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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. 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 the Parties, Prague, Czech Republic 20 – 22 September 2010 (MoP 6) requested the Advisory Committee 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 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, rail, and also airport 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. This document focusses 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 sections.

Chapters 1–4 introduce the background, the issues, and the evidence base. Chapters 5 – 7 provide the guidance and Chapter 8 lists recommendations for research. Technical terms and abbreviations (highlighted in bold blue 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 Natural Habitats (Bern Convention)

The Bern Convention[1] requires the Parties 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 EUROBATS Agreement and CMS (Bonn Convention)

The Convention on the Conservation of Migratory Species of Wild Animals or Bonn Convention[2] requires the Parties 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 to CMS. Therefore, the EUROBATS Agreement was set up under this Convention.

1.2.2.1 EUROBATS Resolution 7.9

This Resolution is concerned specifically with the impact on bat populations of traffic infrastructure (see Foreword and Annex 1).

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]

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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

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[4]

Specific legislation applies to Member States of the European Union (EU) as all European Chiroptera species are listed on Annex IV of the Habitats 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 which Special Areas of Conservation (SACs) are to be designated. Under Article 6 (3) and (4), schemes that may 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 Impact Assessment 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.

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[4] https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

[5] http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/natura_2000_assess_en.pdf

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.

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[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 (IPBES 2019).
- 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.

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 the 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*. 2009), research on the impact of traffic infrastructure on bats initially focused on insectivorous bat species in developed countries (western Europe and North America). A more recent review also included data from South America, Australia, Asia, and Africa (Ramalho & Aguiar 2020).

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 (Kerth & Melber 2009, Berthinussen & Altringham 2012a, Stephan *et al*. 2012, Claireau *et al*. 2019c), and the effects of traffic lighting (Stone *et al*. 2009) and noise pollution (Schaub *et al*. 2008, Siemers & Schaub 2011) 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 (*e.g.* Nowicki *et al*. 2009). 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 (Highways Agency 2006, Limpens *et al*. 2005, National Roads Authority 2005, Nowicki *et al*. 2009, Brinkmann *et al*. 2012, O'Brien *et al*. 2018, Rosell *et al*, 2020).

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*. 2019a, 2021) and genetic studies (Claireau 2018, Wright *et al*. 2018) increase our understanding of bat behaviour and the 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 (Annex 1) 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 2012a, 2015, Elmeros & Dekker 2016, Elmeros *et al*. 2016b, van der Ree 2007, Barrientos *et al*. 2019). Some measures continue to be used or promoted although they have not been proven to be effective (Berthinussen & Altringham 2012b, 2015, Stone *et al*. 2013). Berthinussen *et al*. (2021) have collated studies on the effectiveness of conservation and mitigation actions for bats, including a section on transport.

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 (*e.g.* 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 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 bat habitats and roosting locations and less is known about the disturbance and mortality impacts of the operation of rail and air traffic (see Chapter 4).

Evidence of impacts of aircraft is limited, suggesting that collision occurrences are infrequent, and reviews have concluded that there is little economic impact through damage (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).

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.

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

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 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.

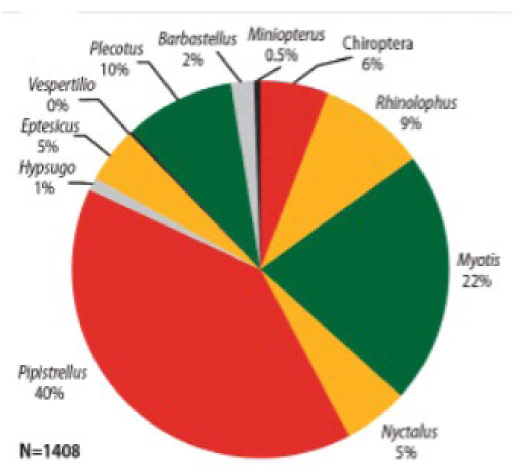

Figure 1. Percentage of bat traffic casualties by genus based on data collated for EUROBATS literature review (Presetnik et al. 2014)

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, HR, HU, PL, PT*	+	+	
Hypsugo savii	ES, FR, IT, TR	+		+
Myotis alcathoe	CZ	+		
Myotis bechsteinii	DE, FR, GB, PT, SK, TR	+		+
Myotis blythii / oxygnathus	AM, ES, 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, SM, SI, SY, TR, UA	+		+

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

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

Family and species	**State**	**Transport type**		
		road	rail	air
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, SK	+		
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 = Kuwait, ME = Montenegro, NO = Norway, PL = Poland, PT = Portugal, RS = Serbia, SK = Slovakia, SM = San Marino, SI = Slovenia, SY = Syria, TN = Tunisia, TR = Türkiye, 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-five bat species from six families occur within the area covered by the EUROBATS Agreement.[9] 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 45 Vespertilionid species present five Rhinolophidae and one Miniopteridae. 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 (see Chapter 4).

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 & Harder 2003, Wilkinson & 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 2023). 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 condi-

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[9] https://www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/Resolution%209.2%20Amendment%20of%20the%20Annex_0.pdf

tions 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 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 1,000 km 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 4 m 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 – 30 g so are vulnerable to being drawn into the slipstream of passing vehicles (Berthinussen & Altringham 2012b).

Figure 2. R. hipposideros road casualty. © M. 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*** include 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 shorter range calls navigate by using sensorial 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 & 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 & 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*. 2012b, 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).

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 or 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.

Figure 3. Flight style and habitat use by insectivorous bats. © N. Forshed

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).

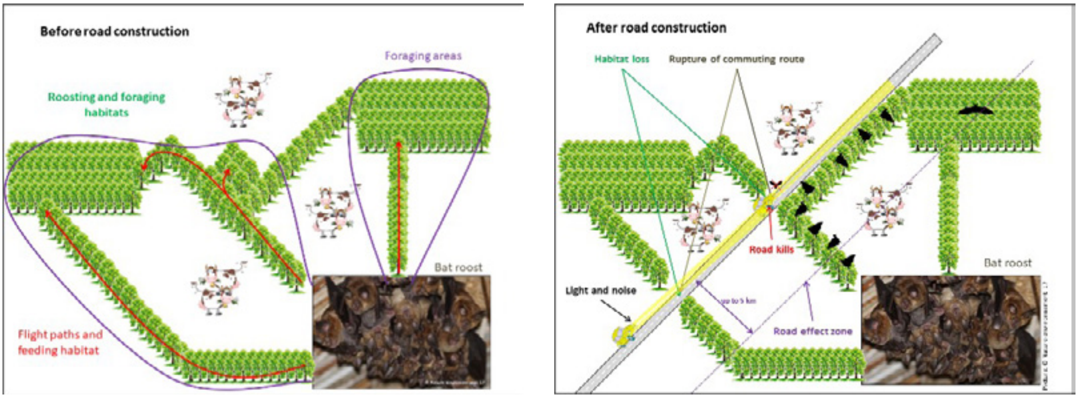


Figure 4. Bat habitat use a) before and b) after construction of new road. © F. Claireau

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 2012a, Medinas *et al*. 2013, Claireau *et al*. 2019c).

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 (Medinas *et al*. 2013, 2019). 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 5.8.3), 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 1.6 km either side of a major road in the UK (Berthinussen & Altringham 2012a).
- A significant negative effect of major roads on bat activity was observed up to 5 km 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*. 2019c).
- A study in Portugal showed that even roads with low and medium levels of traffic can have a negative effect on bat activity up to about 300 m from roads in woodlands or more than 500 m in open field habitat. The effects varied seasonally and by species and by habitat. 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*** (Medinas *et al*. 2019).
- A study in Southern France found a complex interaction between road density and the landscape: bat diversity was greatest in landscapes with intermediate levels of forest fragmentation, while road density had a negative effect on the activity of *R. ferrumequinum*, *R. hipposideros*, *N. leisleri* and *P. pipistrellus*, but only in landscapes with either a low forest amount or a low number of forest patches (Laforge *et al*. 2022).
- *Myotis* species avoided an area 10 – 25 m from a high-speed railway line located in woodland even when trains were not passing through (Lüttman 2012).
- 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, fragmentation of landscape and habitat features, and it can affect 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 (Iuell *et al*. 2003).

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 and context, *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. Roosts in natural features (trees, rock features) require more effort to locate and their importance is likely to be underestimated (Andrews & Gardener 2015). 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).

