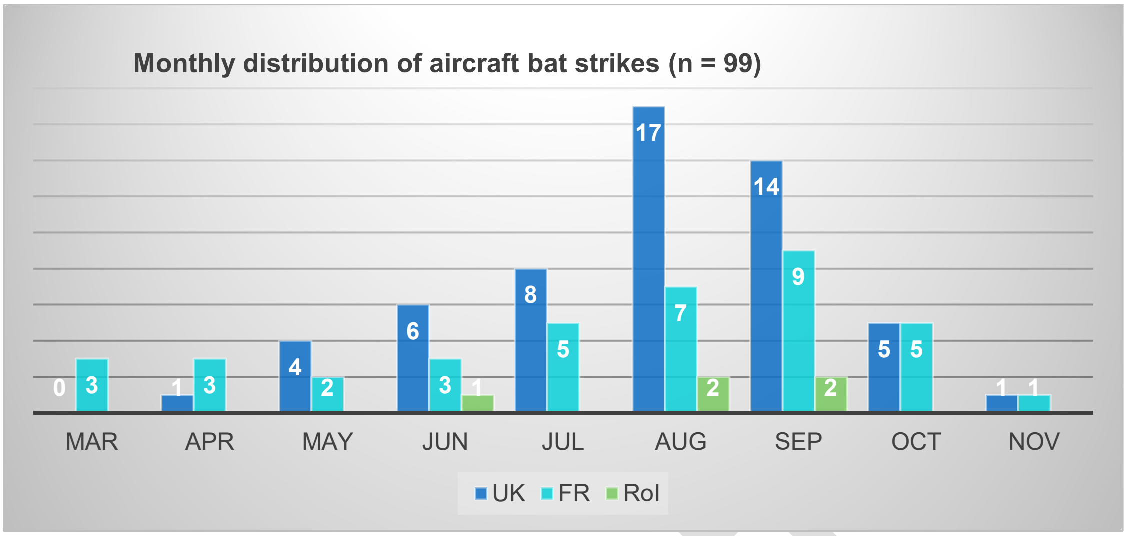


Figure 4. Flight phase (a) and monthly breakdown (b) of bat strikes by aircraft. Data courtesy of the UK Civil Aviation Authority (CAA), the French Service technique de l'Aviation civile (STAC) and from Kelly et al (2017) for the Republic of Ireland.

Of the 94 strike events, 43 could be attributed to a flight phase comprising 10 during descent to the airport, 20 during landing and 13 during take-off. There is an apparent seasonal variation in the distribution of strike events (see Figure 5) with the majority occurring in August and September, particularly in the data provided by the UK CAA.

A collation of data over a 10-year period (2006 – 2015) at civil aviation airports in the Republic of Ireland was able to confirm only 5 bat strike incidents (Kelly et al, 2017). In two cases it was possible to identify the carcass to species (1 x *N. leisleri*, 1 x *M. nattereri*) but in the other three cases identification was made using DNA analysis of blood smears on the aircraft (2 x *N. leisleri*, 1 x *P. pygmaeus*). The likely phase of flight during which the incidences occurred is not given. The proportion of strikes that were not recorded is unknown although it is noted that carcasses were only recovered during daylight hours.

4.6.3.3 Unmanned aerial vehicles (UAV)
UAV or drones are increasingly being used for commercial and recreational activities but their impact on wildlife is unknown since collisions are only reported if the vehicle is damaged, if at all (Voigt et al 2018a). Further research is needed to determine if their increasing use could cause disturbance to bats. The impact may be limited since they are mostly used during daylight hours and their use is often restricted for safety or security reasons.

4. 7 Positive impacts of traffic infrastructure

Overall, the presence of roads leads to reduced bat activity and diversity, but some features associated with roads may be used by bats, e.g. insects swarming around streetlights may give foraging opportunities for some species of bats (Rydell, 1992, Stone et al. 2009, 2012, Mathews et al 2015). Asphalt roads in forests with low to medium traffic levels were found to have more foraging activity by open air foragers than similar unsurfaced forest roads, possibly because the road surface attracts insects Myczko et al (2017). The distribution of *P. pipistrellus* and *N. noctula* had a positive association with roads in situations where roads were sparse and close to woodland (<100m) (Bellamy et al 2013). Vegetation near roads can provide shelter as well as foraging habitat and can increase availability of insect prey for bats (Avila-Flores and Fenton, 2005), resulting in increased bat activity at roads (Verboom and Huitema, 1997, Medinas et al 2019, Roemer et al 2021).

In intensive agriculture areas, where natural linear features are scarce, *H. savii* and *Pipistrellus* spp., use minor asphalt roads (with or without vegetation along) as main commuting routes, *P. kuhlii* also as main foraging areas (Paunović et al. 2015, 2020).

Lines of trees running parallel to roads give bats an opportunity to forage along an edge away from the road (Roemer 2021). Road verges are important foraging areas for ***open airspace and open / edge adapted species*** such as *P. kuhlii* (Medinas et al, 2016).

Bat activity was higher at railway verges compared to surrounding habitats for the more common open and open/edge adapted species, although activity for some of the clutter adapted *Myotis* bat species was reduced (Vandevelde et al. 2014). Similarly, railway verges were found to be a significant habitat for some ***open airspace and open / edge adapted species*** (*P. pipistrellus* and *N. leisleri*) in an intensive agricultural landscape in the absence of semi-natural vegetated linear features such as hedgerows [Reference].

Roadside trees and built structures associated with roads provide roost sites. Bridges are known to be of particular importance for at least 13 species of bat in Europe. Crevices in stone bridges over water courses are used by *M. daubentonii* and other *Myotis* as well as *Nyctalus* species (Marnell and Presetnik 2010). Modern concrete bridges and supporting structures with large interiors provide suitable roosting conditions for large maternity roosts, e.g., *P. pygmaeus and E. isabellinus* in Spain and even the ***clutter adapted species*** *R. hipposideros* uses motorway bridges in Austria (Barova and Streit 2018) and the UK. The number of roosting bats of *Myotis yumanensis* and *Tadarida brasiliensis* in California increased following the replacement of roosts lost during bridge works and the provision of additional roosting spaces, although *Antrozous pallidus* failed to recolonise the roosts. Bat houses created as alternative roosts while work was ongoing were not used by any species (Harvey & Associates H.T. 2019).

Rail and road verge habitats can be positively managed to promote insect abundance (Vandevelde et al. 2014) and may be important habitat where other foraging areas are limited (Medinas et al. 2019). The benefits provided by roadside habitats and structures are species-specific and related to habitat but must be weighed up against the increased risk of collision.

Abandoned railway lines can act as wildlife corridors when disused, or if re-used for low impact activities such as cycling and disused railway tunnels provide roost sites for bats (Barrientos & Borda-de-Água, 2017).

4.8 Cumulative impacts

Transport infrastructure projects may affect bat populations in different ways during the construction and operational phase (Russell et al. 2009, Abbott et al. 2015), and the effects of infrastructure works do not stand in isolation but are cumulative and likely additive. The impact of each individual factor (Sections 4.1 – 4.6) may not be substantial, but in combination may have significant effects on bat populations. It is vital to consider potential cumulative effects otherwise the planned mitigation and compensation can be undermined and may not have the desired outcome.

Road mortality can threaten the local long-term persistence of mammal and bird species that are not considered to be of conservation priority, especially if they are already imperilled by other factors (Grilo et al. 2020).

The cumulative effects and the time lag between impact and detectability of effects on bat populations should be considered when assessing and monitoring a transport development project and the effectiveness of the mitigation strategy. A challenge in this field is that the effects of the different pressures and threats have different time scales (Berthinussen & Altringham 2015, van der Ree et al. 2015). Roost or habitat destruction and direct mortality due to traffic collisions have an immediate effect, whilst barrier effects that affect reproduction or reduce genetic diversity take longer to affect populations negatively and will be harder to detect.

Secondary effects of changes in land use, such as new housing or commercial developments may follow the construction of transport infrastructure. Particular consideration should be given to potential secondary development in areas of high importance for wildlife conservation (IENE 2022).

The effects of increasing access into areas and habitats that may have previously been undisturbed should be considered at the scheme planning stage. Plans to manage increased access or to mitigate the effects should be drawn up during the planning stage and implemented with the infrastructure development.

5 Planning and Impact Assessment of Traffic Infrastructure Projects

All signatories to the EUROBATS Agreement are urged to take bats into account during the planning, construction and operation of roads and other transport infrastructure projects and to ensure that pre-construction strategic and environmental impacts assessment procedures and post construction monitoring are undertaken (EUROBATS Resolution 7.9, See Annex 2).

In general, the approach taken to the planning procedure and impact assessment of traffic infrastructure construction and upgrading is no different to that of other construction projects. However, there are two important differences:

- the additional risk of bat mortality is a significant risk that is not associated with other large-scale infrastructure projects apart from wind farms (see also section 4.6).
- the scale of large traffic infrastructure projects brings particular challenges to the planner and ecologist. Linear developments can result in huge changes to the landscape and topography of an area, potentially affecting many bat commuting routes, foraging areas and roost sites.

Small-scale upgrading schemes, such as road-widening may have less impact because of their smaller scale, but important bat habitat may still be lost, e.g., roosts in buildings, bridges and roadside trees, or hedges used as flight routes. Large scale schemes may present opportunities in terms of space and time: there may be more space to mitigate and compensate effects, and a long planning and construction phase that allows a thorough mitigation plan. Without the latter, there are inherent potential issues with lack of consistency of approach and lack of communication at the various stages of a large scheme.

5. 1 Environmental Impact Assessment (EIA) and SEA

The EU EIA Directive (see 1.2.1) presumes that very large infrastructure projects (Annex I projects such as motorways and large airports) do have significant environmental impacts and that an EIA is therefore mandatory. For large scale projects that do not meet the Annex I criteria (Annex II projects) a screening process to determine if an EIA is needed.

The wider effects are outside the scope of consideration for the individual scheme and should be considered as part of the Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) processes (see 1.2.2). See O'Brien et al. (2018) for more detailed information on the EIA and SEA process.

The EIA process requires detailed baseline bat surveys to be conducted where works are proposed to determine which bat species may be affected and how. The information is also required to develop an effective mitigation strategy that minimizes negative impacts and identifies enhancement opportunities. Many countries have specific detailed guidance on including bats in formal EIA processes for infrastructure projects, e.g. UK, Serbia, Switzerland (CIEEM, 2018, Paunovic et al. 2011, Lugon et al. 2017) and there is formal guidance for projects affecting European Natura 2000 Sites (European Commission 2021).

The Route Corridor Selection (RCS) study will consider alternative route corridor options, taking account of engineering, environmental, traffic and financial implications. It is the most effective way to avoid or reduce ecological impacts. Options that would have unacceptably high levels of impacts and those resulting in significant effects on sites of European importance should be ruled out at this stage wherever feasible (O'Brien et al 2018).

Integrated solutions to avoid or reduce impacts should be considered at all scales - national, regional and site level when undertaking EIA/SEA (IENE 2022). Otherwise, once the scheme is at the EIA stage, some decisions will have been taken that can limit the options for avoidance or mitigation. Individual scheme EIAs can fail to take cumulative effects fully into account and cannot address the impacts of potentially damaging actions that are not regulated through the approval of specific projects (Alshuwaikhat 2005).

It is important to note that there is a lack of knowledge on regional meta-populations of bats even in countries with a long tradition on studying bats. There are particular issues with rarer species and even with more common but cryptic species, e.g. *Pipistrellus* and *Myotis* genera (Barova and Streit 2018). For example, the UK’s National Bat Monitoring Programme provides robust population trend data for some species but does not provide species distribution data, and occupancy and density data are lacking for many UK bat species (Mathews et al. 2018).

5.2. Project geographical scale and extent

The most important known bat habitats and their elements should be identified and screened out at the strategic/regional planning level. However there it can be assumed that there insufficient knowledge of bat species ecology and distribution and therefore bat distribution and habitat use will probably need to be predicted at this stage of planning (see 5.1). Expert judgement is likely to be needed, based on an understanding the requirements of each species, and on the landscape and habitat features present (Bickmore 2003, Limpens et al. 2005b, National Roads Authority 2005).

Modelling of the spatial distribution and habitat use by bats has been shown to be a reliable and efficient tool for predicting bat distribution and habitat use at different spatial scales (Jaberg & Guisan 2001, Razgour et al. 2011, Becker & Encarnação 2012, Steck et al. 2012, Bellamy et al. 2013, Altringham & Kerth 2016). Both expert judgement and habitat suitability modelling can be based on existing data sets, but additional targeted surveys will be needed in most cases (Bickmore 2003, Limpens et al. 2005b, National Roads Authority 2005, Razgour et al. 2011, Becker & Encarnação 2012, Steck et al. 2012, Bellamy et al. 2013). Models that take account of multiple variables such as habitat availability, roost sites and relevant project characteristics, may aid the assessment of impacts (Bennett et al. 2013).

