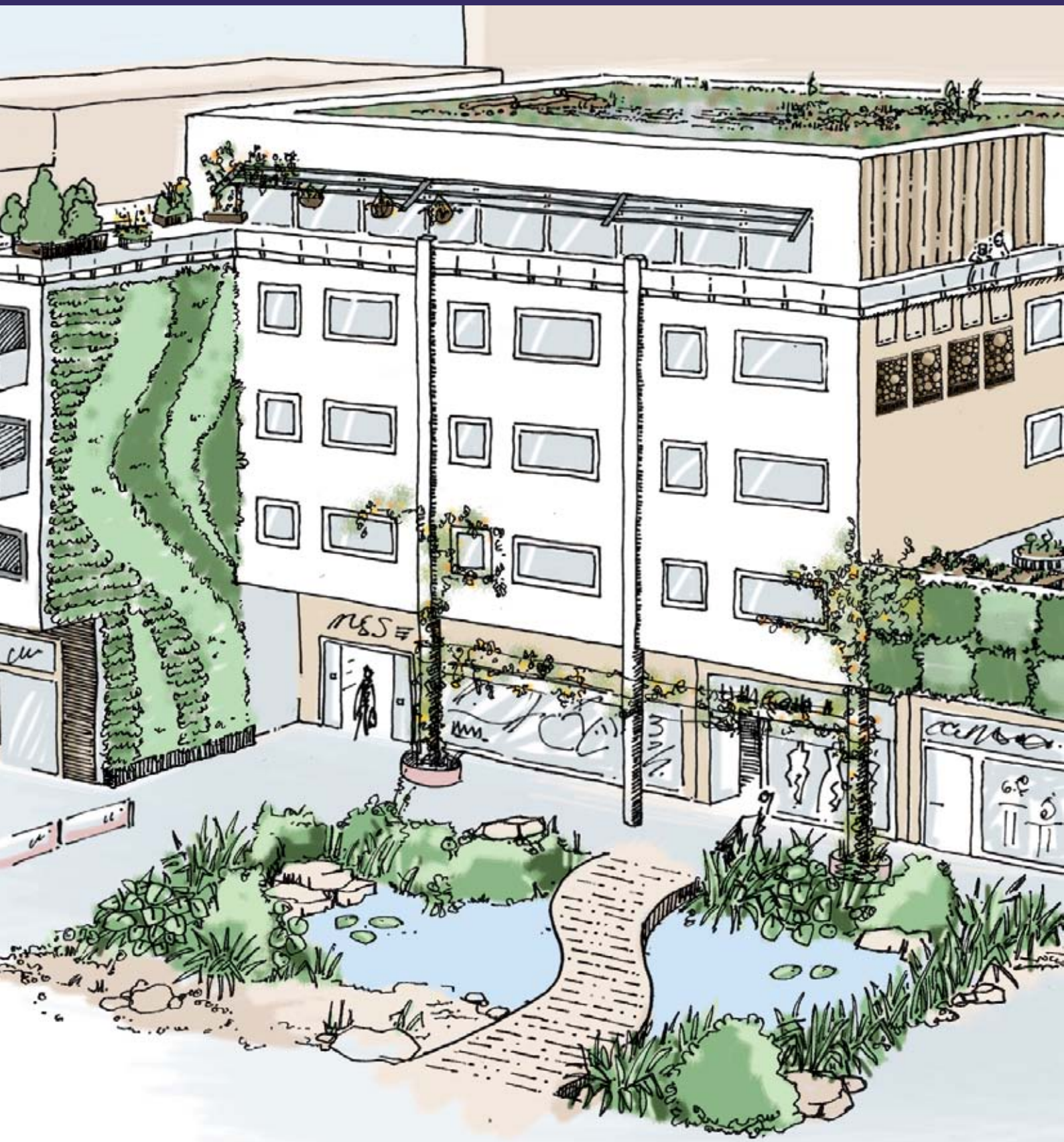
Bat Conservation Trust

Landscape and urban design for bats and biodiversity



Written by Kelly Gunnell, Bat Conservation Trust
with contributions from
Gary Grant, Independent Ecologist
and Dr Carol Williams, Bat Conservation Trust

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Foreword

The new publication by the Bat Conservation Trust, 'Landscape and urban design for bats and biodiversity' will be a useful resource for landscape architects and anyone involved in the design and provision of rural and urban environments, particularly when designing habitats for bats and the insects they feed off. The guide demonstrates that designing for bats can have a positive impact on overall biodiversity improvement and enrich the whole landscape. Inclusion of design for bats enhances wildlife landscapes and a wide range of ecosystems.