Traffic infrastructure projects can affect large areas of undisturbed habitat of high value to biodiversity that cannot be directly replicated by mitigation. Woodland and wetland creation are more likely to be used as enhancement or compensatory measures and are potentially of benefit, but the time taken for such habitats to become useful for bats needs to be factored into the project planning if they are to be effective (Altringham & Kerth 2016).

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*. 2009, 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 influence 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 & Melber 2009, Bennett & 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 & Huitema 1997, Avila-Flores & Fenton 2005, Medinas *et al*. 2019, Roemer *et al*. 2021). 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 hard forest edges led to a higher proportion of bats flying in the collision risk zone compared to roads with sparse tree lines (Roemer *et al*. 2021). However, contrary to expectations, most of the time bats flew parallel to the road axis, even in the presence of perpendicular tree rows. 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). 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. Remote sensing data could be used to help predict risk. Pre-construction surveys undertaken over more than one year could give a more reliable estimate of risk depending on the habitat (Medinas *et al*. 2013, 2021). Further research is needed to determine if similar changes in bat activity patterns occur in different habitats and climate zones.

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). Collision risk is increased when traffic infrastructure is located close to bat roosting, commuting and foraging habitats.

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 increase 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 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 ***edge / open adapted MRE*** species 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).

Higher volume of traffic has been linked to increasing levels of wildlife mortality across a range of taxa (Bennett 2017), although the effect of traffic volume on bats is not clear since less busy smaller roads and railways may have a reduced barrier effect.

4.4 Railways

Most of the research on the impacts of traffic infrastructure on wildlife has been in relation to the impacts of roads (*e.g.* Van der Ree 2015). Railways result in the same types of impacts on wildlife as do roads - habitat loss and fragmentation, the barrier effect and mortality through collision (Borda-de-Água *et al*. 2017). However, there are key differences that affect the causes and scale of impacts (Barrientos *et al.* 2019), *i.e.:*

- Traffic levels are lower on railways than major roads
- Traffic speeds are higher on railways
- There are long intervals without traffic on railways
- Overall, wildlife mortality through collision is lower on railways than on roads
- Railway corridors are narrower than road corridors
- Railways result in less chemical pollution

Research is needed to understand to what extent survey and mitigation techniques developed in relation to road infrastructure are applicable to railways (see 8.1).

4.5 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*. 2018a). 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 4.7.5).

Unmanned aerial vehicles (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.

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

4.6 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.

4.6.1 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*. 2015a, 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, with 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*. 2015b, 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 Publication Series No. 8 Guidelines for consideration of bats in lighting projects (Voigt *et al*. 2018b) (see also 6.4.1).

4.6.2 Noise

Bat abundance and species diversity are lower closer to roads (see 4.1); 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 & 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 used by bats. 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.

It is suggested that low-pitched sounds are unlikely to cause significant disturbance, and there is some anecdotal information indicating that bats may become habituated to background noise; furthermore, ultrasonic noise pollution may in theory have a greater impact, but empirical evidence is lacking on the effects across frequencies (Reason & Wray 2023). See also 5.7.5 and 7.4.3.

4.6.2.1 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 with close proximity to the work.

4.6.2.2 Foraging and commuting activity

Vehicle noise appears to reduce foraging efficiency for some species (Siemers & Schaub 2011). 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).

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 (Luo *et al*. 2015).

Species that use sounds to find or glean 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 20 m away (Finch *et al*. 2020).

An acoustic experiment on a north America species of gleaning bat *Antrozous pallidus* used white noise treatments that either overlapped the frequencies of a prey cue (a cricket walking) or did not overlap this cue. The results for both noise treatments were similar - successful prey localisation declined by half, search time nearly tripled, and bats used 25% more sonar pulses than under ambient conditions. The pallid bat appeared to be "distracted" by the environmental noise and did not seem able to compensate for it, suggesting that mitigation strategies must seek to reduce sources of noise on the landscape rather than attempting to reduce the bandwidth of anthropogenic noise (Allen *et al*. 2021).

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 (O'Connor *et al*. 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).

Traffic levels are lower and disturbance less frequent on railways than major roads. However, one UK study found that 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 & Mathews 2021).

4.6.3 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).

4.7 Collisions

4.7.1 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 of high conservation priority. As with other small animals, collisions with vehicles, even at low speeds, are most likely to be fatal to bats but, in contrast to small terrestrial mammals or birds that produce multiple young in a breeding season, bat populations cannot quickly replace losses. 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 & Fahrig 2012, Grilo *et al*. 2020, Bernotat & Dierschke 2021).

Male bats are more likely to be struck by vehicles than females (Lesiński *et al*. 2011, Medinas *et al*. 2013, Iković *et al*. 2014, Fensome & Mathews 2016) since they fly longer distances increasing the likelihood of encountering traffic (Fensome & Mathews 2016).

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 (Schorcht *et al*. 2009) thus even slight additional mortality may be threatening to bat populations. Annual mortality of 5 – 7% of adult females from a colony would be unsustainable and is possible since a large proportion of females from a colony may be concentrated in a relatively small area at certain times of the year (Schorcht *et al*. 2008).

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*. 2013). Juveniles are more likely to be casualties than adults because of their reduced manoeuvrability and slower flight (Medinas *et al*. 2013, Fensome & 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 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).

4.7.2 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.* LESIŃSKI 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, 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 2011). Carcasses were predicted to disappear more quickly if they are smaller (under 20 g), 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 persist longer although lower traffic levels can allow more removal by scavengers (BARRIENTOS *et al*. 2018).

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 km would be required. Detection rates decreased significantly at speeds above 50 km 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 70 g (STUART & STUART 1993) compared to *P. pipistrellus* c 5 g, or *M. myotis* c 25 g (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*. 2015). 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.

4.7.3 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 2009, Iković *et al*. 2014, Lesiński 2007, Lesiński *et al*. 2011, Secco *et al*. 2017). A positive correlation was found between the height of the roadside cutting and the height at which bats flew across the road, but the effects are species-specific, and deeper cuttings also mean wider gaps for bats to cross (Berthinussen & Altringham (2012b).

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 & Mathews 2016) without consideration or analysis of inter-annual variations in locations or species affected (Malo *et al*. 2004, Skorka *et al*. 2015). See case studies below. See also 5.7.4.

Road casualty case study - 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*. 2013)

- 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 study - 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* 1.4 km from the scheme.

- Daily dawn surveys were carried out between August to November/December 2001 – 2012 (except 2006 and 2011) on a 4 km section of the road.
- The carriageway and verges (up to 50 m 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)

4.7.4 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). However, there is a lack of information on carcass persistence rates associated with railway mortality (Barrientos *et al*. 2018).

Data on rail traffic casualties is 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).

4.7.5 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 of one study from the Republic of Ireland (Kelly 2017). These studies have focussed on safety concerns and the potential economic impact of damage to aircraft from wildlife collisions.

A recent review 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 (Ball *et al*. 2021).

The number of bat collisions is not known but is likely to be underestimated. Inspections are systematically undertaken at airfields to check for damage to aircraft and hazards on the runway. However, the data are not always reported, particularly where a collision has not caused significant damage to the aircraft. The number of wildlife carcasses found during runway checks at one 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 on 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.

Most countries have national reporting forms for recording wildlife collisions (strikes) at airfields or in the air, although these are not consistent and local aerodromes often have their own internal reporting systems. Reporting of airstrikes is mandatory within the European Union (EU) but is not standardised and information is incomplete. Some countries do not report bird and bat strikes separately, and in Germany for example, only mammals the size of a rabbit or larger are reported (Ball *et al*. 2021).

Standardised search protocols and reporting could produce more useful data and improve management strategies to reduce the risk of damage to aircraft and wildlife mortality (see 5.7.4.3).

4.7.5.1 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 six most common species are migratory. 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 >300 m 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.