During the later stages of planning and development (including reconstruction and maintenance works), habitat suitability modelling outputs can be used as a basis, but **not** as a substitute for impact assessment surveys. Only adequate impact assessment can gather sufficient information on spatial and temporal patterns of bat activity and habitat use to enable reliable and precise decision-making on final route selection and/or the siting of supporting infrastructure. All traffic and supporting infrastructure should, wherever possible, be planned to avoid important areas for bats, as identified by the impact assessment.

Landscape-scale surveys of bat activity will be required for proposed infrastructure projects with a large road effect zone, such as new motorways, railway lines and airports. They are used to find out which bat species are in an area and depending on the survey design may provide an index of activity which can be compared with other areas or the same area over time. Landscape-scale surveys provide baseline data for assessing whether habitat functional connectivity and populations are maintained following construction (Barrientos et al. 2021).

Landscape-scale surveys may be appropriate even for small schemes where such information is required for other reasons, for example:

- to understand whether there will be impacts on the conservation status of particular bat species at a regional level,
- to assess the impact of a scheme on a protected site, at a particularly sensitive location
- to help assess the cumulative impact of development in an area,

- as part of research to understand the effectiveness of novel or unproven mitigation measures (Møller et al. 2016).

Localised site-specific surveys are the minimum level of survey effort for small traffic schemes. They are usually targeted at roosts, or at potential crossing points where linear infrastructure (roads, railways, runways) intersect bat flightpaths. Mitigation features may need to be installed and pre-construction survey data are needed for comparison with post-construction monitoring of the mitigation.

5.2.1 Early planning phase and desk study

Taking bats into account at an early stage usually pays off later in the project, saving time and effort to form an overview of the scale of mitigation or compensation measures in the planning phase rather than just before or during construction or upgrading. The first step is to collate existing knowledge of the presence of bats in the area from distribution atlases, biological records centres, non-government organisations (NGOs), or local experts and volunteers, and on bat usage of the habitat types of the area. Finding out if there are species present that are very sensitive to changes in the landscape or known roosts (including hibernacula) and specially protected areas, within the study area will help with planning the EIA more efficiently.

In most cases local distribution data will have been gained from ad hoc reports of the more common species, or from surveys related to other planned schemes or perhaps an active local bat group, and often there will be a lack of information on rare or species that are more difficult to survey. The desk study should look at the national or regional range of such species (e.g., EU Article 17 reporting)[11] to determine if they are likely to occur in the study area.

Background data searches should be carried out up to a minimum of 2km from the proposed development boundary (including temporary works such as construction compounds and haul routes) or extend up to 10km for larger projects (Collins 2016), e.g. guidance in Switzerland based on the average flight distance from the roost of *M. myotis* (C. Eicher pers. comm.). Statutory designated sites such as Natura 2000 sites or nationally important sites for bats within 10km should also be considered.

A new motorway or railway could have large scale effects on the habitat and affect bat populations over a wide area, in which case the **effect zone** (see Section 4.1) will be much larger than the footprint of the scheme. Even relatively small-scale schemes can potentially have significant impacts on **species of conservation concern (SCC)** for example if a roost, key flight route or foraging habitat is affected. The data search should relate to the **effect zone** of the scheme consider the **core sustenance zones** of species likely to be present (see Section 3.2). Further information on critical feeding areas for different European bat species can be found in Kyheröinen et al. (2019) EUROBATS Publication Series no. 9.

New linear infrastructure projects will include phase in the planning stage when multiple variants of the route are considered. Route corridor selection RCS "is the single most effective means of avoiding or reducing ecological impacts" (O'Brien et al. 2018). Adapting the preferred route at this stage may avoid delays and financial costs needed to mitigate or compensate for its impacts. This is especially relevant if the species likely to be present include SCC or species for which no effective mitigation exists.

The design of the scheme should consider the ecological requirements of all bat species present, and those species predicted to expand their range into the study area because of climate change (see 1.2.2.2).

[11] https://nature-art17.eionet.europa.eu/article17/

5.2.2 Pre-survey assessment / Preliminary ecological appraisal

A pre-survey assessment is done using the occurrence data from the desk study from the planning phase, combined with a landscape analysis. Flight routes and feeding areas can be predicted using knowledge of the ecology of bats, the locations of bat roosts, aerial photography etc. Areas of high bat activity can be predicted using satellite imaging to spot areas of high vegetation productivity, water bodies and seasonal water courses (Medinas et al. 2021) and using models based on existing habitat and bat distribution data where available (e.g. see Appendix 1 Berthinussen & Altringham, 2015). The first assessment forms a preliminary evaluation of the impact of the project on bats and an indication of the type and extent of mitigation needed.

The survey and monitoring strategy (See 5.2.1) can be developed based on information about where bats are known to be present and considering where additional survey effort is needed to fill in knowledge gaps.

The appraisal should indicate the level of survey and monitoring effort needed to ensure that it is proportionate to the likely impacts on bat populations. More survey effort will be needed if the scheme is likely to affect:

- rarer bat species (which may have a higher level of statutory protection)
- bat species on the edge of their range
- bat species that are more difficult to detect using standard survey techniques
- sites specially protected for bats (locally, nationally or internationally)
- areas supporting large numbers of bats (important roosts, commuting or foraging habitat)
- many sites over a large-scale area

(Collins 2016)

5.2.3 Timescale

As bats change their behaviour seasonally throughout the year, the planning process must therefore take account of the fact that the survey will take **at least one year**: The presence of roosts, flight routes and feeding areas can be established in spring, summer and autumn, and in winter, the importance of hibernacula can be determined. Since bat activity hotspots may change from year to year (Medinas et al. 2021) surveys conducted over multiple years should provide more accurate data on bat activity patterns and risk.

Pre-construction surveys will need to be updated if there is a delay of 2 years or more between the surveys and the start of construction. The length of delay triggering updated survey information should be based on national guidelines or legislation and should be specified in the pre-survey assessment report for the scheme to allow for local circumstances.

Regular long-term monitoring and assessment schedules should be integrated in the general scheme management plan, including during the construction phase and periodically once the scheme is operational, e.g. every 3 – 5 years (see also 7.6). Hence the methods should be considered when designing the Survey and Monitoring Strategy to ensure consistency of approach.

5.3 Survey and Monitoring

<u>Definitions</u>

For this guidance, a bat **survey** is defined as a systematic sampling activity that aims to observe, measure and record a wide range of variables to establish baseline data (e.g., on presence, abundance, condition) of ecological features relevant to bats in the study area.

Monitoring is defined as repeated systematic sampling activities that aim to observe and quantify changes occurring either over time, or because of particular actions. The information can be used to assess whether a particular objective or standard has been attained. It is distinct from **surveillance** of bat populations i.e., using repeated and standardised observations of abundance over time to detect changes in bat populations and trends in those changes.

A combination of comprehensive baseline survey data and long-term monitoring are essential for understanding how bats respond to changes in roosting locations and habitats whilst vegetation establishes and matures.

5.3.1 Developing the survey and monitoring strategy

Pre-construction surveys of transport infrastructure have tended to use field survey methods that do not allow a comparison with the pre-construction data (see 2.1). This means that it is not possible properly to assess the impact of the scheme on bat populations, nor to evaluate and compare the effectiveness and cost-effectiveness of different mitigation measures. To counter this, researchers should be involved in designing the survey and monitoring programme from the beginning (van der Grift 2013).

It is essential to consider both survey and monitoring together so that the two complement each other. A well-designed survey and monitoring strategy should provide the data needed to assess the effectiveness of the mitigation used in the scheme and can also give insights into the cost-effectiveness of the mitigation techniques that may be applicable to other schemes.

Survey and monitoring objectives

- identifying which bat species will be affected by the proposed works,
- understanding how bats move around in the landscape and how the construction of the infrastructure will affect them,
- predicting the effects of operational traffic on bat populations,
- facilitating the scheme design to avoid, mitigate or compensate for negative impacts and to enhance the area for bats
- providing sufficient information to allow the permitting authorities to decide if the proposed scheme can go ahead as planned, or if it needs to be modified (to comply with statutory obligations)
- monitoring the impacts of the scheme, and the effectiveness of any avoidance, mitigation, compensation, and enhancement measures
- assessing the impact on bat populations at a regional or national level (for large-scale projects, or those affecting rare species)

To meet the objectives the strategy should

- consider data analysis as part of the survey design, taking account of the types of data that will result from the survey and monitoring
- set measurable targets for outcomes (e.g., effectiveness of mitigation measures) and include mechanisms for reporting problems as soon as possible
- follow local, regional or national guidance to take into account the area’s community of bat species, the climate and type of geological and habitat features present
- inform and link to other relevant scheme documents (e.g., Permeability Plan, Habitat Management and Scheme Maintenance Plans. See 7.6).
- consider how to address knowledge gaps (see 5.2.2)
- ensure that processes are in place, and the necessary funding is secured to complete the mitigation and evaluation (see O’Brien et al. 2018)

- ensure that contractors and transport authorities have the appropriate ecological expertise in place for each stage of the process - through planning, construction, survey, monitoring and maintenance (see O'Brien et al. 2018)

5.3.2 Incorporating research into survey and monitoring

Understanding which mitigation methods are effective in which situations benefits bat conservation and can prevent resources being wasted on ineffective mitigation. Research on mitigation has been limited to date and often confined to studies of single schemes [Reference]. It is desirable and more cost-effective in the long term to include a research element in the survey and monitoring strategy for all large-scale traffic infrastructure projects, and in small schemes if novel or unproven mitigation measures are being used.

Incorporating a BACI (Before-After-Impact-Control) research design into the project allows comparison between the study site (e.g., before and after mitigation is employed) and a control site (where no intervention is undertaken) during the same time period. It is useful for studying ecological responses where replication is difficult, or experimentation is unethical (e.g., studying mortality impacts). It provides information for the particular infrastructure project as well as rigorous results for use in future mitigation (Lesbarrerers & Fahrig 2012). There are a number of subjects areas where potentially harmful impacts have been identified (e.g., the impact of noise on bats) but where evidence is lacking and standardised survey methods and mitigation measures have yet to be developed and evaluated.

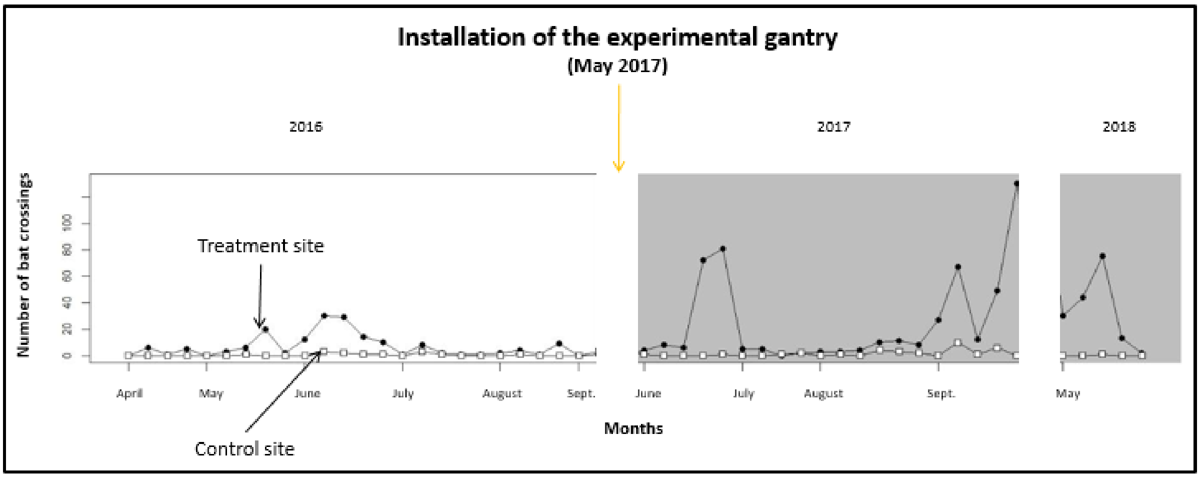


Figure 5. *BACI study of the installation of a road crossing for bats (Claireau et al. 2019)*

As an example, Figure 5 shows how a BACI study (Claireau et al. 2019) demonstrates the effects on bat activity of installing an experimental mitigation measure. Differences in changes in bat activity (the number of times bats cross the road) can clearly be seen at the treatment site (in black) compared to the control site (in white), and before and after the installation.

Overview of steps in a BACI study of bat mitigation in a traffic infrastructure scheme

- Carry out pre-construction surveys to identify the species at risk and their ecological requirements, to determine how they use the landscape and identify risk locations where mitigation is needed,
- Select mitigation type / location and select control locations for monitoring,
- Set quantitative targets for each (e.g., 95% of the particular species will cross safely using the tunnel)
- Design monitoring protocol for mitigation sites and controls
- Collect “before” data on bat movements at mitigation and control sites
- Continue to collect data during construction
- Post-construction - continue to collect data using the same protocols for monitoring at mitigation and control sites
- Analyse data regarding targets and compare with controls to assess effectiveness
- Implement bias correction trials (searcher efficiency and carcass removal) along with casualty searches to estimate the actual mortality
- Use per capita mortality (% of population killed by collisions), rather than numbers found to compare results for different locations
- Amend / redesign the mitigation if it is not effective and repeat the process
- Report to sponsors and make results available via peer-reviewed journals
- Make raw data available through suitable platform for independent scientific analysis (see EUROBATS Resolution 7.9)

Control sites are important to ensure that changes can reasonably be attributed to the mitigation measures, e.g. an observed reduction in road casualties could also be caused by a population depression caused by previous mortality, increased road avoidance behaviour or changes in traffic volume” (Lucas et al. 2017)

5.4 Surveys

Once the preliminary assessment has been completed, field surveys are used to provide baseline data on bat roosts and identify important bat habitat, flightlines and foraging areas.