The guide is divided into three main sections foraging, roosting and commuting and landscape connectivity. The first two sections provide a range of relevant information on types of habitat where bats forage and where they roost. They contain data about specific bat species and their preferred environments which will be new to most landscape architects and most helpful in establishing new habitats. The third section focusses on landscape connectivity, the network of street trees, parks, hedges and gardens that make up our urban spaces and the importance of creating and maintaining these networks to enable bats to move within their environments. There are sections on underpasses and bridges and the effect of artificial lighting all of which are of relevance in creating and maintaining bat-friendly habitats. The ideas and information in this guide will give landscape architects new ideas and present opportunities that help our threatened bat populations.

Together Ecologists and Landscape Architects can provide technical advice and design solutions which most ensure effective bat habitat creation and mitigation measures. Bats are an important element in the biosphere and designing for them delivers benefits for wildlife, the wider environment and the community.

Liz Ford
Chair of the Technical Committee
Landscape Institute
August 2012

Landscape Institute
Inspiring great places

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Contents by design theme

Contents by bat requirements

Introduction

Landscape design, particularly for larger developments and urban areas, can provide great benefit to native wildlife and biodiversity making healthier environments for all. This publication presents simple but effective measures designers, developers and planners can use to enhance biodiversity on sites of all sizes.

Why landscape design for bats?

Bats are a vital part of our native wildlife, accounting for almost a third of all mammal species in the UK and occupy a wide range of habitats, such as wetlands, woodlands, farmland, as well as urban areas. They can tell us a lot about the state of the environment, as they are top predators of common nocturnal insects and are sensitive to changes in land use practices. The pressures they face - such as landscape change, agricultural intensification, development, and habitat fragmentation are also relevant to many other wildlife species, making them excellent indicators for the wider health of the UK's wildlife.

Bats suffered huge declines in the last century (estimated 70% lost). As a result, bats and their roosts are now protected by European and UK law and need to be considered in the development process. Many bats are priority species in the national biodiversity reporting process. The Building Research Establishment Environmental Assessment Methods (BREEAM and the Code for Sustainable Homes) awards credits for retaining, protecting and enhancing features of ecological value, including for bats and birds.

For these reasons bats are an ideal group to target as beneficiaries of landscape design. A landscape design that attracts bats will support other wildlife. Attract bats and you will be creating biodiverse multi-functional green infrastructure which will be capable of providing a wide range of ecosystem services.

How bats use the landscape

Bats are long-lived, social animals that use the landscape intensively for foraging, roosting and commuting.

Foraging: bats are predators, feeding on a wide range of insects, which in turn are ultimately supported by vegetation. Areas rich in native vegetation support a greater abundance and higher diversity of bats and wildlife.

Roosting: bats require a wide variety of resting places or roosts, of different sizes, microclimate and function, which they move between throughout the year. However they are loyal to their roost sites and will return to the same roosts year on year.

Commuting: bats need continuous corridors of habitat to link their roosts to their foraging sites. They follow these corridors in set routes or flight paths.

This document approaches landscape design from a bat ecology perspective by grouping biodiversity features according to the three landscape needs of bats: foraging, roosting and commuting. The sections could also be arranged by design requirement such as masterplanning, public open space and buildings and surrounds (see Contents by Design Theme).

Design process

Before embarking on a design, it is important to understand what existing habitats are in the area. Wherever feasible, **any existing habitat of value should be retained and enhanced**, and links should be made to adjoining habitats. Surveys by suitably qualified ecologists and reviews of existing information will inform and inspire the design process. Taking this into account, it is important to remember that the overall aim is to maintain ecosystems, and the goods and services that these ecosystems provide, and where possible to increase biodiversity and restore natural processes.

A twin track approach is recommended, whereby habitats are created, but care should be taken to ensure that the requirements of a selection of appropriate species are also met. It is tempting to be ambitious and to create a wide range of habitats and features; however **some habitats may need to be above a threshold size in order to function properly**. Remember that habitats cannot be created anywhere – suitable soils and adequate sunshine and rainfall must be available. In addition the role of a site as a stepping-stone or a link in an ecological network must be considered.