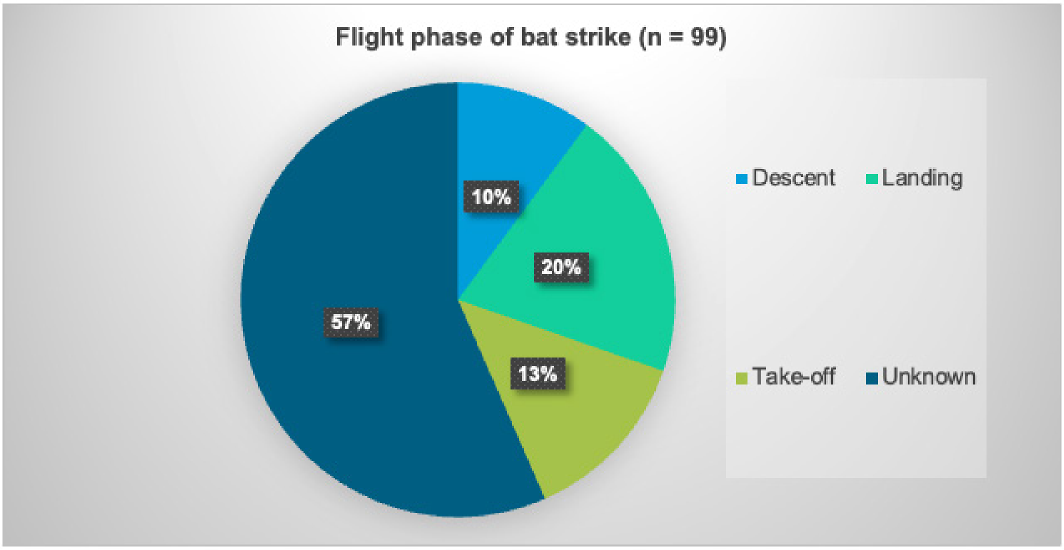
Washburn *et al*. (2014) analysed data on wildlife strikes involving US military helicopters deployed in combat and non-combat missions outside the USA between 1994 – 2011. The majority of the 701 strikes were birds (69 species) but 18 involved bats. Four occurred on or over the airfield and 14 off the 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). More airstrikes occurred in August (28.3%) than any other month. The greatest incident rate occurred at dusk (57.3%), most during the landing phase (85%), compared to 11.2% at take-off. Bat strikes were considered to be low risk and have minimal economic effect on civil aircraft.

4.7.5.2 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 us to undertake a preliminary analysis of bat strike data 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 at an altitude of 1800 m and 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.



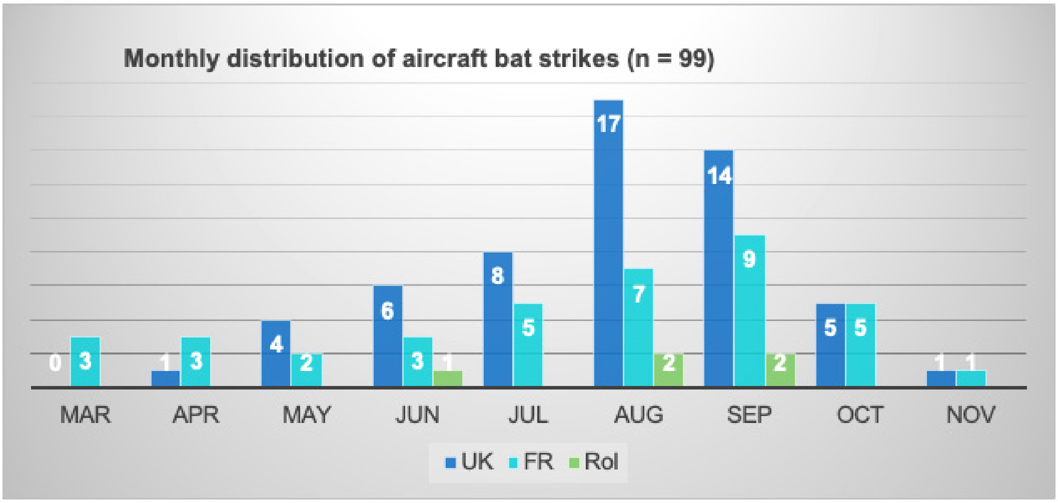


Figure 5. Flight phase (a) and monthly breakdown (b) of bat strikes by aircraft. Data courtesy of the UK Civil Aviation Authority (CAA) (obtained by M. Cooke), the French Service technique de l'Aviation civile (STAC) (obtained by C. Roemer) and from Kelly *et al. (2017) for the Republic of Ireland*

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.

4.8 Positive impacts of traffic infrastructure and potential ecological traps

Overall, the presence of roads leads to reduced bat activity and diversity (see 4.1) and is associated with increased risk of mortality (see 4.3).

Some habitats and features associated with roads may be used by bats, but also have the potential to become ecological traps, *i.e.* low-quality habitat that is used preferentially over other available high-quality habitat but is unsuitable for long-term population sustainability (Donovan & Thompson 2001). Ecological traps occur when animals misinterpret the environmental cues used to select habitat and may result from environmental changes occurring at a rate to which species cannot adapt or evolve (human-induced rapid environmental change or HIREC). Traps can result in direct mortality and more subtle effects such as lower reproductive rates through reduction in genetic diversity. Species that have low and slow reproductive rates are more vulnerable to long term effects (Hale *et al*. 2015b).

Insects swarming around streetlights may give foraging opportunities for some species of bats (Rydell 1992, Stone *et al*. 2009, Mathews *et al*. 2015), however bat populations may be impacted by the landscape-scale depletion of insect prey due to the widespread use of alan (Azam *et al*. 2016).

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 (<100 m) (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 & Fenton 2005), resulting in increased bat activity at roads (Verboom & 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 (Kyheröinen *et al*. 2019).

Lines of trees running parallel to roads give bats an opportunity to forage along an edge away from the road (Roemer *et al*. 2021). Road verges are important foraging areas for ***open airspace and open / edge adapted species*** such as *P. kuhlii* (Medinas *et al*. 2019).

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

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 bats in Europe. Crevices in stone bridges over water courses are used by *M. daubentonii* and other *Myotis* as well as *Nyctalus* species (Marnell & 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 and major road bridges in Austria (Barova & Streit 2018) and the UK (Reason & Wray 2023). 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 2019).

Rail and road verge habitats can be positively managed to promote insect abundance and may be important habitat where other foraging areas are limited (Vendevelde *et al*. 2014, 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 reused for low impact activities such as cycling while disused railway tunnels provide roost sites for bats (Barrientos & Borda-de-Água 2017).

4.9 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 – 4.7) 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 Parties and Non-Party Range States 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, Annex 1).

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 4.7).
- 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 Assessments (EIA) and Strategic Environmental Assessments (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 (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 minimises 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 2016, Paunovic *et al*. 2011) 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 of studying bats. There are particular issues with rarer species but even with more common but cryptic species, *e.g. Pipistrellus* and *Myotis* genera (Barova & 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, in most cases it can be assumed that knowledge of bat species ecology and distribution in the area is insufficient and therefore bat distribution and habitat use will probably need to be predicted at this stage of planning (see 5.1). Expert judgement will be required based on an understanding of the requirements of each species, and on the landscape and habitat features present (Bickmore 2003, Limpens *et al*. 2005, 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 and Encarnação 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*. 2005, National Roads Authority 2005, Razgour *et al*. 2011, Becker & Encarnação 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 (Dekker *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.

5.3 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 an active local bat group, and often there will be a lack of information on 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)[10] to determine if they are likely to occur in the study area.

Background data searches should be carried out up to a minimum of 2 km from the proposed development boundary (including temporary works such as construction compounds and haul routes) or extend up to 10 km for larger projects (Collins 2023), *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 10 km 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 and 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 EUROBATS Publication Series No. 9 (Kyheröinen *et al.* 2019).

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

Route corridor selection

New linear infrastructure projects will include phase in the planning stage when multiple variants of the route are considered. Route corridor selection "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).

5.4 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 or more recently von Hirschheydt *et al*. 2020). 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 5.6.1) 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.

5.5 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 risks.

Pre-construction surveys will need to be updated if there is a delay between the surveys and the start of construction. The length of delay triggering updated survey information should be based on national guidelines (*e.g.* more than 2 years in the UK or 5 years in France) 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.

5.6 Survey and monitoring

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.

5.6.1 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 post-construction data (see 2.1). This means that it is not possible to properly 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 and all stakeholders should be involved in preparing the project evaluation (O'Brien *et al*. 2018).

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 7.7),
- consider how to address knowledge gaps (see 5.2),
- ensure that processes are in place, and the necessary funding is secured to complete the mitigation and evaluation (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 (O'Brien *et al*. 2018).

5.6.2 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 to date has been limited. Where pre- and post-construction surveys are undertaken, the inconsistency in survey methods and equipment and short duration of the survey period often make it difficult to draw conclusions about the efficacy of the mitigation measures (Fensome & Mathews 2016). 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 individual 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 (see 8.2).