Initial survey data are used to indicate if more detailed surveys, mitigation measures and subsequent monitoring are required. Data from the desk study and preliminary assessment should confirm what scale of survey, and level of survey effort are appropriate, depending on the likely impact of the scheme (see 5.1.4). After the survey and monitoring aims have been identified, the next stage is to consider how to obtain the necessary information in the most cost-effective way using methods that cause the least disturbance to bats.

Many countries have national guidance on conducting surveys for development (e.g. Collins, 2016, in revision), and see 2.1. The detailed guidance available elsewhere is not repeated here. The EUROBATS Publication Series No. 5 Guidelines for Surveillance and Monitoring of European Bats (Battersby, 2010) gives details of techniques for long term surveillance of bat populations. It lists recommended survey methods for European bat species. Some of the methods and protocols are also appropriate for surveying and monitoring of infrastructure projects.

In general, surveys should:-

- be designed and undertaken using published best practice guidance
- comply with local permitting arrangements
- be designed and overseen by bat ecologists with an understanding of the complexities of large-scale infrastructure projects and familiar with the range of bat species at the location.
- be undertaken by experienced surveyors, familiar with the ecology of the bat species found in the area. Where possible, the same surveyors should undertake pre-construction surveys and post-construction monitoring, or at least until survey and monitoring protocols are established.
- include preliminary assessments of potential roost structures or habitat features (e.g., trees, caves), followed by field surveys in the appropriate season to determine use
- only use invasive techniques involving capture or handling where justified, e.g., where visual and bat detector observations are inconclusive or more detailed information is needed. The survey design must take account of current guidance on invasive techniques (EUROBATS Resolution 4.6).

5.4.1 Roost assessment and categorisation

This includes surveys of buildings, bridges and other structures, bat boxes, trees, and underground sites (caves, mines, cellars, tunnels, and rock features). They are assessed through daytime surveys combined with emergence (dusk) or re-entry (dawn) surveys.

Confirmed or potential roosts are categorised according to their use by bats (e.g. Collins 2016)

- feeding perch
- night roost
- day roost (non-breeding)
- mating site
- autumn swarming site
- occasional / transitional roost
- satellite roost
- maternity roost
- hibernation site

The survey should aim to establish how many bats of each species use the site and for which purpose. A single site may be used for different functions at different times of the year by one or more bat species. The survey timetable needs to be planned to take account of potential use in different seasons based on the preliminary assessment of potential roosts in the study area. More intensive surveys will be needed for roosts that will be affected by the scheme to establish baseline data.

5.4.2 Roost survey methods

Daytime surveys of buildings and structures involve systematic searches of the exterior and interior, using torches, and endoscopes to search for bats, or signs of bats (stains left by roosting bats, urine stains, droppings, moth wings and other prey remains). Bat species present may be identified from visual observation of roosting bats, and *DNA analysis* of bat faeces. Garrett et al, (2023) demonstrated that airborne sampling of Environmental (e) DNA can be used to detect multiple species, including bats. The technique can potentially be used as alternative to invasive methods such as trapping and handling where identification to species can be problematic but more research to provide robust protocols for its use.

Daytime surveys can result in disturbance of bats. Entering roosts at sensitive times of year (hibernation, breeding roosts with pregnant mothers or dependent young) should be avoided or limited if unavoidable.

Dusk/emergence and dawn/re-entry surveys are usually undertaken by surveyors with hand-held bat detectors. ***Passive acoustic monitoring (PAM)*** may be used, i.e. static detectors left on site to record for multiple consecutive nights. Professional bat surveys should use the best available equipment appropriate to the task; at the time of writing this includes ***full spectrum ultrasonic bat detectors***, with the capacity to record sound files for analysis. ***Night vision aids (NVA)*** including ***infra-red (IR)*** and ***thermal imaging (TI)*** viewers (scopes) or cameras, are becoming accepted as industry standard requirements for observational bat surveys for development (e.g., Fawcett-Williams, 2021, Crompton *in press*). ***NVA*** video footage if recorded can be reviewed and retained.

A combination of daytime and dusk/dawn surveys provides a better indication of the species present. One UK study found that daytime inspections were efficient in detecting open-roosting species (e.g. *Plecotus*) but not crevice-roosting (e.g. *Pipistrellus*). Furthermore, to be 95% confident that a building did not host a roost of *Pipistrellus* species a minimum of three acoustic surveys was needed, or four acoustic surveys for *Plecotus* species (Froidevaux et al. 2020).

Daytime and dusk/dawn surveys alone may not be sufficient to confirm the sex and breeding status of the bats, or the species identification for some species, in which case it may be necessary to handle roosting bats or capture bats in flight (see 5.4.3).

5.4.2.1 Bat roosts in natural features (e.g. trees, rock faces)
Identification of roosts in natural features can be problematic. Tree and rock crevice roosting bats exhibit frequent roost-changing behaviour, reducing the probability of observing bats exiting from the roost (Andrews & Gardener, 2015). It can be difficult to access the roost location (crevice, tree hole etc) to make close observations for faeces that may persist when bats are not present. Climbing surveys and the use of fibrescopes may be necessary. ***NVA*** and bat detectors may be helpful, but it may still not be feasible to confirm the precise location of roosts. See Eurobats Monitoring Guidance for further information on the use of fibrescopes Daytime inspections when vegetation cover is at a minimum may be needed to identify potential roost features and assess the likely value of the features and wider habitat as a resource for bats. See Bat Tree Habitat Key (2018) and Bat Rock Habitat Key (2021).

5.4.3 Bat activity surveys
Bat activity surveys are undertaken away from the roost. They may focus on bat activity at habitats affected by the proposed scheme such as commuting routes, flightpaths, foraging areas and migration routes used by the bat species recorded in the study area. They may also be undertaken to confirm the results of the preliminary assessment or be conducted in areas where information on the assemblage of bat species in the area is lacking.

The aims of the survey will influence the choice of methods used.

5.4.3.1 Acoustic surveys
Acoustic surveys using ultrasonic bat detectors are the basic method for surveying bat activity, either with observers using hand-held bat detectors, or *pam* (see above). Acoustic surveys are used to find out which bat species are in an area and may provide an index of activity which can be compared with other areas or the same area over time. A standardised method of assessing the levels of bat activity is essential so that pre-construction survey data can be compared to post-construction monitoring data.

Detectors may be deployed as *pam* or held by observers along a transect, which may be walked, cycled or driven.

A methodology developed in the UK was designed to be a cost-effective standardised protocol that can be used for both the initial assessment of the study area as baseline data before road construction and for monitoring landscape-scale impacts once the road is operational. The method uses walked bat detector transects with bat activity recorded during 10-minute stationary spot checks at 100 metre intervals on a 1km transect perpendicular to the road or railway. A minimum of 10 transects per site are needed to detect change in bat activity overall, or in activity of the most common species and more for rarer species. A minimum of three years monitoring post construction is recommended. Full details are given in Appendix E of Berthinussen & Altringham (2015).

A study in France found that a longer sampling duration is needed in unfavourable habitats, and habitats that are structurally complex. Adjusting sampling duration according to the ecological context enables relevant comparison between sites (Dubos et al. 2020).

The main benefits of acoustic surveys are that:-

- they are non-invasive
- deployment of detectors can be undertaken by surveyors with limited experience
- using ***pam**,* data can be collected over a wider area, or for longer than with hand-held detectors
- surveys and monitoring methods can be standardised and repeatable
- useful observations on bat flight height and direction and numbers of bats may be obtained if observers are equipped with ***NVA.***

The limitations of acoustic surveys are that:-

- no information is gained on the number of bats present, nor on their age, gender, or reproductive status
- skill is needed to identify species correctly, and it is not possible to identify all bats to species
- some species are less likely to be under recorded
- equipment left out in the field can fail, or be damaged or stolen
- improvements in technology mean that equipment becomes outdated and replaced, so the resulting data is not always comparable
- standardised recording and analysis methods are needed if data are to be comparable year or year and with other sites
- recordings result in a large amount of data which requires significant analysis time and safe storage and back up processes

More detailed information on acoustic survey methods can be found in the revised Eurobats Monitoring Guidelines (in prep)

5.4.3.2 Trapping and tracking surveys

Standard bat detector surveys may not be sufficient to identify flightpaths and pinpoint potential crossing points and more invasive and labour-intensive methods may be required. It may be necessary to trap bats to identify the diversity of bat species in the study area as rarer bat species are under-recorded by acoustic sampling methods (Richardson et al, 2019), or to confirm the age, sex or breeding status of bats.

Radiotelemetry / radio-tracking and ***Global Positioning System (GPS) tracking*** techniques can provide valuable data on roost use, activity patterns, home ranges, habitat use, and foraging and migratory behaviours. Radiotelemetry is useful for locating roosts, especially for tree-roosting species (Collins 2016).

GPS tracking technology makes it possible to obtain more accurate data on flight paths for the larger bat species, e.g., a study on *T. teniotis* showed that they use orographic uplift to ascend to over 1,600 m, and that modelling wind and topography can predict areas of the landscape able to support high-altitude ascents (O’Mara et al., 2020).

Bats must be trapped, and their condition assessed before being fitted with tracking devices. As with other survey methods, trapping should have clearly defined aims and outcomes so that bats are not stressed unnecessarily. Trapping near breeding roosts should be timed to avoid the periods when non-flying young are present unless there is a clear justification for doing so. Guidance on trapping methods is given in the Eurobats Monitoring Guidelines (in prep).

5.4.4 Traffic collisions - predicting and monitoring

As with all survey and monitoring, the aims should be clearly defined at the outset and the appropriate methodology used for the infrastructure type. The design of the survey should take into account the diurnal and seasonal activity patterns of the target species including any migratory species that are likely to be present. The effect of predicted increases in traffic volumes particularly in summer and autumn should be considered at the planning stage.

For new road or rail projects, activity surveys (as described in 5.4.3) should be undertaken at areas where bat activity is predicted or known to be high, and at control locations (since activity hotspots do not remain constant). Carcass searches (see 5.4.4.2) should be considered for projects to upgrade existing traffic infrastructure and for monitoring the effectiveness of mitigation (see 5.5.4) and as part of research to understand the wider impacts of traffic on bat populations.

5.4.4.1 Collision risk prediction

Baseline bat activity surveys (see 5.4.3) are undertaken prior to construction of new infrastructure. More targeted activity surveys are needed to inform scheme design, e.g. at potential crossing points identified using aerial photography, habitat surveys and the results of more general activity surveys. If habitat suitability modelling has been used as part of the early planning process, activity surveys can be used to update the models.

Since collision hotspot locations do not remain constant seasonally or from year to year, activity monitoring should be undertaken in different seasons and over a number of years pre- and post-construction (Medinas et al., 2013, 2021).

Claireau et al (2019b) developed a method of acoustic flight path reconstruction (AFPR) to study three-dimensional flightpaths of bats at roads and compared the orientation of bat flights and the proportion of bat passes at collision risk in different habitats. Bat crossings at overpasses designed to encourage bats to safely cross the road were compared with crossings at the main habitat types in the study area and at a control site in in less favourable bat habitat (open agricultural land) Two automatic stereo acoustic detectors per site were used, one on each side of the road overpass. The stereo microphones on each detector were spaced 3.5m apart to determine the direction of travel of any bat approaching the detector. The method is suitable for surveying at potential crossing points prior to construction and for monitoring the effectiveness of any mitigation structures once they are in place and when the road or railway is operational.

Paired or multiple static detectors combined with thermal-imaging recorders (Claireau et al. 2021) can be used to track or predict bat flightpaths to assess collision risks at roads and the effectiveness of mitigation measures. Claireau et al. (2021) demonstrated a method of reconstructing bat flight behaviour (bat tracking toolbox) using data from a thermal-imaging camera to estimate the flight trajectory and height of bats flying over a highway before and after construction of a bat gantry.

5.4.4.2 Carcass surveys for linear infrastructure projects
Roadkill locations and hotspots may change as bats alter their flightpaths in response to changes in the environment. Large-scale carcass surveys can test the accuracy of the collision hotspot predictions.

A standardised method should be followed to minimise bias and make data more comparable Analyses must take into account carcass characteristics, detectability, persistence and entry rates to obtain unbiased estimates of roadkill (Guinard et al. 2015).