When creating new habitats, restoration ecologists recommend mimicking natural habitats by using native species in natural associations. Non-native species should be avoided whenever possible but if there is no other alternative we recommend that species with a documented value for local wildlife are chosen. In formal open spaces exotic shrubs and plants that attract insects, especially night flying insects, are also valuable. To establish non-native species with low ecological value is to waste an opportunity. Invasive species must be avoided.[1]

Considerations for designers in creating locally appropriate habitats within green infrastructure include

- Bioregion and landscape character
- Climate, micro-climate and aspect
- Sensitivity to water conservation and sustainable drainage
- The existing and potential role of the site as part of an ecological network
- Habitats and species identified in Biodiversity Action Plans (BAPs). Species may be very specific in their requirements for food, shelter and breeding places
- The use of locally appropriate native species in natural associations or non-invasive introduced species with a documented value for wildlife

Serotine bat in flight.
Photo credit: Hugh Clark

1 https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm

Foraging

Providing and enhancing foraging habitat is probably the most important intervention that can be done to improve landscapes for bats. All UK bat species are insectivores. Interventions that increase insect abundance, particularly nocturnal flying insects, will benefit bats.

Planting

To attract nocturnal flying insects, plant:

- Mixtures of flowering plants, vegetables, trees (including fruit trees) and shrubs, to encourage a diversity of insects to sustain bats and other wildlife throughout the year.
- Flowers that vary in colour, fragrance, shape, amount of nectar and time of flowering.
- Pale flowers that are more easily seen in poor light, so attracting insects at dusk.
- Single flowers, which tend to produce more nectar than double varieties.
- Flowers with insect-friendly landing platforms and short florets, like those in the daisy or carrot families.

A planting list is provided in the Appendix .

Woodlands

Although the term “woodland” is used in this document, the advice given applies equally to parks, gardens and urban squares with mature trees. Good woodland for bats has a well-developed canopy layer, a shrub layer and a ground layer.

Woodlands are a valuable source of insect prey for all bat species, even those that are not woodland specialists. The large number of insects associated with many of our **native trees** plus those associated with the understory and ground flora, and additionally those that seek the sheltered woodland environment, make the insect numbers supported greater than any other habitat. **Wet woodlands** are especially valuable as foraging sites. **Standing and fallen deadwood** are vital elements of the woodland ecosystem and their breakdown occurs in part through the work of invertebrates, including insects. Open glades, rides, woodland edge and coppice are areas within woodlands where extra light allows different plants and insects to thrive at different times.

Managing woodland for foraging bats

- Leave some areas of the wood unmanaged (‘tidying up’ is not good for bats or biodiversity in general).
- Retain native climbers such as ivy and honeysuckle.
- Maintain sunny glades to maximise insect abundance and diversity.
- Retain a dense understorey.
- Retain standing and fallen dead wood or create log piles where public perception of tidiness is an issue.
- Restore streams and create ponds and wet areas.

Trees

Native trees are host to a large array of insects[2] and can be important to foraging bats even outside of a woodland setting. For instance, willow, birch and oak can support very high numbers of insects. If the tree is a veteran then even more associated invertebrates will be found.

Trees in an urban environment

Trees in cities and towns, whether on streets, in woodland or in parks, gardens, schools or hospitals, provide a wealth of benefits relating to biodiversity. They are unique in their ability to support a great variety of wildlife in some of the harshest locations in our urban areas.

2 C. E. J. Kennedy and T. R. E. Southwood (1984) The Number of Species of Insects Associated with British Trees: A Re-Analysis. Journal of Animal Ecology, Vol. 53, No. 2, pp. 455-478

Tree pits at Barking Central receive surface water run-off and contain underplanting.

Photo credit: Gary Grant

When considering foraging think about the ability of trees to support insects. This might be because they are a native species that has a large number of associated insect species or because of the shelter provided. In planting or retaining trees, remember that these should not be illuminated by artificial lighting.