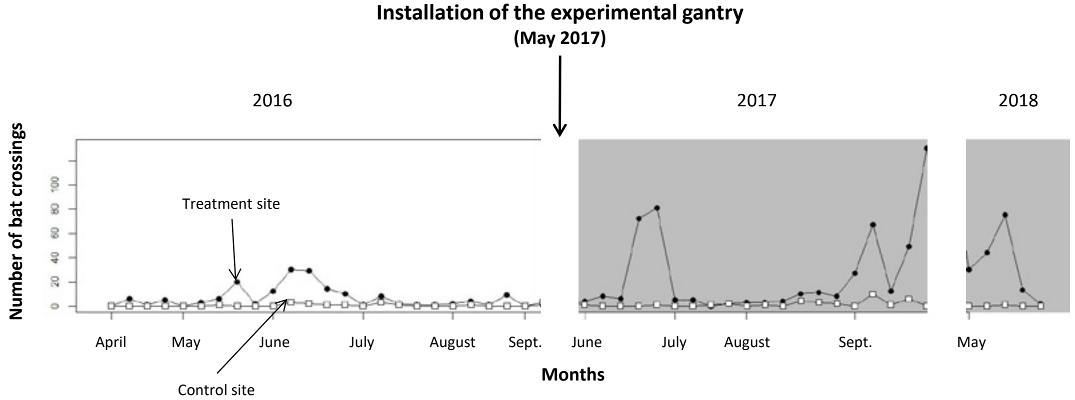

Figure 6. BACI study of the installation of a road crossing for bats (Claireau et al. 2019a)

As an example, Figure 6 shows how a ***BACI*** study (Claireau *et al*. 2019a) 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 due to a population decline caused by previous mortality, increased road avoidance behaviour or changes in traffic volume (Lucas *et al*. 2017).

5.7 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 5.2). 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 2023, 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) recommends techniques designed for long term surveillance of European bat populations. 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), and current restrictions such as advice published by EUROBATS regarding SARS-CoV-2.

5.7.1 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 2023):

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

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.

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

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. More research to provide robust protocols for its use is needed.

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 2019, Bat Conservation Trust 2022). ***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 5.7.3.2).

5.7.2.1 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 (*e.g.* 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. 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) for examples of roost features used by different bat species and suggested assessment methodologies.

5.7.3 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, flight-paths, 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.

5.7.3.1 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 can provide an index of activity that 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 (see Lintott *et al*. 2018).

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 1 km 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*. 2021).

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 age, gender, reproductive status, or the absolute number of bats present. However, *pam* allows the quantitative assessment of bat activity by a relative comparison of the number of bat passes per night recorded on different study sites or over time
- Skill is needed to identify species correctly, and it is not possible to identify all bats to species
- Some species are more 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
- 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 will be given in the revision of the EUROBATS Guidelines for long-term monitoring of European bats.

5.7.3.2 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 2023).

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*. 2021).

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 revision of EUROBATS Monitoring Guidelines (Battersby 2010).

5.7.4 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.

5.7.4.1 Collision risk prediction

For new road or rail projects, activity surveys (as described in 5.7.3) 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). Baseline surveys 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, remote-sensing imagery, 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.

Collision hotspots may change seasonally or from year to year. This may be due to previous mortality (see 4.7.3) or changes in vegetation, since a key factor in explaining bat collision patterns is habitat quality, but it is not constant. Therefore activity monitoring should be undertaken in different seasons and over a number of years pre- and post-construction (Medinas *et al.* 2013, 2021).

Medinas *et al.* (2021) found that areas of high net primary production (NDVI) equated with high quality habitat for bat foraging and that data from remote sensing could be used to detect changes in habitat quality over time that could help predict hotspot locations and persistence to inform decisions on locating mitigation structures.

The use of carcass searches (see 5.7.4.2) should be considered, depending on the scale of the scheme and likely level of risk, for schemes to upgrade existing traffic infrastructure, for monitoring the effectiveness of mitigation (see 5.8.4) and as part of research to understand the wider impacts of traffic on bat populations.

Roemer *et al.* (2021) 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. They used a pair of stereo recorders to triangulate the position of bats. This method is useful to study collision risks at secondary or smaller roads for all bat species except *Rhinolophus*, which have too short echolocation ranges and are not recorded by all four microphones at the same time. It is particularly adapted to calculate a per capita collision risk, design mitigation measures and monitor their efficiency.

Claireau *et al.* (2019b) developed a method to study one-dimensional flight paths of bats to assess bat crossings at highways. 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 the 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 3.5 m 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 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.

An example of a collision risk model for an operational airport is given as Annex 3. This includes use of comprehensive surveys at dusk and dawn using acoustic detectors and thermal-imaging cameras of bat activity at the site as a whole to quantify the proportion of bat activity within the collision risk zone.

5.7.4.2 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 consider carcass characteristics, detectability, persistence and entry rates to obtain unbiased estimates of roadkill (Guinard 2015).

The design of the survey should consider 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). Regular surveys are often undertaken as part of routine management tasks to remove carcasses from operational roads but additional surveys will be needed to detect carcasses of small fauna (Rosell *et al.* 2020).

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).

Carcass searches should:

- Be undertaken at or immediately after dawn
- Take place daily throughout the chosen sampling period
- Sample during different seasons
- Use walked transects in preference to driven transects

- Use experienced observers. 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 (second research places a known number of carcasses).

For detailed examples and protocol for searcher efficiency trials and data analysis please refer to Rodrigues *et al*. (2014).

5.7.4.3 Carcass searches at airfields

Inspections are systematically undertaken at airfields to check for damage to aircraft and hazards on the runway, however search protocols and reporting lack consistency (see 4.7.5).

Protocols could be improved using trained search dogs and searcher efficiency tests (see 5.7.4.2).

Reporting of air strike mortality data could be improved by:

- Encouraging all national aviation authorities to report bat strikes
- Ensuring that "bat strike" is specified on internal / external strike report forms
- Ensuring that the report form includes the flight number and aircraft registration to enable the event to be tracked
- 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).

Standardised systems for recording other types of data are available and recommended for use. The spreadsheet "Standardised form for recording survey data relating to lighting and bats.xlxs" has been adapted as a pro forma for reporting or collating bat strike data "Airstrike Spreadsheet Template.xlxs" (available via the EUROBATS website).

5.7.5 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 (Reason & Bentley 2020):

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

As noted in 4.6.2 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. Until better information is available, a pragmatic approach 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).

5.7.6 Survey and monitoring reports

EUROBATS Resolution 8.10 recommends that assessment reports of projects are objective and meet appropriate quality standards. A checklist has been developed to assist authorities in assessing the soundness of reports and was published as an Annex to Resolution 9.5.

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
- Survey methods used, referring to manuals or guidance that have been followed
- Details of equipment models and settings used
- 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
- Details of the mitigation feature under observation using standardised forms (*e.g.* Rosell *et al*. 2020).

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[11] where they will be catalogued and made available on request.

Recent technological advances in equipment have not yet been matched by standardisation of methodologies for analysing and interpreting survey data, making the assessment of the ecological value of a site very subjective (Lintott *et al*. 2018). 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 techni-

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cal 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*. 2018).

5.7.7 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 Chapter 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.

5.8 Monitoring

As noted in 5.6.1 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 different types of monitoring undertaken at different stages of the construction and operational phases of a project are described.

5.8.1 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 that may encourage bats to fly through the gap rather than along the linear feature.

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.

5.8.2 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 during the development of the survey and monitoring strategy (5.6.1) 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 (see 2.1) In some cases, this is because of the length of time that has elapsed since the initial assessment was undertaken, or that previous studies used survey techniques that are not comparable (Fensome & Mathews 2016). 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.

For 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).

On very large schemes it is good practice to have an independent audit system for checking and reporting on compliance (O'Brien *et al*. 2018).

5.8.3 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 5.6.1). Acoustic monitoring (see 5.7.3.1) can be used to measure bat activity pre- and post-construction, or in comparison with control sampling sites. 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).

5.8.4 Collision prediction and monitoring

On established roads, the location of roadkill hotspots may change if previous mortality has already reduced populations in the area (see 5.7.4.1). 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). 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 4.7.3, 5.7.4 and Annex 3).

There are mechanisms for reporting wildlife strikes for aircraft and standard templates for reporting are used by many aviation authorities, although there are no consistent search protocols and reporting varies widely.

5.8.5 Reporting on monitoring

See also 5.7.6 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 should be made available for analysis to further understand the impacts and to promote effective mitigation (EUROBATS Resolution 7.9).

Reports should be made publicly available and can be hosted by the World Bat Library (see 5.4.6).