The design of the survey should take into account the diurnal and seasonal activity patterns of the target species and if and when migratory species are most likely to be present. Regular and systematic monitoring for at least one year is recommended to take account of seasonal variations in weather conditions and animal behaviour (Santos 2011).

As with work on wind turbine collisions, it is crucial that future research on traffic infrastructure assesses observer efficiency and predator removal rates, so that better estimates of true casualty numbers can be derived. Searcher efficiency and carcass persistence trials should use trial carcasses with a similar body mass to the target species, and should be of the same taxon (e.g. bird carcasses remain longer than mammals), thawed carcasses are suitable for use (Barrientos et al. 2018).

Recommendations for bat carcass searches

- should be undertaken at, or immediately after dawn
- take place on a daily basis throughout the chosen sampling period
- sample during different seasons
- walked transects are preferable to driven transects
- use experienced observers and ideally the same observer should be used for consistency, although two people may be preferable for safety reasons
- use trained search dogs
- include tests of searcher efficiency rate (a second research places a known number of carcasses)

For detailed examples and protocol for searcher efficiency trials and data analysis please refer to EUROBATS publication (see section 4.2.2 in Rodrigues et al, 2014).

5.4.4.2 Casualty searches at airfields
Inspections are systematically undertaken at airfields to check for damage to aircraft, or hazards on the runway although the data are not always reported, particularly where a collision has not caused damage and is not considered to be significant (see 4.6.3).

A collision risk model for an operational airport could include comprehensive surveys at dusk and dawn using acoustic detectors and thermal-imaging cameras of bat activity at the site as a whole and quantify the proportion of bat activity within the collision risk zone. Carcass search protocols could be improved using trained search dogs. Searcher efficiency tests should be undertaken adapted from the methodology in Rodrigues et al. (2014). See also 5.5.4.

5.4.5 Noise assessment
Until a protocol for assessing noise impacts on bats is agreed it is recommended that the following factors should be considered as part of the EIA;

- Tolerance to noise, for different species and different activities (roosting, hibernating, foraging, commuting)
- Baseline conditions indicating existing levels of tolerance,
- Disturbance impacts may be greater for species with smaller range size and higher roost fidelity,
- Season and duration of potentially disturbing activities,
- Possible avoidance of areas resulting in loss or fragmentation of habitats used for roosting, foraging or commuting,
- Character of potentially disturbing noise (e.g. regular, continuous, intermittent, variable in volume) and its source

(Bentley & Reason, 2020)

As noted in 4.5.2 there is a lack of evidence regarding the effects of noise on bats and without further research it is not possible to give recommendations for thresholds above which additional noise may have a detrimental effect. In the absence of data, a pragmatic approach is recommended that assumes that bats are adapted to existing baseline conditions and impact assessments should consider the effects of additional noise (West, 2016).

Baseline and additional noise level data should be collected using unweighted high-frequency noise measurements based on frequencies audible to bats (~8 kHz upwards). Data collection should continue during construction and during the operational phase to monitor the bats’ response to noise (Reason & Bentley, 2020). The resulting data should be made freely available so that impacts can be better understood, and evidence-based mitigation methods developed for the future. (EUROBATS Resolution 7.9).

5.4.6 Survey and monitoring reports

EUROBATS Resolution 8.10 recommends that assessment reports of projects are objective and meet appropriate quality standards. A checklist is being developed to assist authorities in assessing reports and will be published as an Annex to Resolution 9.

The system and format for recording the results of surveys should be consistent throughout the pre-construction survey and post-construction periods.

Reports should include information on -

- personnel involved in the survey and data analysis and their relevant experience
- how sampling sites were chosen,
- date, time and duration of sampling activities,
- weather conditions,
- equipment and survey methods used, referring to manuals or guidance that have been followed
- any limitations to the sampling activities (e.g. access restrictions, unsuitable weather, equipment failure)
- if non-standard or novel methods or equipment are used, the report should give specific details of the methods or equipment used and explain why they were chosen.

The reports should give a clear summary of information including quantitative results, statistical analyses and conclusions and should be publicly accessible. Reports in the public domain can be submitted to the World Bat Library in Geneva[12] where they will be catalogued and made available on request.

[12] batbiblio-cco.mhn@ville-ge.ch

Recent technological advances in equipment have not yet been matched by standardization of methodologies for analysing and interpreting survey data, making the assessment of the ecological value of a site very subjective (Lintott et al, 2017). For acoustic surveys it is important to state which acoustic recorder and microphones were used, and which settings were used (trigger level, gain, time of recording, etc). Without this information, it is impossible to compare the results with other study sites or to reproduce the methodology on the same study site year on year. Relevant definitions should be provided for technical terms where these would otherwise be open to interpretation, e.g. quantifying relative abundance using the unit of a “bat pass” considered as the sequence of a minimum of two echolocation pulses within a 5 second acoustic recording, as in Millon et al. (2015).

In the case of acoustic surveys, the raw data are large “.wav” files which are processed using algorithm-based sound analysis programmes, each often associated with a brand of bat detector, making standardisation problematic. Online systems are being developed to allow users to upload sound files for analysis and storage, e.g. “Ecobat” (www.ecobat.org.uk) an online system developed to allow users to compare the levels of activity for each bat species identified to a reference data collection at similar sites within a specific geographical region (Lintott et al. 2017).

Standardised systems for recording other types of data are available and recommended for use, e.g. the spreadsheet “Standardised form for recording survey data relating to lighting and bats.xlxs” and “Airport Spreadsheet Template.xlxs” (available via the EUROBATS website).

Most countries have national reporting forms for recording wildlife collisions (strikes) at airfields or in the air, however these are not consistent and local aerodromes have their own internal reporting systems. Some countries do not report bird and bat strikes separately and some do not report strikes of any small mammals (Ball et al. 2021).

Reporting of bat mortality data could be improved by

- ensuring that “bat strike” is specified on internal / external strike report forms
- encouraging all national authorities to report bat strikes
- encouraging airport operators to collect and retain bat strike carcasses and submitting them to museums or other appropriate agencies for identification and retention. The use of forensic DNA analysis to identify specimens to species is recommended (Peurach et al. 2009, Kelly et al. 2017)

5.4.6 Evaluation of survey information

In this phase, the survey data are combined with the understanding of impacts that the type of traffic infrastructure has on each of the species present and their ecological functionality in the scheme area. If the proposed scheme will have a significant impact on these that cannot be avoided, then mitigation or compensation must be incorporated [see **Chapters 6 and 7).**

The survey and monitoring strategy should be reviewed at this stage to check if the proposed levels and methods are still considered to be appropriate and proportionate or need to be changed in the light of the results so far.

5.5 Monitoring

As noted in 5.3.1 monitoring must be considered as part of an integrated survey and monitoring strategy otherwise, it will not be possible to draw conclusions from the monitoring. Monitoring of impacts should consider the potential impacts of the scheme on **each** species recorded during the pre-construction survey.

Survey and effort should be proportional to the risk to the species and its importance at the site. The assessment of risk should include an appraisal of the likelihood of the mitigation being effective. The effectiveness of some mitigation techniques is unclear (e.g. Møller et al, 2016) and more effort may be needed to demonstrate that novel or unproven techniques are effective. This will be beneficial to all parties in the long term. In the case of large infrastructure projects, it is generally easier and more cost-effective to incorporate mitigation into the design than to retrofit.

Below we describe different types of monitoring undertaken at different stages of the construction and operational phases of a project.

5.5.1 Compliance monitoring

This type of monitoring is undertaken to check that all elements of works undertaken for mitigation / avoidance / compensation purposes have been carried out as intended; that any mitigation structures, hedgerows etc. have been constructed or planted in accordance with the design. Some minor issues (snags) are inevitable so there needs to be a system in place to identify where mitigation measures are not compliant with the design and to remedy them.

In the case of a planting scheme, if many young trees die off, perhaps due to unseasonal weather conditions, then there may not be a recognisable hedgerow for commuting bats to follow. The system of compliance monitoring should initially check that the planting has been undertaken using the tree species and size specified in the design and that the trees have been planted in the correct location. There should be an appropriate management routine in place with regular checks to ensure that the planting has established. In the longer term, the vegetation should be included in the habitat management plan (HMP) for the scheme. It is not uncommon for mistakes to occur because the contactor does not understand the need or rationale for specific items detailed in the design, so that the constructed mitigation seems to be compliant to the contractor but fails to meet its objective. A common example is for linear mitigation features to be discontinuous e.g., gaps between fencing and hedgerow which can encourage bats to fly through the gap, rather than along the linear feature. [e.g. In Practice article – Reference]

Except for very small schemes, a suitably qualified and experienced Ecological Clerk of Works should always be employed to supervise and check that mitigation measures have been installed as designed. On very large schemes it is good practice to have an independent audit system for checking and reporting on compliance.

For more complex mitigation structures such as purpose-built bat roosts, there are numerous factors that can affect the likelihood of the mitigation being effective and which need to be considered when assessing the effectiveness of mitigation (Schofield et al, 2018).

5.5.2 Monitoring of effectiveness

It is essential when designing a pre-construction survey and a monitoring strategy to set specific questions that both should answer. Specific measurable criteria need to be set so that the effectiveness of mitigation can be determined.

The distinction must be made between "use" and "effectiveness" (Berthinussen & Altringham 2015) (see Box in 7.1). For example, if a new section of road includes tunnel as a mitigation feature to guide bats safely under the road, if some bats use the tunnel but the majority fly over the new road, at risk of collision, then the mitigation feature is "used", but not "effective". A monitoring scheme that simply observes the mitigation feature (bats' use of the tunnel) without monitoring movement above the road will fail to pick up the critical information that the mitigation structure is not functioning as intended and remedial action will not be triggered.

In the past, there has often been a lack of good baseline data, making it difficult to draw reliable conclusions about the effectiveness of the mitigation at a site, or of the impacts of a scheme, or more widely of the effectiveness of particular mitigation techniques and strategies [References HA review, Altringham]. In some cases, this is because of the length of time that has elapsed since the initial assessment was undertaken and previous studies used survey techniques that are not comparable. Update surveys will be required where the survey information is considered to be insufficient to provide a baseline or where local circumstances have changed since the initial assessment. Changes of personnel also account for lack of continuity as different surveyors use different survey protocols.

Standardised survey methods, including the analysis and reporting of data are available in the UK Bat Survey Guidelines (Collins, 2016), although these do not specifically address large-scale infrastructure projects.

5.5.3 Monitoring landscape-scale impacts

Different methods may be appropriate, depending on the aims of the study. These should be decided as part of the process of designing the survey and monitoring strategy. (See 5.3.1).
Acoustic monitoring can be used to measure bat activity pre- and post-construction, or in comparison with control sampling sites (e.g. Berthinussen & Altringham, 2015, see 5.4.3.1).

Genetic analysis of bat populations can demonstrate whether mitigation measures have been effective in maintaining functional connectivity affected by traffic infrastructure (Barrientos et al 2021).

5.5.4 Collision prediction and monitoring

On established roads, the location of roadkill hotspots may change if previous mortality has already reduced populations in the area. Per capita road collision mortality (the chance of an individual in a population being killed) may indicate the most effective location for mitigation (Zimmerman Teixeira et al 2017), see also Chapter 7. In the absence of casualty data, per capita mortality can be estimated by multiplying the proportion of individuals flying in the collision risk zone by the proportion of bat passes flying in this zone simultaneously to a vehicle pass (Roemer et al. 2021) See also 4.6 Medinas et al.[Date].

There are mechanisms for reporting wildlife strikes for aircraft but it is not clear how consistently they are applied in the case of events that do not result in damage or delay to operations. Standard templates for reporting are used by many aviation authorities. There are no similar templates for road or rail bat casualty reporting.

5.5.5 Reporting on monitoring

See also 5.4.5 for recommended information that should be included in survey and monitoring reports.

At each stage there should be a feedback mechanism identified to address any problems preventing the mitigation from being effective. It is not sufficient just to monitor non-compliance or mitigation failure; action to remedy the issues must be taken as soon as possible.
Interim reports for monitoring success of mitigation should be produced at appropriate intervals (e.g. at least annually at the end of the bat activity season) so that any issues arising can be dealt with before the following season. Reports should include summary statistics (e.g. means and associated variances) and test statistics (e.g. t-values and df from a t-test comparing impact and control sites, and the exact p-values (Rytwinski et al, 2016).

Wherever possible raw data made should be available for analysis to further understanding of the impacts and promote effective mitigation (EUROBATS Resolution 7.9).