When planting new trees select a tree species that has the form and tolerance needed for that location. When selecting which species of tree should be planted, various factors are taken into consideration, including:

- size and shape when full grown
- life span
- suitability for local soil types and other ecological limitations
- pollution tolerance
- ornamental value
- disease resistance
- any tendency to shed branches
- suitability to the urban environment
- future proof with regard to climate change

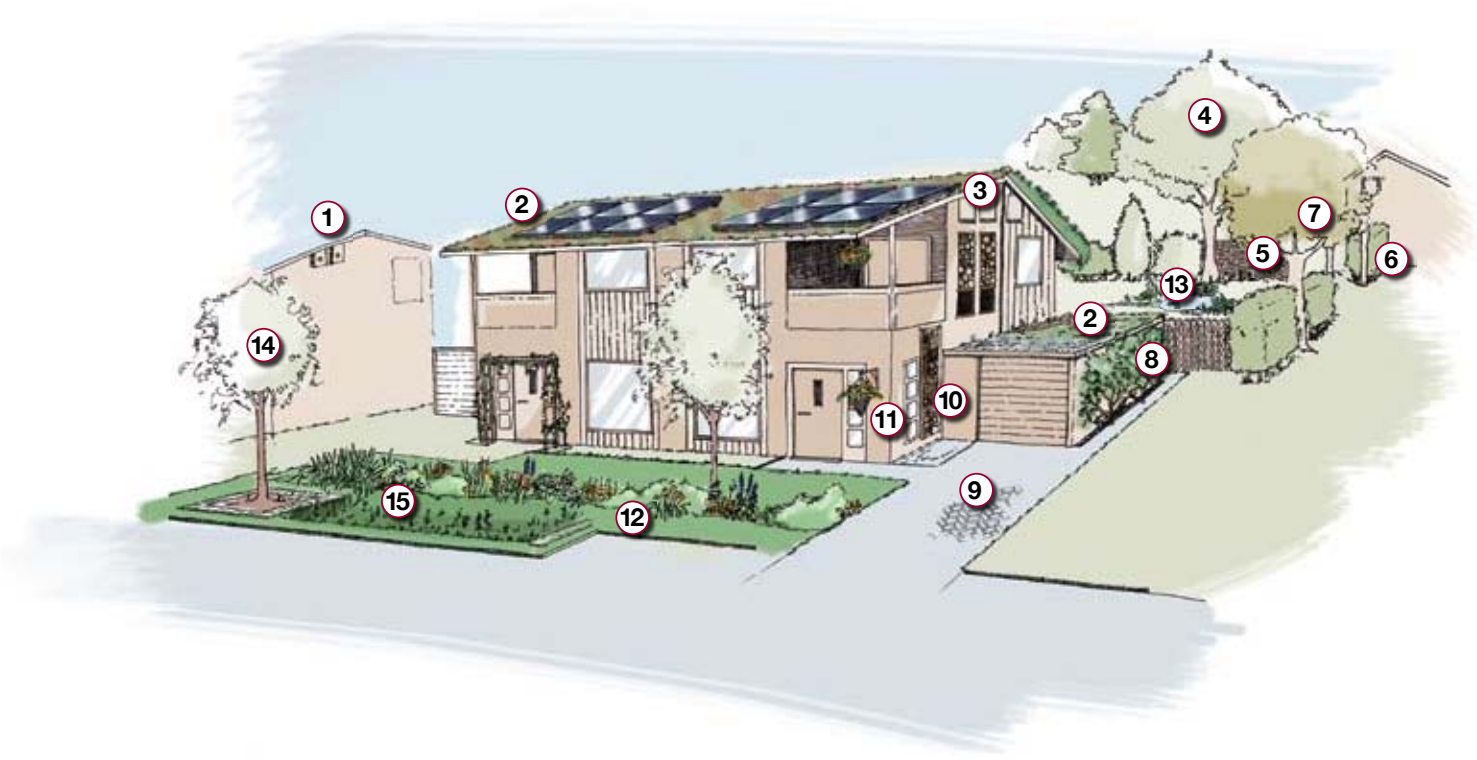
Trees should be chosen and located based on their category as either:

- **Signature trees** – provides a visual landmark and has potential as roost tree.
- **Avenue trees** – potential as roost trees, linear features for flight paths and foraging.
- **Street trees** – should be tolerant of pollution; potential as roost trees, linear features for flight paths and foraging.
- **Ornamental feature trees** – provides insect source for bat foraging.
- **Belts and groups** – provides landscape structure and foraging source.
- **Courtyard trees** – examples include fruit and flowering trees; provides insect source for bat foraging.