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*. 2005, 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*. 2005, 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 (see 4.3). 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*. 2005, 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) (see 5.3). 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 & Wyatt 2009 and see Annex 2).

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 and 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 (Iuell *et al*. 2003, O'Brien *et al*. 2018).

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*. 2005, 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; during the winter they can also take place after sunset if hibernation roosts are not present). Temporary fencing can be used to maintain a linear feature during the construction phase and can be removed during the day and replaced before dusk.

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*. 2005, 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. 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*. 2005, 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*. 2005, 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*. 2005, 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 Light

Current recommendations are 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 (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 were 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). 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). Dimming LED streetlights to 25% of their typical intensities may also be effective for maintaining activity levels of *Myotis* bat species that usually avoid light (Rowse *et al*. 2018). 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*. 2021) 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. 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). However, there is a lack of evidence regarding the effects of noise on bats (see 4.6.2) and 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 and 8.2).

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 2012b) although mitigation needs to be effective for all affected species (see Chapter 7).

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.* 2012a).

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. Avoiding zones with dense vegetation should minimise collision risks, as bats are more prone to fly in the zone at collision risk when vegetation is dense (*e.g.* hard forest edges) compared to areas with sparse tree lines (Roemer *et al.* 2021). While there is little that can be done to alter factor 3 above, it contributes 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 (Iuell *et al*. 2003).

The effectiveness of implemented measures should be monitored (see section 5.8 and 7.1 below), and changes suggested if needed, until the effectiveness 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 success 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, Van der Ree *et al*. 2007, Berthinussen & Altringham 2015, Møller *et al*. 2016). Mitigation features are only "effective" 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, and see Chapter 3). Furthermore, only if such figures have been confirmed by robust long-term monitoring (see section 5.8), can effectiveness be confidently demonstrated (Berthinussen & Altringham 2015, Møller *et al*. 2016).

Figure 7. Flight routes under and over a major road. © J.Matthews

"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 is 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 & 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, Dahl Møller *et al*. 2016, Christensen *et al*. 2016, Dekker *et al*. 2016). 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 7.2.1–7.4.3 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), and Berhinussen *et al*. (2021) for a collation of studies on mitigation and conservation actions. For detailed descriptions and photographs of mitigation features and their uses please refer to Iuell 2003 (as updated) https://handbookwildlifetraffic.info/ch-7-solutions-to-reduce-transport-infrastructure-impacts-on-wildlife/7-4-reducing-barrier-effect-wildlife-passages/.

The recommended measures (see section 7.2 and Table 3 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 / functional groups and in certain ecological settings. 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 indicate that features such as strategic location, size, connectivity of tree lines and mature vegetation encourage the use of overpasses by bats (Abbott *et al*. 2012a, Berthinussen & Altringham 2012b; Bhardwaj *et al*. 2017), whereas road flyovers (high level road bridges) or footbridges are not effective (Abbott *et al*. 2015; Altringham & Kerth 2016). It is likely that a key factor determining the use of overpasses by bats is the presence and structure of appropriate vegetation at the location.

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 using viaducts or open span bridges.

7.2.1 Green bridges (ecoducts, 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. They can vary in size from very wide structures, supporting trees, hedging, grassland, ponds, rocky habitats to provide continuity of habitats from both sides, to single lane sized features located on specific faunal crossing points. Green bridges are the optimal mitigation structure for guiding bats safely over roads.

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, Berthinussen & Altringham 2015, Møller *et al*. 2016, McGregor *et al.* 2017). If well-designed and appropriately located, they are likely to be effective for all bat species regardless of their flight ecology.

They are unlikely to be constructed as a mitigation measure exclusively for bats due to demanding technical issues and high cost. However they can be cost-effective since they can mitigate barrier effects and collision risk for a range of taxa. 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 for bats 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
- Maintaining habitat continuity (*i.e.* gaps can encourage low-flying species to flying under, rather than over the bridge (Abbott *et al*. 2012b)
- Being planted with dense woody vegetation of fast-growing native species (2 – 4 m high)
- Installing screens along each side of the overpass to deflect noise and light (Elmeros *et al*. 2016a).

7.2.2 Bridges and viaducts as underpasses

Bridges and viaducts (long extended bridges, usually supported by pillars) built to support traffic infrastructure across a watercourse or a valley are not usually specifically designed to mitigate the barrier effect for wildlife, but they can provide large and suitable underpasses for a range of taxa (Iuell *et al*. 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 *et al*. 2012a, Abbott *et al*. 2012b, Møller *et al*. 2016).

Bridges and viaducts can perform a mitigation function for bats and, therefore, the requirements of bats should be considered in the choice of bridge location, design and 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 are often the preferred alternative to open-span bridges or viaducts for financial reasons (Iuell *et al*. 2003) but increase both barrier effect and collision risk for bats and other wildlife (Nowicki *et al*. 2009, Berthinussen & Altringham 2015). They 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). Therefore, bridges are clearly preferable long-term alternatives when considering bat conservation and multiple ecological benefits (Iuell *et al*. 2003).

Figure 8. Open-span bridge taking a re-routed river under a new road. Temporary fencing is used to guide R.hipposideros under the structure until new hedgerow planting is established. Bethesda Bach Bridge, A487 Llanwnda, Wales, UK. © J. Matthews.

7.2.3 Tunnels and culverts as underpasses

Tunnels and culverts are structures built under the road or railway, where the transport infrastructure is on an embankment or on a slope. They may be purpose-built wildlife underpasses, or structures built for other purposes – tunnels to lead minor roads, railways and farm tracks etc., and culverts to allow the passage of water under the carriageway.

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, and height in particular rather than length (Boonman 2011, Abbott *et al*. 2012a, Abbott *et al*. 2012b, Berthinussen and Altringham 2012b, 2015, Møller *et al*. 2016) thus leading to published recommendations on the required species-specific dimensions of underpasses (*e.g.* Limpens *et al*. 2005, 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, for example tunnels for pedestrian access: by restricting the lighting and increasing the size of wildlife underpasses and culverts designed for other taxa, especially if bats are considered early in the planning stage (Abbott 2012b).

Table 3. Mitigation measures and their effectiveness – adapted from Møller *et al.* (2016)

		Effectiveness for	
Safe crossing mitigation measure	**Intended function**	**Clutter- adapted species**	**Open/edge air-space 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
🟥	Proven ineffective or results are ambiguous. Not recommended

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 (Møller *et al*. 2016). 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 found no studies that demonstrate the effectiveness (rather than the use) of tree and shrub hop-overs (Møller *et al*. 2016).

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, 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 be a mechanism in the management plan for the highways estate to ensure that regular maintenance is undertaken. A further consideration amongst highways agencies is the potential risk to road users posed by objects (trees, bat gantries, etc.) in close proximity to traffic, and also of the resulting additional maintenance requirements. 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*. 2005, Nowicki *et al*. 2009, O'Connor *et al*. 2011). However, extensive review by Elmeros *et al*. (2016) found only a few studies investigating the use of these features and none on their effectiveness.

Guidance features, when used in conjunction with other mitigation measures (underpasses in particular) may increase the effectiveness of the mitigation (*e.g.* Fuhrmann & Kiefer 1996, Britschgi *et al.* 2004, Pickard 2014). However, attempts to divert bats from their original commuting routes to underpasses by planting trees and shrubs were not found to be successful (Berthinussen & Altringham 2012). Continuity of habitat features is important during the construction phase. *e.g.* use of temporary 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) and a pan-European review (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 existing 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). A further study found the flight height of bats increased significantly after the installation of the bat gantry (Claireau *et al*. 2021), although further studies in different habitats are required. Without evidence on effectiveness through other case studies, 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 other open constructions probably are also, *e.g.,* nets and lattice gantries (Cichocki 2015, Schut *et al*. 2013). However, some other designs may have some potential and merit further study: 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. One experiment on an avian subject concluded that the birds' predator avoidance behaviour initiated by vehicle proximity was ineffective at higher vehicle speeds (DeVault *et al*. 2015). Speed reduction has been proposed as a mitigation method for bats in the absence of alternative mitigation options (Secco *et al*. 2017), however no studies have demonstrated that reducing traffic speed could 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 the use of acoustic deterrents at wind farms (*e.g.* Arnett *et al*. 2013) without success.