Reports should be publicly available. The BatLibrary hosted in Western Switzerland is willing to host all such reports [Reference]

Table 3 Steps for including research on ecopassage effectiveness in a road construction project (Lesbarreres and Fahrig 2012)

Step	Description
1. Preconstruction: determine the potential connectivity impacts of the road in the area of concern	• Identify the set of species whose movements are most likely to be affected by the road, as well as their relevant ecological requirements • Identify the relevant spatial and temporal scales for these species, the former based on movement range and the latter based on movement frequency
2. Identify goals for the ecopassages	• Set quantitative targets for species (e.g. increased frequency of crossing) • Determine type(s), size(s) and other design criteria for the planned ecopassages
3. Identify control and ecopassage sites and collect 'before' data	• Determine the number and location(s) of planned ecopassages as well as two types of 'control' site [(i) no road planned at the sites; or (ii) road but no ecopassage planned] using a suitable (e.g. randomized or blocked) experimental design • Determine alternative designs in case resources are insufficient to implement the optimal design • Conduct power analysis to determine the replication (in time and across sites) needed to detect effects of the ecopassages • Design monitoring protocols for both the future ecopassage sites and the control sites • Collect 'before' data on animal movement at the future ecopassage sites and the control sites
4. Post-construction monitoring	• Install the ecopassages • Continue with the same protocols for monitoring animal movement at the ecopassage sites and the control sites for a period determined by the power analysis (see above) • If possible, maintain the same field personnel throughout the study to reduce the observer bias and limit training needs
5. Analyze data and report	• Analyze data with regard to the goals in Step 2 and draw conclusions. The ecopassage is partially successful in maintaining connectivity if the reduction in road crossings before versus after the road is built is less at the ecopassage sites than at the no-mitigation control sites. The ecopassage is completely successful in maintaining connectivity if the difference in road crossings before versus after mitigation is the same for the ecopassage sites as for the no-road control sites. • Report on the study results to sponsors, stakeholders, other transportation agencies and road ecology researchers. Publish results in peer-reviewed journals that can be accessed by the widest audience • If the mitigation is unsuccessful or less successful than desired, redesign it and repeat the process

[a]Research is needed to evaluate effectiveness of ecopassages. This is best done by incorporating a BACI research design [18] directly into a road project. This should result in both improved ecological condition for the site itself and new information that can be used to improve other road projects either at the same or other sites.

6. Preventing and minimising impacts

If significant adverse impacts are expected, the impact assessment should provide effective and adequate measures to **avoid** and then to **mitigate** (if avoidance is not possible) these impacts. Finally, it will be necessary to **compensate** for any residual effects that cannot be completely avoided or mitigated (**the mitigation hierarchy**) with the aim of resulting in “no net loss”. Mitigation or compensation will also be necessary if any unpredicted significant adverse impacts are identified by the post-construction monitoring. Compensation (e.g. habitat creation) is unlikely to be sufficient to negate significant negative impacts on bat populations because of their slow reproduction rate.

The significance of impacts will depend on the species’ ecology and the features of the particular site and the proposed project (see Chapter 3). Thus, effective and adequate measures for avoidance, mitigation and compensation of any traffic infrastructure can only be designed based on the detailed findings of the impact assessment (Bickmore 2003, Limpens et al. 2005a, National Roads Authority 2005, Hinde 2008, O’Connor et al. 2011, Berthinussen & Altringham 2015, Elmeros et al. 2016a).

These measures will always have to be site-specific and most often also species-specific.

A thorough understanding of the ecology of the different bat species affected by a scheme is essential for developing adequate and effective measures, therefore advisors to the project need to have specialist knowledge of the species and the type and scale of the development (Bickmore 2003, National Roads Authority 2005, Limpens et al. 2005a, Elmeros et al. 2016a).

The aim of avoidance and mitigation measures is to enable bats to safely cross the road whilst preventing or minimizing both the barrier effect and collision risk simultaneously; otherwise, increased permeability might be compromised by a continued risk of collision mortality (Limpens et al. 2005b, Wray et al. 2006, Altringham 2008, O’Connor et al. 2011, Berthinussen & Altringham 2011, 2012, 2015, Møller et al. 2016, Elmeros et al. 2016). These potentially conflicting requirements need to be considered at an early stage of the scheme planning process so that mitigation is integrated into the design rather than being a costly add-on later.

The effectiveness of implemented avoidance, mitigation and compensation measures should also be monitored against baseline data collected during impact assessment prior to construction, and changes suggested if needed, until success has been proven.

6.1 Selection of traffic routes / infrastructure locations

Routes of roads and railways, as well as the location of supporting infrastructure, should be selected to avoid important bat habitats and their key elements wherever possible (Bickmore 2003, Limpens et al. 2005a, b, National Roads Authority 2005, Hinde 2008, Nowicki et al. 2009, Elmeros et al. 2016a). Disruption of commuting routes and destruction of roost sites should be avoided, or minimised, otherwise complex and expensive mitigation measures are likely to be required. Careful consideration of the route corridor is the single most effective means of avoiding or reducing ecological impacts (O’Brien et al. 2018). In at least one case, a proposed road scheme was rerouted at the design stage to avoid key bat commuting routes close to a maternity roost (Green and Wyatt, 2009) (see Annex 5).

A permeability plan should be designed for the scheme to include all connecting elements, such as tunnels, viaducts, underpasses, overpasses, stream and river crossings and culverts designed or adapted to facilitate wildlife movement should be integrated into an assessment of connectivity. The primary objective must be to maintain permeability for wildlife across transport infrastructure and to ensure the connectivity of the habitats within the landscape (Luell et al. 2003, IENE 2022).

6.2 Construction timetable

Although roost destruction must be avoided whenever possible in some cases roosts will be destroyed or damaged (see 4.2). Bat fatalities must, however, be prevented. The risk of fatalities as a result of the construction phase is highest for hibernating bats and for juveniles in maternity roosts (see Chapter 3).

The best strategy to avoid disturbance, as well as fatalities in roosts, is careful planning of the work schedule (Limpens et al. 2005b, Keeley 2005, Green & Rasey 2006, Hinde 2008).

- Destruction of, and damage and disturbance to hibernation or nursery roosts, must be prevented in all cases by restricting works in their vicinity while bats are present within them (i.e., works should be scheduled for the time of the year when bats are active but outside the maternity season).
- Destruction of, and damage and disturbance to other roosts should be prevented whenever possible, also by restricting works in their vicinity while bats are present within them (i.e. works must be scheduled for the time of the year when bats are not using these roosts).
- Disturbance to foraging and commuting bats should be prevented by restricting construction activities to times of the day and year when bats are active (i.e. works should generally be planned for the daytime; only during the winter can they also take place after sunset, but only if hibernation roosts are not present).

Annual and daily life cycles of bats vary across Europe and they also differ between species (see **Chapter 3**). The impact assessment should gather sufficient information on temporal patterns of bat activity and on bat roosts in the study area to determine the appropriate periods for works that may affect bats. However, since many bat species switch roosts frequently, **additional roost surveys immediately prior to tree felling, or the destruction of other structures with potential to support roosting bats**, is needed and timing changes applied accordingly (Keeley 2005, Limpens et al. 2005b, Nowicki et al. 2009).

6.3 Bat roosts – preventing destruction, disturbance and killing

During construction or maintenance works, movements of construction machinery and other activities may accidentally destroy or damage trees and other structures with roosting potential (Hinde 2008, Nowicki et al. 2009). To avoid this, all roosts (and potential roosts) on the site and in the immediate vicinity that are identified during surveys should be clearly marked (with coloured tape etc.) and/or fenced-off during the works (Keeley 2005, Nowicki et al. 2009).

The unlicensed destruction of bat roosts is prohibited by law in most EUROBATS range states and must be avoided (see **Chapter 3**). Destruction of some identified or potential bat roosts may be inevitable in certain cases such as major transport infrastructure projects in forests and/or the reconstruction/maintenance of bridges and may be allowed under a licensing or permitting system where it cannot be avoided. Normally destruction of maternity and hibernation roosts is not permitted. Destruction may only be carried out when bats are absent, which must be confirmed by survey immediately prior to destruction (Keeley 2005, Limpens et al. 2005b, Nowicki et al. 2009). Only very exceptionally can an occupied roost be destroyed, and only after the bats have been safely excluded as a last resort to avoid fatalities (Keeley 2005, Limpens et al. 2005b, Hinde 2008, Nowicki et al. 2009). In most of the European countries exemption and exclusion procedures are legally regulated, they require a robust justification and can only be done under licence.

The licensed exclusion of bats and destruction of an identified bat roost must be undertaken or supervised by a suitably experienced bat specialist, so that emergency measures can be taken promptly to prevent unpredicted fatalities (Keeley 2005, Limpens et al. 2005b, Nowicki et al. 2009). Planning and licensing authorities should require this as part of the permitting process for actions that would otherwise be unlawful.

Two Eurobats publications focus on the protection and management of underground sites for bats (Mitchell-Jones et al., 2007) and overground roosts (Marnell & Presetnik, 2010) EUROBATS Publication Series Nos. 2 and 7.

6.4 Preventing and reducing pollution – light, noise, chemical.

Preventing or minimising pollution of all types is intrinsic to good infrastructure design.

6.4.1 Lighting

Current recommendations are to firstly to avoid unnecessary artificial light at night (alan), and secondly to work with qualified lighting engineers to balance the requirements and regulations regarding lighting for safety with obligations to minimise environmental impacts.

The effects of lighting must be considered for the construction as well as the operational phase of an infrastructure project. Lighting of compounds and construction sites should be kept to the minimum and targeted where required for security and safety purposes.

A thorough review and guidance on the subject can be found in EUROBATS publication series No 8 *Guidelines for consideration of bats in lighting projects (Voigt et al 2018b).* The EUROBATS Intersessional Working Group will consider revising the guidelines when new evidence is available. The UK’s Bat Conservation Trust’s guidelines will be updated in 2023 (see https://www.bats.org.uk/our-work/buildings-planning-and-development/lighting for the latest version).

The most important parameter to control is the placement of the lights. The decision to retain or introduce new lighting remains the principal factor in limiting light pollution, especially in protected areas where protected sensitive species exist. (Pauwels et al 2021).

With new technologies light flux can be changed even after being installed. Modern street lights may be modified to reduce the amount of light and direction to reduce light spill (Kinzey et al., 2017). Dimming LED streetlights to 25% of their typical intensities may also be effective for maintaining activity levels of *Myotis* bat species that typically avoid light (Rowse et al. 2018).

Switching off illumination for part of the night may reduce the impacts of lighting for *Plecotus* species but may not necessarily be effective for other bat species (Azam et al. 2015, Voigt et al 2021). Part-night lighting schemes intended as mitigation need to be designed around bats’ activity patterns wherever possible, i.e. avoiding disturbance during the peak activity periods after evening emergence and in the early morning whilst taking account of road safety requirements (Azam et al. 2015). See also Voigt et al. (2018b).

The presence of vegetation close to light sources may alleviate negative impact on bats by providing dark corridors (Mathews et al. 2015, Straka et al. 2019, Barré et al. 2021a) but may also increase the chance of bats flying within the collision risk zone.

6.4.2 Noise

Potentially harmful noise pollution should be considered as part of the early project planning stage as they may influence the scheme design and timetable. Disturbance at the construction stage can be minimised by timing necessary works to avoid sensitive periods, for example avoiding blasting near known hibernation sites during winter close to known bat roosts. Where this is not possible, temporary sound shields may be installed, provided these can be sited in a position that limits noise at the roost whilst maintaining access for bats (Caltrans 2016). Permanent noise barriers can be incorporated into barrier screens that also function as light barriers (Cichoki, 2015).

As noted in 4.5.2 there is a lack of evidence regarding the effects of noise on bats. Further research, including BACI studies of the disturbance impacts of noise on bats and the efficacy of mitigation methods is needed (see recommendations in 5.4.5).

6.4.3 Chemical

Changes in air quality due to infrastructure projects tend to be considered during the environmental impact assessment (EIA) process primarily because of the negative impact on human health but impacts on habitats and wildlife should also be considered. Preventative measures to reduce contamination of water courses and aquatic habitats through run-off water and from maintenance practices should be considered in the scheme design and when drawing up the scheme’s long term management plan.

6.5 Minimising collision risk

If motorways are built through bat habitat, trade-offs between optimal mitigation of impacts on protected bats and cost/engineering practicality are inevitable. For example, large underpasses are advisable where possible as they accommodate a wider range of species, and bats are less likely to fly over them, however, their construction is costly and dependent on landscape topography. Incorporating a greater number of suitably located small tunnels into new roads may facilitate safe passage for ***clutter adapted species*** more effectively than fewer large underpasses (Abbott et al., 2012b) although mitigation needs to be effective for all affected species.

The road traffic collision risk for a species depends on (1) its **local abundance/activity** (2) the **proportion of time spent in the collision risk zone** and (3) the **simultaneous presence of bats and vehicles in the collision risk zone**. It is therefore necessary to take each of these into account when investigating collision risk (see Abbott et al., 2012).

An understanding of the **local abundance / activity** of each species can be gained through the environmental impact assessment process and must be considered during the route selection and detailed planning stages. The aim of any scheme must be to maintain or increase permeability for bats whilst limiting mortality risks, which is challenging. Bats flying in or close to the collision risk zone may be using the linear route as a commuting route or foraging area or crossing over the road / track. While there is little that can be done to alter factors 2 and 3 above, they are crucial to an understanding of collision risk.