Table 1. Foraging and roosting characteristics of UK bat species

Flight paths	Bat species	Foraging				Roosts		
		Closed Woodland	Open woodland	Wetland	Open/ parkland	Trees	Buildings	Underground sites
Species that hunt close to or in vegetation and follow structures.	Lesser horseshoe bat	•	•		•		•	•
	Natterer's bat	•	•			•	•	•
	Bechstein's bat	•				•		•
	Brown long-eared bat	•	•	•		•	•	•
	Grey long-eared bat	•	•	•			•	•
	Greater horseshoe bat				•		•	•
Species that hunt along border structures and follow structures.	Whiskered bat	•	•	•	•	•	•	•
	Brandt's bat	•	•	•	•		•	•
	Barbastelle	•		•	•	•		•
Species that hunts over water and follows structures.	Daubenton's bat			•	•	•	•	•
Species that hunt along linear features out into the half-open surroundings.	Soprano pipistrelle	•	•	•	•	•	•	
	Common pipistrelle	•	•	•	•	•	•	
	Nathusius pipistrelle	•	•	•	•	•	•	
Species that hunt in half-open to open surroundings and sometimes follow features.	Serotine		•	•			•	
	Noctule		•	•		•		
	Leisler's bat		•	•		•	•	

Residential biodiversity enhancements



Residences can incorporate the following features for biodiversity:

1 Bird boxes (shady orientation)
2 Green roof
3 Integrated bat boxes (majority located on southern orientations)
4 Tree clusters
5 Hedgehog passages (+ 15cm gap)
6 Hedgerows
7 Standard trees
8 Climbing plants
9 Permable paving for drainage
10 Habitat walls
11 Planters and baskets
12 Rain garden
13 Wildlife pond
14 Street tree
15 Unmown edges and verges

The orientation of the features and proximity to artificial lighting should be carefully considered.

Table 2. Tree species for foraging and roosting potential

Native Tree species	Roosting potential	Supporting foraging
Oak	Very good	Very good
Willow	Minimal	Very good
Beech	Very good	Good
Ash	Good	Good
Elm	Good	Good
Birch	Minimal	Very good

Trees are vital for ecosystem services. They have a key role in filtering pollutants, storing carbon, reducing flooding and reducing temperatures in warm weather, as well as positive influences on human health and well-being. A key step in promoting biodiversity on our streets is ensuring the preservation of mature trees during development; as large and mature trees provide all of these benefits to a greater extent than small or young trees. The Torbay i-tree eco project is looking at quantifying the value of urban trees in this context.[3]

Open habitats, recreational areas and grassland

Open habitats, recreational areas and grassland can support a range of insects suitable for foraging bats. Feeding opportunities are increased by the presence of flower-rich meadows, scrub and groups of trees. It is important to provide native flowering plants, shrubs and trees throughout spring, summer and autumn. Furthermore it is vital to have appropriate management regimes - more intensively managed amenity grasslands may still have large numbers of insects, but fewer species, which can lead to food shortages at certain times of the year.

Key improvements to consider are:

- Develop species-rich grasslands through planting or re-seeding and the introduction of specific management regimes.
- Vary grass heights through selective cutting to provide diversity of vegetation structure.
- Avoid the use of fertilisers and pesticides as these reduce plant and invertebrate diversity.
- Avoid cutting until after the plants have finished seeding.
- Maintain or reinstate flooding or wetting of grassland areas in association with riparian corridors.
- Expand lightly managed borders on areas of intensively mown grassland.
- Scalloped edges and bays will provide sheltered areas with higher insect concentrations.

Urban wetlands

Freshwater is an important resource for all bat species in the UK. Bats drink from open water and many species also forage on emerging insects – such as caddis flies, crane flies and midges – that have aquatic larval stages. Bankside vegetation provides food and valuable cover for foraging. Bat species particularly attracted to freshwater habitats are: whiskered bat, Leisler's bat, Daubenton's bat, common pipistrelle, soprano pipistrelle, Nathusius and noctule bats.