A study was 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 thermal-imaging 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 impact of noise on bats is not fully understood and requires further research (see 4.5.2 and 8.2), thus, the potential effectiveness of this as a mitigation measure has not been fully evaluated (Møller *et al*. 2016). In addition, the use of noise as a deterrent may cause unwanted disturbance effects on bats and on other wildlife, *e.g.* birds or insects, that has not been assessed to date (Amorim *et al*. 2012).

7.5 Mitigating roost loss

A review for EUROBATS (Schofield *et al*. 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.

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). For detailed information on roosting preferences for European bat species see Dietz *et al*. (2009), Simon *et al*. (2004). 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*. 2018a). 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 protect, 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).

Table 4. Example of mitigation hierarchy and measures to address impacts on bats

Measure / Project stage	**Recommendations**
Avoidance	
Route selection / Planning stage	• Use survey information & modelling to select route avoiding high quality bat habitat (roosts, foraging areas, commuting routes) • Prepare permeability plan to aid route selection • After route is selected, further survey to identify commuting routes, roosts, foraging areas • Design lighting plan to minimise light spill
Construction phase	• Retain commuting route features (hedgerows, treelines, etc.) • 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	• Create replacement roosts & habitat where possible for any that will be lost • Monitor flight routes and roosts
Construction phase	• Timetable unavoidable destruction of roosts or habitat to minimise disturbance to bats at critical times • Ensure crossing structures are located on identified flightpaths and habitat links are in place to guide bats to them • Use temporary structures (*e.g.* netting) to retain connectivity across construction site until mitigation structures are ready • Mark (*e.g.* with hazard tape) or fence off habitat to be retained • Replant habitat features (*e.g.* hedgerows) as soon as practically possible • Monitor flight routes and roosts and note any changes

Table 4 (continued). Example of mitigation hierarchy and measures to address impacts on bats

Measure / Project stage	**Recommendations**
Operational phase	• Continue to monitor flight routes and roosts • Ensure that mitigation features are functioning as intended and take necessary action if not
Compensation - where impacts are predicted still to occur even after mitigation	
Planning stage	• Identify possible locations for habitat enhancement and creation based on the species present and likely to be affected
Pre-construction phase	• Start habitat creation enhancement as soon as possible (*e.g.* tree and shrub planting, changes in land management to encourage insect prey) • Construct additional new roosts and improve existing roosts (*e.g.* installation of hot boxes, cool roost areas, grille underground sites)
Operational phase	• Monitor new and enhanced habitats and roosts and take remedial action if required

7.7 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. (Elmeros & Dekker 2016, Rosell 2020).

- 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 should include inspections following adverse weather events, accidents, etc.

Rosell *et al.* (2020) provides detailed guidance on developing an adaptive ecological asset maintenance plan and example maintenance checklists. See also Iuell *et al.* (2003) and O’Brien *et al.* (2018).

8 Recommendations for further research

This chapter gives recommendations for future research on the topic of traffic infrastructure and bats to ensure that the goals in relation to bats and roads set by the EUROBATS Parties are met.

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).

8.1 How do railways affect bats?

Most studies on traffic infrastructure and wildlife have focussed on the effects of roads, and on large mammals. There are few studies on the effects of railways on bats. Although superficially both roads and railways have the same impacts (loss of roosts and habitat, fragmentation and the barrier effect and collision mortality), they differ in a number of ways including the size and shape of area affected (the effect zone), the types of vehicles, temporal patterns of traffic activity, pollution impacts. There is a lack of information as to how these affect the behaviour and population stability of different bat species, and how far survey and mitigation techniques developed in relation to road infrastructure are applicable to railways. Research is needed into the following areas:

- Better wildlife collision estimates are needed for railways, including data on searcher efficiency, carcass persistence and the influence of fencing along railway lines on the latter (Barrientos *et al*. 2019).
- Understanding the barrier and fragmentation effects of railways, and how these are affected by other linear infrastructure elements in the landscape. Use of models may help to separate the different effects. Genetic studies should be used to demonstrate which, if any, mitigation measures effectively restore connectivity (Barrientos *et al*. 2019).
- The potential benefits of managing railway corridors for wildlife whilst minimising collision risk (Vandevelde 2014).

8.2 How does noise affect bats?

There is a lack of evidence about the impact of noise on bats in general. There is anecdotal information and some research but a review by Reason & Bentley (2020) concluded that it is difficult to compare studies on noise since it was not measured or reported in a consistent way. Information gained will be relevant to other infrastructure construction projects and other developments. Research is needed into the following interrelated areas:

- The development of standardised protocols for measuring and reporting noise across the range of frequencies applicable to bats.
- How are different bat species affected and which activities are affected (*e.g.* roosting, foraging, communicating)?
- Which characteristics of noise affect bat behaviour, *e.g.* temporal (constant / infrequent / very rare), volume; frequency (kHz)?
- Do bats tolerate or become habituated to noise pollution?
- How can negative impacts of noise be avoided or mitigated?

8.3 How does traffic mortality affect bat population sustainability?

Direct mortality is the most obvious effect of traffic on bats. Traffic infrastructure can also be a barrier, resulting in fragmented landscapes, loss of foraging or reproduction sites and it 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 the infrastructure construction process itself and the usual scale of monitoring its effects. This means that a local study might miss large impacts of the infrastructure on the surrounding bat populations.

The following research needs are recognised:

- A shift in focus to larger scale studies (Van der Ree *et al*. 2011) to road and other transport networks, rather than single sections of roads (Barrientos *et al*. 2021).
- Long-term studies are needed to investigate the effects of traffic infrastructure on habitat availability and gene flow and the resulting effects on populations. For example, Medinas *et al*. (2023) studied the effects of roads on lesser horseshoe bats (*R. hipposideros*), noting that roads can lead to genetic isolation affecting the structure of the population or potentially local extinctions. Field data can be used to forecast population dynamics, genetic effects and mortality thresholds using population modelling.
- An understanding as to how mortality through traffic collisions relates to other causes of mortality. This is challenging research, requiring long-term studies of individuals and overcoming the problem of detectability of different causes of mortality. Some research has been undertaken to look at mass or large-scale mortality events but the effect of ongoing mortality on bat populations is unknown.

8.4 How to find traffic collision hotspots - where and when?

The location of mortality hotspots does not remain constant from year to year and is affected by habitat changes and previous mortality (see 4.7 and 5.8). A combination of techniques should be used to predict areas where collision risks are highest and which should be avoided at the route selection stage, or where mitigation structures will need to be installed. Data from studies should be made publicly available.

- Bat activity surveys - to identify areas of high activity and confirm the suite of species present,
- Radio-tracking studies - to identify roosts, flight routes and confirm species identification,
- Habitat suitability modeling and use of remote sensing data - to predict areas where hotspots are likely to occur and to persist over time,
- Determination of flight paths at potential crossing locations, *e.g.* through acoustic flightpath reconstruction and surveys using night vision aids (see 5.7.4.1),
- The applicability of new techniques being investigated for other purposes should be considered (*e.g.* environmental DNA to identify bat species presence).

Specific searches are needed to find bat carcasses since they are unlikely to be detected through routine carcass inspections of roads or railways. Regular inspections of aircraft and runways may identify bat collisions, but reporting systems are not necessarily in place to make use of the data (see 5.7.4.3). Traffic mortality data is valuable but not always available in a format that can used. It can be improved by

- the use of standardised survey methods,
- corrections for carcass persistency,
- use of searcher efficiency trials,
- use of per capita mortality estimates (% of population killed),
- identification of carcasses to species (use of DNA analysis), and sex and age if possible,
- the publication of survey and monitoring results.

8.5 How to design and test new mitigation measures?

Although there are a number of mitigation measures that have proven effective for a number of species (see Chapter 7), innovation is needed in the search for cheaper and more effective mitigation measures. Designs need to be species-specific and location-specific, based on the ecology of the bat species affected 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 ***BACI*** design, taking account of the conflict between a) the need for robust data on effectiveness and also b) increasing risk by not implementing mitigation measures if 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 be effectiveness in preventing fragmentation and mortality, and preferably also effects on the population, not simply usage.

Monitoring should be sufficiently long 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 published papers accompanied by a "Conservation Evidence" style synopsis (https://www.conservationevidence.com/synopsis/index).

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Glossary and abbreviations

Before-After-Control-Impact (BACI) - study design used to compare ecological responses before and after treatment. 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).

Colony - usually refers to a sub-section of a population of bats of one species that are roosting together with a shared ecological function (*e.g.* maternity colony).

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 aimed to off-set unavoidable negative impacts where residual effects exist after mitigation.