7 Mitigation and compensation

A variety of approaches have been tried across Europe to mitigate the impacts of roads and traffic on bats. This section provides a general guidance on design and implementation of mitigation and compensation measures. However, any specific mitigation programme can only be designed based on the impact assessment of particular traffic infrastructure (see Chapter 6).

A multi-species approach is recommended, but it is essential to clearly identify the main target species and recognise that different taxa and even different species within the same taxon require different types of structures and habitat (IENE, 2022).

The effectiveness of implemented measures should be monitored (see section 5.5), and changes suggested if needed, until success of a mitigation programme has been proven.

7.1 Effectiveness

Qualitative data and even anecdotal records of bats using certain structures have quite often been used to demonstrate the effectiveness of particular mitigation measures. However, use by a number of bats, does not guarantee that the local population will not be affected, i.e. usage does not equate to effectiveness (Corlatti et al. 2009, Ree, Van der et al. 2007, Berthinussen 2013, Berthinussen & Altringham 2015, Møller *et al*. 2016).

Mitigation features may be “used” by bats but are only “effective” as mitigation if bats cross the road safely, out of the collision risk zone.

For a crossing structure to be effective, at least 90% of bats crossing the road must use it to fly safely over or under, whilst for the overall mitigation programme to be successful, the same target should be met relative to the total number of bats crossing in the relevant area before construction (Berthinussen & Altringham 2015). Although this is a precautionary figure and not all bats crossing elsewhere will be killed, a potential increase in mortality of 10% within a population, or even just 5%, would be unsustainable (Schorcht et al. 2008, Altringham 2008, see Chapter 3). Furthermore, only if such figures have been confirmed by robust long-term monitoring (see section 5.5), can effectiveness be confidently demonstrated (Berthinussen 2013, Berthinussen & Altringham 2015, Møller *et al*. (2016).

Figure 6 Flight routes under and over a railway the TGV Rhin-Rhône railway in France (Alain Lugon, from l'Azuré, reproduced from Elmeros et al, 2017)

"Use" versus "effectiveness"

Bats may "use" a mitigation feature, e.g. be guided to follow the same line as a gantry to cross a road. However, if the bat's flightpath takes it within the airspace used by vehicles, then it is still in danger of collision and the mitigation is not "effective" in preventing mortality.

Demonstrating **use** can be achieved by observations of bats crossing the road, e.g. detecting bats on one side and then on the other side within a short time frame. However, proving **effectiveness** is more difficult. Observations need to show without doubt a) that bats are not deterred by the mitigation structure and avoiding crossing the road and b) that bats cross the road at a safe height, either above or below the airspace used by vehicles.

Targets should be set using data on numbers of bats of **all** species crossing the area before construction. Monitoring should be undertaken using methods (see section 5.5) that will be able to confirm that **90%* of each bat species** crossing the road is doing so safely after construction

**The figure of 90% is based on the precautionary principle, taking into account the lack of evidence available on population impacts and the inability of methods to detect change in bat activity data that is already intrinsically variable. If a majority of bats is "using" the structure but the 90% threshold I not met, it suggests that the structure may potentially be effective with some improvements but until this has been demonstrated, the structure cannot be considered to be effective and may result in a local population decline (Berthinussen and Altringham, 2015).*

Properly controlled and extensive studies into the effectiveness of mitigation measures have only become available in recent years, the most comprehensive being those commissioned by the UK Department for Environment Food & Rural Affairs – DEFRA (Berthinussen & Altringham 2015) and the Conference of European Directors of Roads – CEDR (Elmeros & Dekker 2016, Elmeros *et al*. 2016a, b, Møller *et al*. 2016, Christensen *et al*. 2016, Dekker *et al*. 2016, Van der Grift et al., 2018). These and other studies have identified certain general principles/criteria that any mitigation success depends on, which are listed in the box below.

Effective mitigation measures are:

- Able to minimise both barrier effect and collision risk simultaneously, i.e. to ensure permeability and safe crossing
- Appropriate for the species affected (especially with regard to flight ecology)
- Located on pre-existing traditional commuting routes
- Functionally integrated into (connected to) landscape and habitats
- Undisturbed and free of danger during the night (appropriate lighting, protective vegetation or screens, etc.)
- Developed in advance and planned alongside the development stages of the scheme
- Implemented in a timely fashion (some must be put in place before construction works start and some before operation)
- Permanent and properly managed and maintained (included in management/maintenance plans)

An overview of structures and strategies used to mitigate impacts of roads and traffic on bats is given in sub-sections 7.2.1- 7.2.3 along with recommendations for or against their use. For more detail, see the DEFRA and CEDR reports (Berthinussen & Altringham 2015 and Møller *et al*. 2016). The recommended measures (7.2 below) are those that have been proven to be effective, though it should be noted that none of them will be effective in all circumstances. Measures are described as potentially effective (7.3) if studies have indicated that they are effective in some situations for some species, but further research is needed. Those shown to be ineffective in all circumstances (7.4) are not approved and should not be used. Research on the effectiveness of all mitigation measures is needed as this has been lacking to date. However, as some methods are known to be effective, the use of proven methods should be prioritised over novel or unproven methods to prevent unnecessary bat mortality.

7.2 Structures and features effective in facilitating safe crossing (Recommended)

The structures in this section have been proven to be effective, at least for certain species / ecological groups and in certain ecological setting. Crucial factors determining effectiveness are emphasised, though it should always be remembered that all the criteria set out above (in the text box) must be met.

Some studies looking at bat interactions with structures over roads (e.g. footbridges) or unvegetated overpasses (Abbott et al., 2012; Berthinussen and Altringham, 2012; Bhardwaj et al., 2017), indicate that features such as strategic location, size, connectivity of tree lines and mature vegetation encourage the use of overpasses by bats, whereas road flyovers (high level road bridges) or footbridges, are not effective (Abbott et al., 2015; Altringham and Kerth, 2015). It is likely that a key factor determining the use of overpasses by bats is the presence and structure of appropriate vegetation.

Efforts should be made to avoid affecting key habitats and to avoid bisecting linear features used as flightpaths, as this can increase collision risk. If bisecting flightpaths is not avoidable, the vertical alignment of the road may be altered so that underpasses of sufficient height can be installed beneath the carriageway as mitigation for clutter adapted species. Raising the height of the carriageway increases the land take required for the scheme, so needs to be considered at an early stage. Increasing road height as mitigation for open airspace adapted species is only likely to be achievable through the use of viaducts or open span bridges.

7.2.1. Green bridges (fauna overpasses)

Green bridges are purpose-built bridges, usually over a major road or railway, intended to mitigate the barrier effect of transport infrastructure for all terrestrial groups of animals.Their integration into the surrounding landscape and habitats and resemblance to natural features are crucial factors determining their effectiveness for bats (Bach & Mueller-Stiess 2005, Bach & Bach 2010, Stephan *et al.* 2012, Berthinussen & Altringham 2015, Møller *et al*. 2016), but if well-designed and appropriately located, they are likely to be effective for all bat species regardless of their flight ecology. Green bridges are the optimal mitigation structure for guiding bats safely over roads but are unlikely to be constructed as a mitigation measure exclusively for bats due to demanding technical issues and high cost. Nonetheless, bats should be considered whenever green bridges are planned, regarding their location and design. In practice, there is a trade-off between the number of structures installed, their locations and their effectiveness.

Their effectiveness depends on:

- being sited at the optimal location (i.e. on an existing bat flight path)
- connecting hedgerows and trees with other bat habitat in the surrounding landscape

- being planted with dense woody vegetation of fast-growing native species (2 – 4m high)
- screening along each side of the overpass to deflect noise and light (Elmeros, 2018)

7.2.2. Bridges and viaducts as underpasses

Bridges and viaducts built to support traffic infrastructure across a watercourse or a valley and are not usually specifically designed to mitigate the barrier effect for wildlife, but they can still provide large and suitable underpasses (Iuell *et al*. eds. 2003). Since they are built over the landforms that often define bat commuting and migration routes (and where foraging activity is also highly concentrated) they are likely to be effective for many bat species, providing that the clearance height above water or vegetation is sufficient to avoid putting open-space foraging bat species at risk of collision (Altringham 2008, Berthinussen & Altringham 2012, Abbott 2012, Abbott *et al.* 2012a, Møller *et al*. 2016). Bridges are unlikely to be built specifically as a mitigation measure for bats, but as they can perform this function, the requirements of bats should be considered in the choice of location, design and the clearance height. Retaining wide walkways or riverbanks under open span bridges or viaducts can allow passage for bats and other wildlife; these extended stream crossings are cost-effective as they provide connectivity for most wildlife and may reduce the number of mitigation structures needed (Lesbarreres & Fahrig 2012).

Roads built on raised embankments pose a particular danger to bats, especially if they sever treelines where bats flying at canopy height enter the collision risk zone as they cross the road (Berthinussen & Altringham 2015) Furthermore, embankments, which are often preferred alternative to open span bridges and viaducts from economic point of view (Luell *et al*. 2003), increase both barrier effect and collision risk for bats and other wildlife (Nowicki *et al.* 2009, Berthinussen & Altringham 2015). Therefore, bridges are clearly preferable long-term alternatives when considering bat conservation and multiple ecological benefits (Luell *et al*. 2003).

7.2.3. Tunnels and culverts as underpasses

Tunnels and culverts are structures built under the road or railway, usually in hilly areas or where the transport infrastructure is on an embankment, either as purpose-built wildlife underpasses, or for other purposes – tunnels to lead minor roads, railways and farm tracks etc., and culverts to allow the passage of water (Luell *et al*. 2003).

Underpasses are potentially effective for all except open-air bat species, providing that their location and design does not require bats to alter flight height or direction.

Species-specific effectiveness of underpass is determined by the cross-sectional area, height in particular, rather than its length (Boonman 2011, Abbott 2012, Abbott et al. 2012b, Berthinussen & Altringham 2012, 2015, Møller et al. 2016) thus leading to published recommendations on the required species-specific dimensions of underpasses (e.g. Limpens et al. 2005b, Hinde 2008, Berthinussen & Altringham 2015), although further research is necessary (Møller *et al*. 2016).

The required heights are generally lower for clutter-adapted species (~3 m) compared to generalist / edge-adapted species (~6 m) (Berthinussen & Altringham 2015). Even narrow drainage pipes may be effective for certain species (Bach et al. 2004, Berthinussen & Altringham 2015) but such small structures are unlikely to meet the requirement to mitigate for all bat species affected at a site.

Species-specific effectiveness is also determined by the landscape / habitat setting (Laforge et al 2019).

Culverts seem to be more effective than (dry) tunnels, possibly because the watercourses function as commuting routes for many smaller low-flying bat species (Møller *et al*. 2016). Being cost-effective, multiple culverts can be installed in areas where numerous commuting paths are intersected. Underpasses built for other purposes can also be adapted for bats (e.g. tunnels for pedestrian access by restricting the lighting and small wildlife underpasses and culverts made larger), especially if bats are considered early in the planning stage [Abbott – reference].

		Effectiveness for	
Safe Crossing Mitigation Measure	**Intended function**	**clutter-adapted species**	**open/ edge airspace foragers**
Green bridge	Overpass		
Modified bridge with green verges	Overpass		
Modified bridge with screens/panels	Overpass		N/A
Hop-over	Overpass		
Bat gantries (bat bridges)	Overpass		
Viaduct, open span bridge -	Overpass	N/A	
Viaduct, open span bridge -	Underpass		N/A
Tunnel / culvert	Underpass		
Treeline / hedgerow	Guide		
Barrier	Deterrent		
Lighting	Deterrent		N/A
Road surface noise	Deterrent		N/A

KEY	N/A = not applicable
	Proven effective
	Further development required to improve effectiveness
	More research needed - potentially effective for some species
	Proven ineffective or results are ambiguous. Not recommended

Table 4 Mitigation measures and their effectiveness – adapted from Møller et al., (2016)

7.3. Partially effective mitigation structures and features

The structures in this section have been demonstrated to have limited effectiveness but may be appropriate at locations where mitigation is targeted for a particular species or species group, or where a combination of measures can sufficiently increase effectiveness. Because the evidence for their effectiveness is variable, some of these measures should only be applied with caution and rigorous monitoring of effectiveness must be ensured.

7.3.1. Modified bridges as overpasses

Traffic and pedestrian bridges may be effective as overpasses if they are sited along existing flightpaths and have vegetated verges that connect to existing bat commuting routes (Møller *et al*. 2016). Screens, panels or railings can provide shelter or cover to increase the likelihood of success. Bridges identified as mitigation features must be unlit and have minimal vehicular traffic at night (Elmeros 2018). However, in some cases more bats were found to cross the road between unmitigated severed treelines than at overbridges, as well as below the crossing structure in the collision risk zone (e.g. Bach *et al.* 2004, Abbott *et al.* 2012a).

7.3.2. Hop-overs, fences and screens

A hop-over is a group or line of trees and shrubs already in place, or specially planted on either side of a road so that bats following the vegetation will maintain or increase their flight height and cross the road safely. It is usually recommended for narrow roads, but it is suggested that a tall structure could be located in the central reservation on wider roads (Limpens et al, 2005).