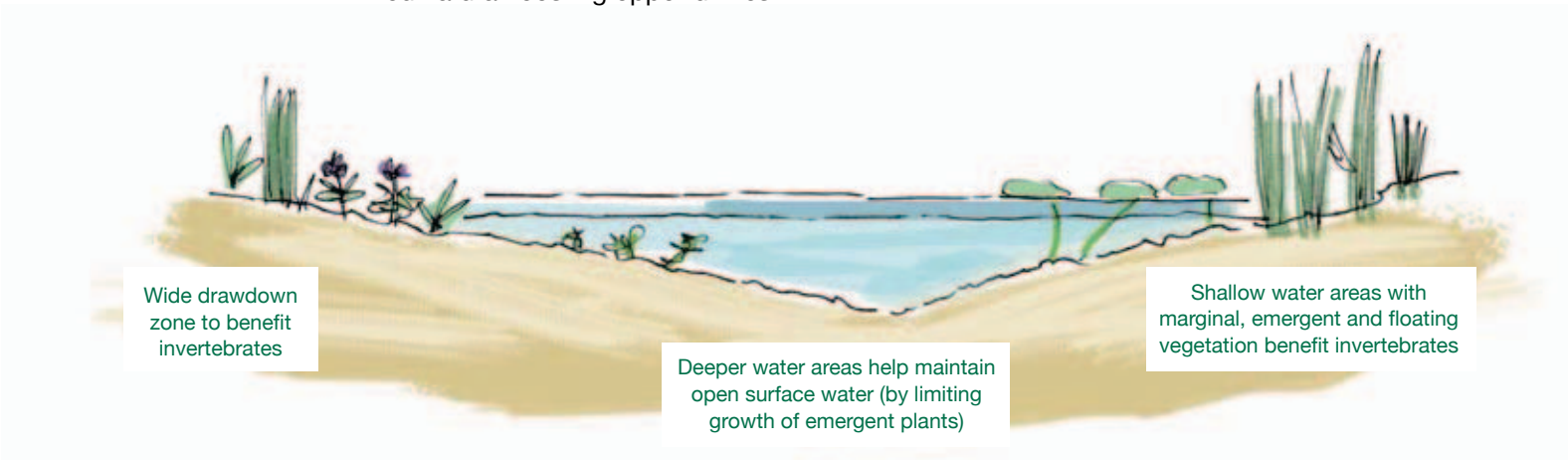
Ponds

Creating and managing ponds encourages greater numbers of bats and also higher species diversity of bats visiting a site. Bats will visit a wide range of pond types and sizes. There are, however, specific habitat features and aspects of pond location, design and management, which can improve value for bats by enhancing drinking and foraging opportunities.

3 http://www.torbay.gov.uk/vi/index/environment-planning/planning/planningservice/arboriculture/itree.htm

Key points for creating ponds for bats are[4 5]

- Ponds can provide foraging habitat for some bat species, even in dense urban centres.[6]
- Locate ponds within 40 m of landscape features that are likely to be used by bats as commuting routes or foraging areas, such as river corridors, woodlands, treelines or hedgerows with mature standard trees.
- Retain trees and shrubs around part of the margin of larger ponds and other water bodies, to provide shade and shelter for foraging and roosting opportunities.[7]
- Make ponds as large as possible (if possible 50 m^2 or more) to benefit the widest range of bat species.
- Ideally, create pond complexes with a range of pond types, including some with shallow water areas (to boost invertebrate prey) and others with deeper water areas (to maintain areas of open surface water).
- Shallow margins will provide suitable conditions for a range of wetland plants including marginal and emergent species.
- Create pond complexes that include ponds sheltered and shaded by mature trees, to benefit smaller woodland bat species and open ponds to benefit larger bat species.
- Consider installing bat boxes or bat houses near to ponds and pond complexes, in areas with limited natural roosting opportunities.