Control - a constant and unchanging standard of comparison in scientific experimentation.

Culvert - A covered channel used to convey surface drainage water or other watercourse under a road (or other structure).

Day roost - used by individual or small numbers of bats to rest during the day but rarely used overnight.

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 Assessment (EA) - a procedure that ensures the environmental implications of infrastructure development are taken into account before the decisions are made. EA can be undertaken for public plans or programmes known as Strategic Environmental Assessment (SEA) or for individual projects Environmental Impact Assessment (EIA).

EIA (see EA)

Feeding / foraging area - habitat patches to which bats travel to feed.

Feeding roost / perch - a place where individual or small numbers of bats rest or feed during the night but are rarely present in the day.

Flightpath / flightline - a route used by 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.

Hibernation site - a roost site typically with cool stable temperatures where bats roost during cold winter weather.

Mating site - a site where mating takes place usually from late summer onwards.

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 roost - used by bats to rest or shelter during the night but rarely used during the day.

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

Infrared radiation (IR) - scopes or cameras that are sensitive at very low light levels. Active IR systems 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 that sense and display differences in heat between objects and do not use additional illumination.

NGO - non-governmental organisation

Open/edge adapted species - bat species that can forage in open air spaces but often commute and forage along edges of vegetated habitats, highly maneuverable bat species able to fly in complex aerial spaces (see also **clutter-adapted species** and **open airspace adapted species**).

Open airspace adapted species - fast-flying bats species that commute and forage in open environments (see also **clutter-adapted species** and **open/edge adapted species**).

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

Population - a group of bats, all of the same species, which occupy a particular area. Also, the total number of individuals of a species within an ecosystem.

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.

SEA (see EA)

Satellite roost - an alternative roost used by breeding females located in close proximity to the main maternity roost.

Swarming - usually refers to seasonal (autumn swarming) 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 to describe the behaviour of bats flying repeatedly around the roost entrance (especially at maternity roosts in summer) at dawn before entering (dawn swarming).

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

Transitional / occasional roost - used by bats for short periods of time usually just before or just after entering hibernation. Often used by small numbers at any one time but may be many different individuals.

Tunnel - a covered passage under a road (or other structure) used to convey traffic, pedestrians, livestock or as a wildlife mitigation crossing.

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Annex 1 – EUROBATS Resolution 7.9 Impact of Roads and Other Traffic Infrastructures on Bats

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, Minffordd and Tremadog bypass, Wales, UK

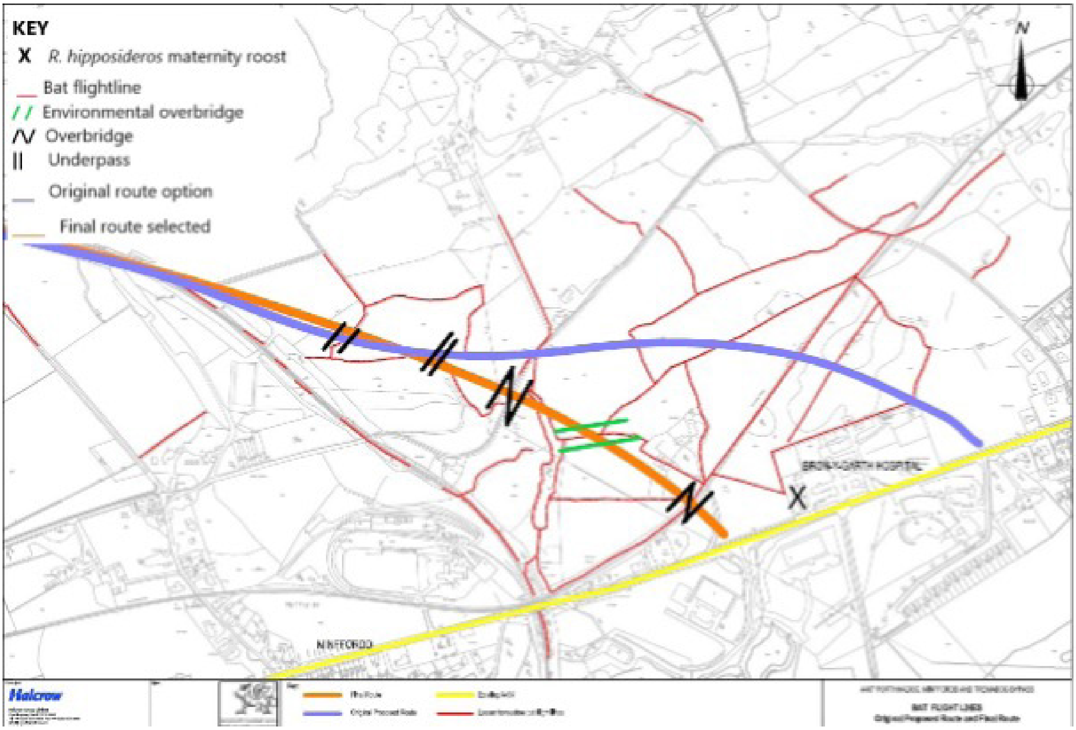

Figure A2.1. Map showing location of R. hipposideros maternity roost, bat flightlines and route options and mitigation structures (adapted from Green & Wyatt, 2009)

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

Issues – The scheme was required to reduce traffic congestion, especially during the busy tourist season in an environmentally sensitive area close to Eryri National Park, affecting multiple nationally and internationally designated sites, including a Natura 2000 site designated for *R. hipposideros*.

At the start of the process of planning the scheme, a significant *R. hipposideros* maternity roost (300 adults) was discovered.

Surveys showed bat use of the surrounding habitat for foraging and key flight routes from the roost that would be severed by the road scheme. Due to the topography, the original proposed route lay in a cutting close to the roost and there was no option to provide underpasses as crossing routes. An alternative route was chosen that cut across fewer flightlines and could accommodate both overpasses and underpasses as mitigation to reduce the barrier effect and collision risk.

Methods – Flightpaths from the roost were identified by radio-tracking surveys. The scheme was also used as a study site for two research projects, on lighting and lesser horseshoe bats (Stone 2009) and on bats and roads (Berthinussen & Altringham 2015).

Solution – The route was altered to avoid key flightlines and some foraging areas. Mitigation structures were installed at identified crossing points, including underpasses, a modified overbridge (carrying a single-track steam rail line) and a wildlife overpass. The latter consisted of a vegetated overpass with 2 m high vertical sides and a line of deadwood and planters containing hawthorn (*Crataegus monogyna*). It was designed to have the same appearance as the nearby overbridge carrying a single-track steam railway line and farm track. Woven wooden fencing was installed to guide commuting bats to both overpasses (see Figure 8).

Figure A2.2. Wildlife overpass (foreground) and combined rail bridge and overpass (background). © J. Matthews

Figure A2.3. Detail of Environmental Overbridge showing shrub saplings in planters and dead wood stumps in 2012 (a) and 2015 (b). © J. Matthews (a,) © Hyder Consulting (b)

Results – Overall a significant proportion (≥95%) of the bats crossing the scheme utilise the purpose-built crossing structures rather than crossing over the open road.

Early monitoring of the environmental overbridge (2013) found that significantly more bats crossed the road using the wildlife overpass (62% within 2 m and 65% within 5 m) than crossed the road below at unsafe heights next to the structure (19%). Six species (*Pipistrellus pygmaeus, Pipistrellus pipistrellus, Plecotus auritus, Rhinolophus hipposideros, Myotis nattereri, Myotis brandtii/mystacinus*) were recorded using the bridge to cross the road. *Pipistrellus pygmaeus*, the most abundant species, 'used' the bridge significantly more often (71% within 2 m and 75% within 5 m) than crossed the road below at unsafe heights (17%). *Pipistrellus pipistrellus*, the second most abundant species, used the bridge less frequently, and no significant difference was found between the number of bats crossing unsafely (27%) and using the bridge within 2 or 5 m. The remaining species all crossed the road more often using the bridge than crossing unsafely below, but numbers were too low for statistical analysis (Berthinussen & Altringham 2015).

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Annex 3 – Collision risk modelling case study

Example – Airport Runway in the UK

1. **Desk study**
   To determine survey locations, species records collated, searches for maternity and hibernation sites within a minimum of 2 km of the study area.
   Aerial photography used to identity habitats and features likely to be of value to bats.
   Roosts and commuting routes identified by bat surveys (active, static, radio-tracking studies).