There are examples of some bat species being observed crossing over two-lane roads using a connecting tree canopy above the road (e.g. *Myotis bechsteinii* and *Rhinolophus ferrumequinum* (Kerth & Melber 2009, Nowicki et al. 2016), however, the proportion of bats crossing at a safe height was not reported. A review of mitigation (Elmeros et al, 2016) found no studies that demonstrate the effectiveness (rather than the use) of tree and shrub hop-overs.

The use of screens on elevated stretches of roads, or on bridges or viaducts may act as hop-overs and encourage LRE and some MRE species (*Nyctalus, Eptesicus, Pipistrellus* species) to fly at a safe height (Bach 2008, Bach & Bach 2008) but further research is needed on this. Experiments using two parallel screens at natural gaps in flightpaths to mimic hop-overs resulted in some bats crossing at a safe height, others continuing to fly at unsafe height and others diverting to alternative flight paths. The results varied between species and between sites (Christensen et al 2016).

As with other mitigation measures, any solutions need to take into account the flight characteristics of all species at risk at the site. Hop-overs are **potentially** effective for open adapted bat / LRE and some open/edge adapted / MRE species but not for low-flying, clutter-adapted species unless the branches overhang the carriageway to form an almost continuous canopy. The vegetation would require maintenance in order to retain its dense structure to prevent bats flying through gaps onto the carriageway (Elmeros et al. 2016). There would need to a mechanism in the management plan for the highways estate to ensure that regular maintenance is undertaken. A further consideration amongst highways agencies about the proximity of trees, bat gantries and other mitigation features is the requirement for maintenance and concerns about the safety of road users. These latter concerns have been exacerbated by tree disease (ash dieback) in the UK resulting in large-scale removal of roadside trees.

Earth banks with shrub vegetation may be effective and involve less maintenance but their effectiveness needs to be tested.

7.3.3. Guidance/diversion – only recommended when used in conjunction with other measures

Use of screens, fences, nets or vegetation as guidance to safe crossing or barriers against collision has been suggested by a number of sources (Brinkmann *et al.* 2003, Bickmore 2003, Limpens et al. 2005a, Wray *et al.* 2006, Nowicki *et al.* 2009, O'Connor *et al.* 2011). However, extensive review by Elmeros *et al*. (2016) found no studies on the effectiveness of these features, and only a very few investigating their use.

Some studies (e.g. Fuhrmann & Kiefer 1996, Britschgi et al. 2004, Picard 2014) indicate that guidance/diversion features, when used in conjunction with other mitigation measures, underpasses in particular, increase the effectiveness of the mitigation. Other studies (Berthinussen & Altringham 2012) found attempts to divert bats from their original commuting routes to underpasses by planting trees and shrubs unsuccessful. Continuity of habitat features is important during the construction phase – e.g. use of fencing to maintain linear features along flightpaths (Davies, 2019).

7.4 Structures and features not proven to be effective (not recommended)

The mitigation measures described in this section include those that have been subject to rigorous study and shown not to be effective in those particular cases, or measures that are proposed as potential mitigation, but which have not been studied rigorously. Although not recommended as mitigation, further research on design and effectiveness of these measures is considered justified.

7.4.1 Bat bridges, gantries

Bat gantries are narrow, linear open bridge-like structures crossing over the road and intentionally constructed to guide bats over the road at a safe height (sometimes called “bat bridges” or “bat overpasses”). Gantries have been shown to be ineffective as mitigation in the UK even after being in place for several years (Berthinussen & Altringham 2012). Pan-European review by Elmeros *et al*. (2016) reached a similar conclusion.

Other more solid designs that reduce noise and light spill may be more effective but have not been subject to research at the same standard. Their use is not recommended unless their effectiveness can be supported by robust evidence.

There is some evidence that bat gantries have potential as mitigation features. A study in France evaluated three bat overpasses in different contexts (Claireau et al. 2019b). They found that bat crossings are more numerous if a gantry is located where bat commuting routes have been identified by an EIA study. However, the proportion of bat crossings along the commuting routes was the same with or without a gantry, highlighting that gantries do not fully restore habitat connectivity. Another study using a BACI design demonstrated a significant increase of bat crossings after construction of a bat gantry, although it is not known if bats were crossing at a safe height (Claireau et al. 2019a). Further studies found the flight height of bats increased significantly after the installation of the bat gantry (Claireau et al. 2021). Nevertheless, without evidence on effectiveness, use of gantries cannot be recommended as mitigation to prevent bat fatalities.

The designs of gantries vary with some having additional elements such as mesh panels; they include wire gantries, signage gantries and closed gantry structures. Wire gantries were proven ineffective (Berthinussen & Altringham 2012a, 2015, Elmeros et al. 2016), and so are other open constructions probably as well, e.g. nets and lattice gantries (Cichocki 2015, Schut et al. 2013). However, some other designs may have some potential and should be studied further. These include gantries with a closed design (Naturalia Environnement & FRAPNA 2015), and wire gantries with large spheres installed at short distances on the wires (Pouchelle 2016).

7.4.2. Speed Reduction

Traffic speed has been shown to affect road mortality of other vertebrate species (DeVault et al, 2015) but no studies have demonstrated that reducing traffic speed can be used effectively as a mitigation measure to reduce bat mortality.

7.4.3. Deterrents

A study in Scotland, UK looked at the possible deterrent effects of radar (associated with airports) with the aim of reducing bat fatalities at operating wind farms but did not prove its effectiveness (Nicholls & Racey 2009). Other studies have considered acoustic deterrents for the same purpose (Szewczak & Arnett 2007, Arnett *et al.* 2008) without success. Also, the impact of such measures on other wildlife, like birds or insects, has not been assessed to date (Amorim *et al.* 2012).

A study has been undertaken in France on the use of a noise-generating road surface as a potential means of discouraging *R. ferrumequinum* from approaching a road (Fourasté et al. 2014).
Observations with thermographic cameras were conducted in the summer of 2011 and in the summer of 2013 before and after the installation of the special road surface.

In 2011, 74% of bats crossed the road and 2% aborted the crossing attempt.
In 2013, 65% of bats crossed the road and 22% aborted the crossing attempt.
When a vehicle was outside the band of noise generated by the road surface, 47% crossed the road directly and 40% turned back compared to 27% crossing the road directly and 64% aborting the crossing when a vehicle was on the treated road surface.
The effectiveness of this as a mitigation measure has not been fully evaluated (Elmeros … 2016 CEDR mitigation overview report), and such an approach may cause other unwanted disturbance effects.

Lighting

Many bat species avoid lit areas (see also 4.4) and so lighting has been used to try to discourage bats from crossing roads at unsafe locations, however, its effectiveness has not been proven. While it may have some protective effect from collision for light averse species, it may exacerbate any barrier effect for them in the absence of alternative safe crossing structures. Other bat species are recorded as foraging on insects attracted to streetlights and may be out at increased risk. This is a complex topic and much depends on the type of illumination and the design and placement of the lighting structures. Therefore, although research into deterrents might have potential, these measures cannot currently be considered reliable and in general, there is a recommendation against the installation of artificial light at night in bat habitats. For a thorough review of bats and lighting see EUROBATS Publication no. 8 (Voigt et al. 2018b).

7.5 Mitigating roost loss

In designing replacement roosts, it is essential to understand the roosting requirements of the target species (e.g. Mackintosh, 2016). The physical characteristics of the roost, thermal properties, the number of entry points, their dimensions, locations, orientation and relationship to the surrounding habitat all need to be considered (Reason & Wray, 2023).

A review for EUROBATS (Schofield et al, Eurobats 2018) found that uptake of purpose-built roosts can be slow, and it may be many years before bats fully adopt them. Designs for new roosts in many cases may be satisfactory for the roosting ecology of the target species, but uptake may be influenced by a range of other factors such as the social structure of colonies.

For detailed information on roosting preferences for European bat species see Dietz et al (2009), Simons et al (date). See Reason & Wray (2023) for a thorough review and guidelines for mitigating the impacts of developments on bat species in the UK.

7.6 Compensation

In contrast to habitat impacts, where loss of certain areas at the development site may be compensated by protection or restoration of appropriate areas of habitat elsewhere, the possibility of compensating for fatalities is questionable. As the current levels of bat mortality caused by traffic and the impact on populations is not known, it is not possible to develop effective and measurable compensation schemes. This is particularly problematic for long-distance migratory species, because it would require improving their birth and survival rates hundreds of kilometres away from the development site, on a sufficiently large scale and before the road is opened to traffic (Voigt *et al.* 2012). All of these are strong arguments in favour of avoiding or mitigating fatalities as much as possible. However, as some fatalities may still occur, even after all known mitigation options are exhausted, some form of compensation might then be required.

A compensation scheme could include measures to protection, enhance, or restore off-site habitats (and their functional elements) of the affected populations, principally roosts, foraging areas and flight paths not directly affected by the infrastructure project. These would be implemented outside, but as close as possible to the development site.

Habitat improvement and creation, especially the creation of artificial water courses and wetlands are likely to be beneficial if done on an appropriate scale (Berthinussen *et al*. 2021). They must be planned long in advance since habitats such as woodland and wetland take many years to establish and mature (Berthinussen & Altringham 2012).

Compared to avoidance and mitigation, compensation is less efficient, in terms of bat protection and economics – it is more costly, and it is less certain that it will have the desired outcomes. Therefore, it should be used only as a last resort when significant effects cannot be avoided or mitigated.

Compensation must be informed by adequate impact assessment; it should be species-specific, effective, at least proportional to the loss, timely, permanent and not destructive of other features with nature conservation value. The effects of major roads are less easily detected in high quality habitat and so habitat suitability models may be helpful in determining where habitat improvements may be most effective for the species affected (Berthinussen & Altringham 2012).

Measure / Project stage	**Recommendations**
Avoidance	
Route selection / Planning stage	• Use modelling / surveys to select route avoiding high quality bat habitat (roosts, foraging areas, commuting routes) • After route is selected, further survey to identify commuting routes, roosts, foraging areas • Design lighting plan to minimise light spill
Construction phase	• Protect important features from damage / accidental destruction (clearly mark and/or zone off)
Mitigation - if it is not possible to avoid loss or damage to roosts and habitat, or potential mortality	
Pre-construction	• Retain commuting route features (hedgerows, treelines etc) • Create replacement roosts & habitat where possible for any that will be lost • Monitor flight routes and roosts
Construction phase	• Use temporary structure (e.g. netting) to retain connectivity across construction site until mitigation structures are ready • Replant habitat features (e.g. hedgerows) as soon as practically possible • Ensure crossing structures are located on identified flightpaths and habitat links are in place to guide bats to them • Monitor flight routes and roosts and note any changes
Operational phase	• Continue to monitor flight routes and roosts
Compensation - where impacts are predicted still to occur even after mitigation	

Planning stage	• Identify possible areas for habitat enhancement based on the species present and likely to be affected
Pre-construction phase	• Start habitat enhancement as soon as possible (e.g. tree and shrub planting, changes in land management to encourage insect prey). • Construct additional new roosts and improvements to existing roosts (e.g. installation of hot boxes, cool roost areas, grille underground sites)
Operational phase	• Monitor enhanced and new habitats and roosts and take any necessary remedial action

Table 5. Example of mitigation hierarchy and measures to address impacts on bats

7.6 Management and maintenance

Structures and habitats intended as mitigation can fail to fulfil their function if not correctly managed or maintained. Maintenance of bat mitigation and compensatory measures needs to be integrated into the general management plan for the infrastructure scheme the scheme (Elmeros & Dekker 2016).

- The objectives, target species and maintenance requirements for the mitigation structures should be clearly defined
- Standardised maintenance guidelines and schedules for the measures should be developed
- Maintenance task sheets should be produced listing e.g. inspection tasks, maintenance tasks for each feature, or set of features (
- The maintenance scheme should include both the mitigation structure itself, adjacent bat habitats and landscape elements.
- Maintenance plans must be adaptive to changes in land-use or land management practices etc which may or may not be part of the project and include inspections following adverse weather events, accidents etc

For details of examples see IENE (2022) and O’Brien et al (2018).

8 Recommendations for further research

This chapter gives recommendations for future research on the topic of roads and bats. More general research recommendations and research agendas on road ecology as a discipline can be found in Van der Ree et al. (2011), and Roedenbeck et al. (2007). There are three topics that merit research in the future to ensure that the goals in relation to bat and roads set by the Eurobats member states are met:

8.1 How do railways affect bats?

The number of studies on the effects of railways on bats is scarce (see chapter 2), and although superficially both roads and railways have the same impacts, they differ in among others the traffic volume is much lower on railways, and there are long periods without traffic, but speeds generally are (much) higher and long stretches of railways tend to be fenced. This differences combined with the lack of studies so far, merit more research on railways in the future. Barrientos et al. (2019) provide a general (i.e. not exclusively focussed on bats) research agenda.