Key habitat features of ponds with benefit to bats[4]

Rivers and banks

Management and enhancement of river-bank habitats.[8]

- Retain natural features such as shallows and riffles to promote high insect diversity.
- Gently shelve banks and encourage gently sloping grassy margins.
- Promote aquatic plants and tall riverside plants.
- Retain bankside trees. Overhanging branches and leaves provide shelter and food for insects, cover for bats, and cast shade on open water further enhancing the range of conditions for insects. Gaps should be replanted.
- Pollarding extends the life of a tree, benefiting insect diversity and roosting opportunities for bats. Seek guidance on the correct timing to pollard.
- Avoid pollution and nutrient enrichment. A minimum 3 m grassland buffer strip will help to minimise and reduce risks. This can be further enhanced with a species rich flower mix.
- Daubenton's bat activity has been shown to be significantly related to aquatic macroinvertebrate diversity. Aquatic macroinvertebrate diversity is improved with good chemical water quality and the quality of the riparian vegetation.[9]
- Restrict or remove artificial lighting from river footpaths as many bat species associated with water, such as Daubenton's bat, avoid light.

4 Creating ponds for bats. Million Ponds Project. Pond Conservation.: http://www.pondconservation.org.uk/Resources/Pond%20Conservation/Documents/PDF/Bat%20dossier.pdf
5 http://www.sustainable-eastside.net/Eastside%20Planting%20guide_Final.pdf
6 Hale, J.D., Fairbrass, A.J., Matthews T.J., Sadler, J.P. 2012. Habitat Composition and Connectivity Predicts Bat Presence and Activity at Foraging Sites in a Large UK Conurbation. PLoS ONE 7(3): e33300. doi:10.1371/journal.pone.0033300
7 Scott SJ, McLaren G, Jones G, Harris S 2010. The impact of riparian habitat quality on the foraging and activity of pipistrelle bats (Pipistrellus spp.). Journal of Zoology 280: 371–378
8 Entwistle, A.C. et al. 2001. Habitat management for bats: A guide for land managers, land owners and their advisors. Joint Nature Conservation Committee.
9 Langton, D.A, Briggs, P.A. and Haysom, K.A. 2010. Daubenton's bat distribution along rivers–developing and testing a predictive model. Aquatic Conserv: Mar. Freshw. Ecosyst. 20: S45–S54 doi: 10.1002/aqc.1077

Rain gardens

A rain garden is a man-made depression in the ground that is filled with free-draining material and planted in order to slow surface water run-off and to improve water quality. Rain gardens are valuable components of sustainable urban drainage systems, helping to reduce run-off from buildings and other impermeable surfaces. Rain gardens should be placed strategically to intercept runoff from downpipes and paved surfaces.

Combined rain garden and tree pit designed to receive run-off from the street.

Photo credit: Dusty Gedge

Plants selected for rain gardens must be able to tolerate extremes. There will be periods when they are inundated with water for a few hours and also extended dry periods. Most perennial native plants will do well in rain gardens, including wildflowers, sedges, rushes, ferns, shrubs and small trees, and take up excess water flowing into the rain garden. Suitable plant species are listed in the Appendix.

Swales and infiltration pits

Swales and infiltration pits combined with features like rain gardens and ponds, help to create sustainable drainage systems. As well as performing an important function in reducing the quantity and improving the quality of surface water run-off, they also present an opportunity to create linear features that support flying insects. Swales are surface water channels that can be planted with native vegetation that can be lightly managed in order to support an abundance of moths and other flying insects. Infiltration pits are typically found in more urban situations. They are filled with free draining but absorbent soils that can store and filter urban runoff. This presents an opportunity to create habitat in what would otherwise be a barren environment. There is increasing interest in using infiltration pits and trenches as tree pits. In this way trees require little or no irrigation and often grow more quickly. Careful selection of tree species and locations can result in the creation of valuable linkages and feeding areas for bats.

Linear wetland feature at Surrey Docks, London.

Photo credit: Gary Grant

Insect hotels and habitat walls

Insect hotels, bug stacks and habitat walls can increase the numbers of beneficial insects and spiders in a location. They are usually untreated timber structures designed to provide shelter, egg-laying and hibernation sites for various insects and spiders. They occasionally include nesting materials for birds and some of these structures may also be used by bats as roosts. South-facing habitat walls with nesting holes can benefit mason bees and shadier places can shelter lacewings, beetles, moths and spiders.

Habitat wall at Lend Lease's headquarters, London. Solitary bees took up residence the first spring after installation.

Photo credit: Derek Brown

Brown long-eared bat roosting in an insect wall in Kent.