2. **Field survey methods**
   Thermal imaging surveys undertaken (minimum) of 2 x dusk surveys and 2 x dawn surveys in each of the following periods:
   - Pre-maternity season (May and June)
   - Maternity season (July and August)
   - Post maternity / dispersal season (September and October)

Dawn surveys start 2 hours before dawn and end at dawn; dusk surveys start at dusk and end at midnight. This is based on peak daily bat activity periods and air traffic (usually reduced between midnight and 5am).

Active and static detector surveys undertaken within 0.5 km radius of new development throughout the pre-construction period to identify any new features or habitats used by bats, to include the location of the proposed development and all habitats within the study area that are likely to be used by bats.

Camera Locations

a. Linear features crossing the proposed runway. Two thermal cameras should be deployed at each side of the feature. The distance from the camera to the feature will depend on the capabilities of the equipment (*e.g.*, a camera with a 45-degree lens and an infra-red resolution of 1024 x 768 pixels will provide a maximum detection distance of a bat in flight of 104 m (Fawcett Williams 2019).
b. Habitats or linear features along the proposed runway – a minimum of two thermal cameras per habitat identified in close proximity to the proposed runway location.

Equipment

a. Acoustic recording - hand-held **full spectrum bat detectors** should be placed between filming locations to record bat passes. Detectors should be set to record any sound event between 13kHz and 155kHz (or as appropriate for the geographic location).
b. Thermal imaging equipment should have the following specifications:

- Long Wave (LW) spectral range
- Temperature range of -40^{0}C to +120^{0}C
- Video recording capability in radiometric data files
- Video frame rate of 30 Hz or greater
- Thermal sensitivity of 20 – 50 mK at 30^{0}C
- Detector resolution: Image size of a minimum of 640 x 480 pixels (Note that the high-thermal equipment will allow the detection of bats in flights at a much greater distance)
- 45-degree lens to allow the field of view (FOV) to record activity on the proximities on the proposed runway.

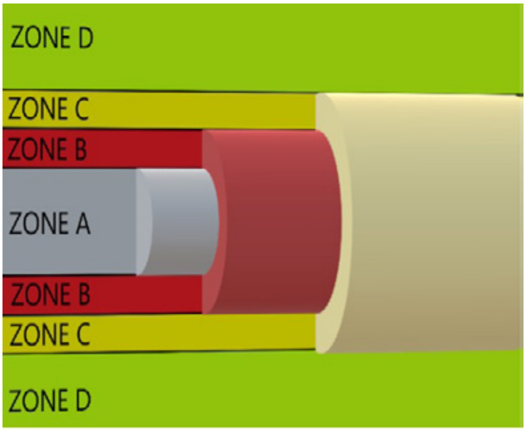
Thermal cameras should be set to record on radiometric format, ideally in 10- or 20-minute radiometric videos to allow image optimisation analysis.

3. Data analysis

a. Species identification - sound files should be manually analysed to species level (when possible). Identification criteria should be based on the association between acoustic call type, call shapes and measurable parameters (start frequency, end frequency, signal length, peak frequency), interval duration between calls and the environment (clutter / open space).
b. Radiometric data analysis - radiometric files should be manually analysed utilising an appropriate software package. During the processing of the radiometric files, the image should be enhanced utilising a high-definition colour palette and by adjustment of the thermal span parameters.

Footage should be viewed in real time. For each bat pass identified within the footage, the following should be noted:

- Time of pass in bat detector / recorder
- Species (if correlation with a file from the detectors deployed is possible)
- Number of bats
- Activity type (commuting or foraging)
- Direction of flight
- Flight height (*e.g.*, grouped in three height classes: [0–20) m, [20–40) m, >40 m)
- Approximate distance of bat from camera
- Risk zones where the bats were observed, and approximate time spent in each zone rounding up to the closest second
- Comments: to include thermal imaging file name and time of the observation.



A = area used by aircraft or airport traffic (existing or proposed runway)

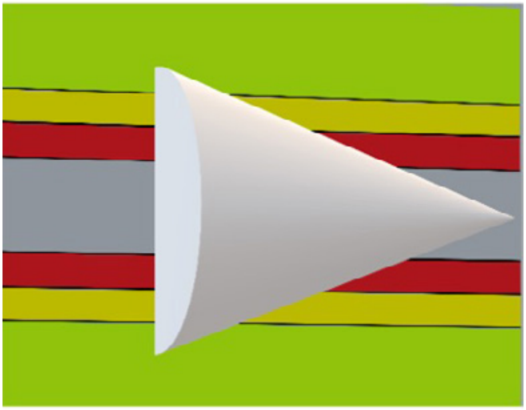
B = area where bats may be susceptible to barotrauma

C = area between 25 m and 50 m from the taxiway where bats may be impacted by high-speed moving objects due to its proximity to zones A and B

D = area further than 50 m from the edge of the taxiway where bats are considered to be safe from impacts such as those in zones A – C

Figure A3.1. Four hazard zones used to classify bat passes observed on camera.

4. Collision risk modelling



The area covered by the thermal imaging survey can be calculated using the camera resolution, the field of view of the camera lens and the maximum detection distance.

The volume covered by a survey (using the acoustic recording equipment specified above) would be defined by the volume of a half cone with a 45-degree opening angle and a height of 104 m, resulting in a volume of 20,600 m^2 (see Figure A3.1).

Figure A3.2. Volume of survey coverage (indicated by half cone).

Statistical analysis

A Bayesian method is recommended to predict the annual bat fatality rate, collision probability, fatalities and to account for uncertainty and prior information.

In this example, the unit of a “bat seconds” (defined as a second within which a bat was seen) is used as a measure of exposure of bats to collision or barotrauma. Bat seconds are used in the calculations for the exposure and the collision probability. Collision probability is calculated using uninformed priors to model the lack of knowledge in the absence of pre-existing applicable data.

The total annual bat fatalities (F) as the result of collision with moving planes or from barotrauma is represented as the product of **the rate of bat exposure** (λ) to runway hazards, **the probability that the bat exposure will result in a collision** with a plane or suffer from barotrauma (C), and an expansion factor (ε) that scales the resulting fatality rate to the hazardous footprint of the proposed development.

The annual number of predicted fatalities for the project is calculated:

$$F= \varepsilon \lambda C$$

The exposure rate (λ) is the expected number of exposure events (bat-seconds) per hour between dusk and dawn per cubic kilometre of hazardous space (h/km).

The following information can be used to inform the calculation of the exposure rate if available:

- Records of bat strikes at the airport
- A search for bat carcasses along the length of an active runway and a minimum area of 50 m at each side of the runway. Carcass removal by scavengers in airports is limited to birds and, therefore, carcass searches should be undertaken at a minimum frequency of two weeks* during the bat active season (April to October or as appropriate to the study location). *or see the latest recommendations for wind farm carcass searches.

Where bat exposure data has been collected during the pre-construction phase surveys, it should be utilised to determine the posterior distribution which is used to predict bat fatalities.

Collision probability C is the probability, given exposure (1 second of flight in zones A and B, δ) of a bat colliding with a moving aircraft or suffering from barotrauma when the bat is hit by the vortex pressure wave created by a passing aircraft. This collision probability will be used to estimate the annual predicted fatalities.

The expansion factor (ε) scales the resulting per unit fatality rate (fatalities per hour per km^2) to the night hours, τ, during the bat active season (*e.g.* April to October) and total hazardous area (km^2) in both time and space within the project footprint.

The number of predicted annual fatalities is generated as the expanded product of the posterior exposure rate and the prior collision probability.

$$F= \varepsilon \text{ x } \textit{posterior } \lambda \text{ x } \textit{prior } C$$

The mean, standard deviation and 80% quantile (considered to be the upper credible limit) is determined directly from the distribution of predicted fatalities.

EUROBATS

The continuing global expansion of the traffic infrastructure network has a detrimental impact on bats and other wildlife through indirect effects such as loss of habitats and roost sites, increased habitat fragmentation, avoidance of habitats (the barrier effect) and directly through collisions with vehicles. Some impacts can be avoided or minimised through an effective planning process and good design. Mitigation features are used to promote permeability whilst reducing mortality, however, solutions should be species-specific and site-specific.

These guidelines bring together information on the impact on bats of road, rail and air traffic infrastructure. There is a need for transport commissioning authorities to work with researchers to better understand how traffic infrastructure and operation affect bat behaviour, and impact bats at the population level. Robust survey and monitoring of traffic infrastructure projects are required to improve the effectiveness of avoidance and mitigation measures (EUROBATS Resolution 7.9).

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