8.2 How does traffic mortality affect bat population sustainability?

Direct mortality is the most obvious effect of traffic on bats, and relatively easy to measure. But infrastructural structures can also be a barrier without killing bats, resulting in fragmented landscapes, and loss of foraging or reproduction sites for the populations and can limit gene flow. These three factors: mortality, loss of habitat and loss of gene flow may in turn all affect population sustainability. The processes happen on a greater spatial scale and longer timescale than that of the road (re)construction process itself, and the usual scale of monitoring of the effects. This means that a local study might miss large impacts of roads on the surrounding bat populations. There is thus an urgent need to shift focus to larger scales (Van der Ree et al., 2011).

We recommend long-term studies on the effects of traffic infrastructure on habitat availability and gene flow and the resulting effects on populations. A good example of such a study can be found in Medinas et al. (2023), which focus on the effects the landscape and particular roads on Horseshoe bats. This study also highlights the low speed in which fragmentation affects genetic structures of populations. Field data can then used to forecast population dynamics, genetic effects and mortality thresholds using population modelling.

8.3 How does traffic mortality relate to other causes of morality?

Traffic infrastructure is only one of the causes of bat mortality. To formulate effective conservation of bat populations, it is necessary to increase our insight in how different mortality factors relate and interact. This is challenging research, requiring long term studies of individuals, and overcoming problems of differences in detectability of different causes of mortality. Some research has been undertaken to look at mass mortality events but there is a lack of understanding about small-scale ongoing causes of mortality.

8.4 How to find hotspots in traffic mortality in time and space

Bats that have collided with traffic are hard to detect: they have a low persistence time after being killed, and may be blown away from the road. Combined with the long stretches of road over which collisions may occur, this challenges researchers. Apart from technical innovations, solutions may be to focus monitoring on short stretches of roads at predicted roadkill hotspots, by radiotracking animals from nearby colonies (assisted by automated telemetry at potential crossing sites).

8.5 How to design and test of new mitigation measures

Although there are a number of mitigation measures that have proven effective for a number of species (see chapter 7), there is still innovation needed in the search for cheaper and more effective mitigation measures. Design should be based on the ecology of the bat species needing mitigation, and adapted to the landscape in which the measure will be implemented. Designs should take into account not only costs of construction, but also costs of maintenance, time needed to integrate into the landscape (allowing for the time taken for vegetated mitigation features to grow).

New measures, and those that already are implemented but where evidence of effectiveness is lacking should be rigorously tested.

Testing should be done in a before-after-control-intervention design, although bearing in mind the conflict between needing good data on effectiveness and not implementing mitigation measures where mortality is expected to occur.

It is important to set target species and goals that can be quantitatively measured. The focus of the study should not be the usage of the mitigation measure, but effectiveness in preventing fragmentation and mortality, and preferably also effects on the population.

Monitoring should be sufficiently long enough to control for learning effects and should be integrated in the general road management plan.

Results must be made publicly available, preferably in reports or paper accompanied by a "Conservation Evidence" style synopsis
(https://www.conservationevidence.com/synopsis/index).

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Glossary and abbreviations

BACI – Before-After-Control-Impact – designs are used to study ecological responses where treatment sites cannot be randomly chosen and for which replication is difficult or impossible. Two units are monitored over time; one unit receives an intervention at some intermediate time, while the other is left as an undisturbed control.

Catenary - a system of overhead wires used to supply electricity to an electrified railway

Clutter adapted species - highly maneuverable bat species able to fly in complex aerial spaces (see also open/edge and open airspace adapted species)

Commuting route – a flight path regularly used by bats, to travel between roosting sites and foraging areas, often associated with a linear landscape feature.

Compensation - Compensatory measures aim to off-set unavoidable negative impacts where residual effects exist after mitigation.

Control – a constant and unchanging standard of comparison in scientific experimentation

Core sustenance zone (**CZS)** – the area surrounding a communal bat roost within which habitat availability and quality will have a significant influence on the resilience and conservation status of the colony using the roost (Collins, 2016).

Culvert - A closed channel used to convey surface drainage water or other watercourse under a road.

Designated site - An area that is particularly good for wildlife or geology may have a 'designation' placed on it. This can be statutory or non-statutory and can offer varying degrees of protection.

Desk-study - Desk-based information gathering exercise, involving contacting government departments, biological record holding centres and other specialist groups.

Ecological Clerk of Works (ECoW) - A site-based ecologist who oversees all works on site which may have an ecological impact.

Enhancement - a measure that benefits the baseline condition following the completion of a project over and above any requirements for avoidance, mitigation or compensation.

Environmental Impact Assessment (EIA)

Feeding / foraging area – habitat patches where bats perform area-restricted foraging

Flightpath route used bat/s to move between roosts and foraging areas

Full spectrum bat detector – equipment for detecting and / or recording bat echolocation calls simultaneously across the full range of frequencies

Habitat fragmentation - The partitioning of larger habitats into smaller more isolated parcels, usually as a result of development. Fragmentation of habitat can negatively affect the abundance and diversity of plants and animals in an area.

High altitude

Migration – regular, usually seasonal movement of all or part of a population of bats to and from a given area

Mitigation - measures intended to reduce and, where possible, remedy significant adverse environmental effects where it is not possible to avoid them

Monitoring - repeated sampling, either year-on-year or periodically, usually to quantify changes over time or to assess whether a particular objective or standard has been attained (as distinct from a Survey).

Night-vision aids (NVA) equipment used to aid and/or record visual observations of bat behaviour in the dark.

- **Infrared radation (IR)** scopes or cameras are sensitive at very low light levels. Active IR systems but use short wavelength infrared light emitted by the device or by external devices to illuminate an area of interest.
- **Thermal-imaging (TI)** scopes and cameras use id-or long wavelength IR energy to sense and display differences in heat between objects and do not use additional illumination.

NGO – Non-governmental organization

Open/edge adapted species - bat species that can forage in open air spaces but often commute and forage along edges of vegetated habitats

Open airspace adapted species - fast-flying bats species that commute and forage in open environments (see also Clutter adapted species)

Passive acoustic monitoring (PAM), surveying and monitoring of bats' echolocation calls using sound programmable ultrasonic recorders (bat detectors). The detectors are deployed in the field and are usually left on site at least overnight, but often for several days. The data from the recordings are processed to extract information on identification to species, or species group level and activity patterns and an index of activity.

Population A group of organisms, all of the same species, which occupy a particular area. Also, the total number of individuals of a species within an ecosystem, or of any group of similar individuals.

Precautionary principle - The idea that if the consequences of an action are unknown but are judged to have some potential for major or irreversible negative consequences, then it is better to avoid that action or take appropriate actions to minimise the likely impacts.

Road-effect zone - the area of land including the road itself and the wider adjacent landscape affected by the traffic and associated infrastructure.

Soft estate - the land within the highway boundaries that is not part of the carriageway.

Swarming – usually refers to seasonal behavior of some temperate bat species mainly occurring from late summer to autumn. Bats may travel for many kilometres to underground “swarming sites”, flying in and around the site during the night. Some such sites may also be used for winter hibernation.

May also be used for “Dawn swarming” when bats returning from foraging fly repeatedly around the roost entrance (especially maternity roosts) at dawn before entering.

Survey - a sampling activity in which a wide range of variables is measured to describe a site or an area (as distinct from Monitoring).

Annex 1 – EUROBATS Resolution 7.9

7th Session of the Meeting of the Parties

Brussels, Belgium, 15 – 17 September 2014

Resolution 7.9 Impact of Roads and Other Traffic Infrastructures on Bats

The Meeting of the Parties to the Agreement on the Conservation of Populations of European Bats (thereafter “the Agreement”),

Recalling CMS Resolution 7.12 on migratory species and environmental impact assessment

Recognising the potential for roads and other transport infrastructure projects to impact on bats, bat roosts, commuting routes and foraging habitat

Recognising further the need for good-practice guidelines on how to avoid or mitigate for negative effects on bat populations

Urges Parties and non-party Range States to:

1. Take bats into account during the planning, construction and operation of roads and other transport infrastructure projects;

2. Ensure that pre-construction strategic and environmental impacts assessment procedures and post construction monitoring are undertaken and recommend that the data collected are made available for independent scientific analysis;

3. Promote further research into the impact of new and existing roads and other transport infrastructure on bats and especially into the effectiveness of mitigation measures;

4. Develop appropriate national or supranational guidelines, drawing on the general guidance to be published by the Advisory Committee;

Requests the Advisory Committee to publish EUROBATS guidelines highlighting the effects of roads on bats and providing guidance on minimising the impact of transport infrastructure projects on bats.

Annex 2 – Case Study, A487 Porthmadog bypass, Wales, UK

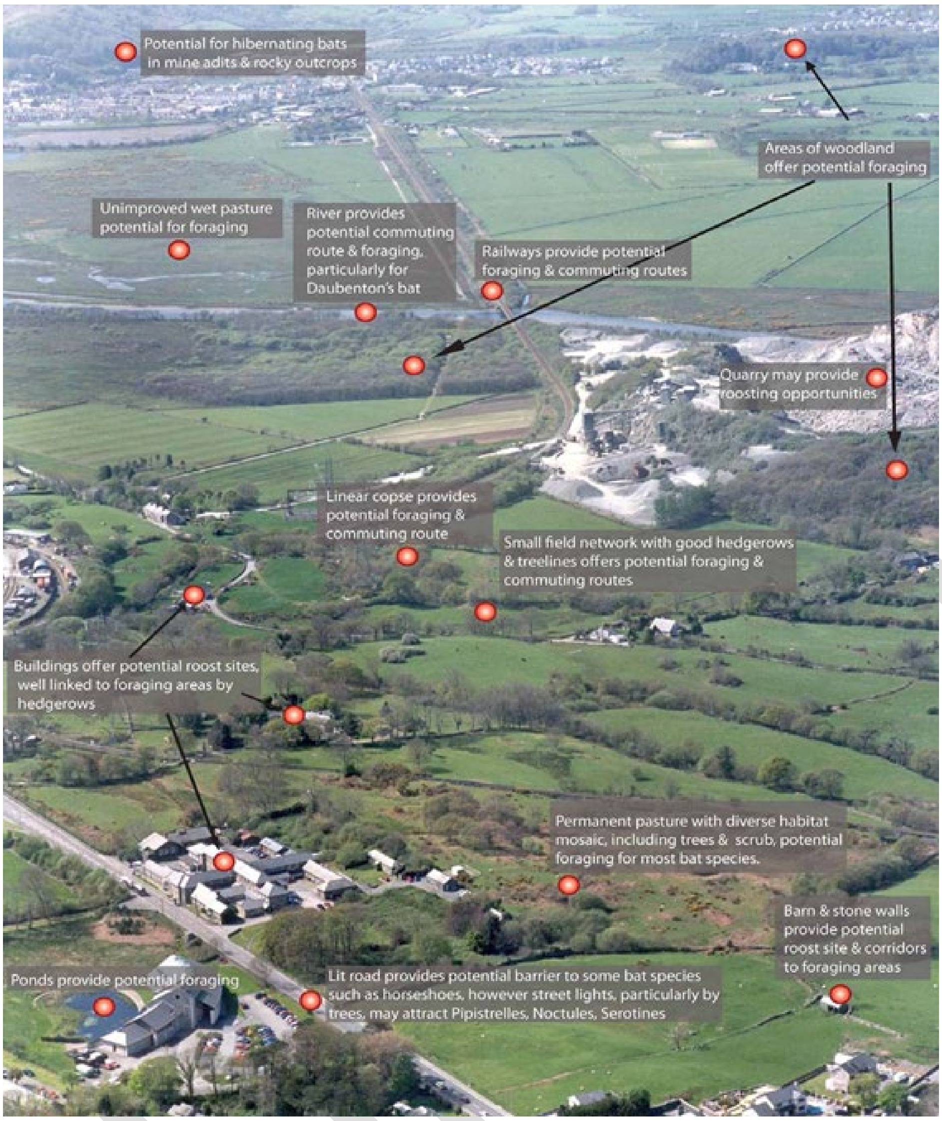

Figure 8. Aerial photo of scheme location showing potential bat habitats and roosts [to edit]

Summary
Noteworthy - the proposed route was altered to avoid bat maternity roost. Effectiveness of mitigation. Collaboration with research projects Main species impacted – *R. hipposideros, P. pipistrellus, P. pygmaeus, Myotis* spp*, P. auritus*

Issues – requirement to reduce traffic congestion especially during busy tourist season in an environmentally sensitive site close to National Park and affecting multiple national and internationally designated sites, including bat Natura 2000 designated site.

Significant *R. hipposideros* maternity roost discovered at start of process of planning scheme. Surveys showed bat use of surrounding habitat for foraging and key flight routes from roost. Due to topography proposed road is in cutting close to roost therefore no option to provide underpasses as crossing routes close to roost.

Methods – defined measurable targets for mitigation. Also used as site for study on lighting and horseshoe bats [Stone] and Defra bats & roads research project and in PhD study (Berthinussen, 2013).

Solution - alter route of road to avoid key flight paths and some foraging area, provide vegetated overbridge on next main flight path, provide underpasses at other key locations further from roost where feasible.

Results – effective mitigation for *R. hipposideros* and other bat species

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