Photo credit: Steve Ashfield and Amanda Hedges (Kent Wildlife Trust)

Green roofs

A green roof, also known as a living roof, is vegetated to varying degrees. Green roofs come in a wide variety of designs, with many offering an opportunity to enhance biodiversity in an otherwise wasted space. They can provide both environmental and building performance benefits and are increasingly becoming a planning requirement for local authorities.

A green roof can be designed specifically to benefit wildlife (a biodiverse roof). What makes biodiverse roofs different is the inclusion of features to attract particular species of plants, birds and insects. They are usually seeded with drought-tolerant mixed plants or locally appropriate native wildflowers. Biodiverse roofs can include habitat features, including banks of bare sand, rough stone, and dead wood, which increase microclimate diversity and provide nesting and refuge areas for insects.[10] Some of the best roofs for insects may be sparsely vegetated for the majority of the year.[11]

It is thought that some green roofs may benefit bats in the urban landscape by improving foraging resources. Green roofs could also act as stepping-stone habitats, increasing the resilience of insect communities in urban areas.

Green roof design considerations

- Underlying structure: The roof structure must be strong enough to support the saturated load of the planted system. A typical extensive green roof weighs 150 kg/m². Always check with a qualified structural engineer that a roof is capable of supporting the additional load.

10 http://corporate.marksandspencer.com/documents/publications/2010/biodiversity-pages-20.pdf
11 Gedge, D et al. 2012. Creating green roofs for invertebrates: A best practice guide. Buglife.

- Planting: A range of predominantly native herbaceous perennials, hardy succulents, alpines and bulbs can be utilised to attract flies, moths and other invertebrate species that will provide a feeding resource for bats. Plants that are night flowering and provide nectar/ feeding resources for moths. Planting should be matched to bioregion and microclimate.
- Growing medium: It is recommended that specially formulated green roof substrates, which are a mixture of inorganic and organic materials, are used because these provide the necessary nutrients for plants as well as being free-draining and water-absorbent. Ideally substrate should be varied in depth to promote vegetation diversity and to provide a range of habitats for invertebrates.
- Habitats that need minimal maintenance can help to reduce long-term costs.
- Refer to the Green Roof Code[12] and livingroofs.org for advice

Extensive biodiverse green roofs in Basel, Switzerland, showing that adjacent features can act as stepping stone habitats.

Photo credit: Gary Grant

Newly planted biodiverse green roof in Camden, London.

Photo credit: Bernd Saliger, Arup

Walls

Living or green walls

Green walls are completely or partially covered by plants and foliage. Green walls can provide habitat in a narrow space. They also cool buildings in summer and filter pollutants from the air. Green walls can take the following forms:

Climbing plants

Green walls can be created by planting climbing plants in the ground and training these onto the building façade or onto trellis systems such as steel cables. Additional coverage and height can be gained through growing plants in irrigated containers supported at height. It is possible to create an instant green wall or green screen using established climbing plants rooted in containers and grown onto frames. Plants can also be hung from containers or troughs on the parapet or within the wall to create a hanging wall. Climbing plants are also a good way to enhance fence railings and balconies.

Climbers can provide nesting sites for birds and a haven for insects. Native climbing plants include: ivy, clematis (Traveller's Joy), honeysuckle and wild rose.

12 2011.The GRO Green Roof Code. Groundwork Sheffield. http://www.greenroofcode.co.uk/

Modules

Green walls can be created using planted modules or mats that are attached directly to the wall of a building. These proprietary systems may contain growing medium or be soil-less (hydroponic) and are normally irrigated. These systems do not rely on climbing plants and therefore a wide variety of plant species can be used. Consideration should be given to the aspect when planting living walls – walls in very sunny locations can be prone to rapid drying. Careful consideration should be given to the long-term costs of maintenance and to managing the risks of irrigation failure. If possible, modules should be designed to be irrigated by rainwater or grey water.

We recommend the use of native plants to improve the ecological value (insect productivity) of intensive green walls.

Dry stone walls

Dry stone walls and similar features are built without mortar. This traditional method of securing field boundaries in upland areas can be created in unexpected places or mimicked to create features that create valuable habitats and micro-climates that can benefit bats. Dry stone walls and cairns include many crevices which are colonised by lichens, mosses and other plants and can provide hiding places for wildlife including insects, amphibians and reptiles, as well as roosting sites for bats. Dry stone walls can also be combined with earth banks and unmown grass to generate insects for bats to feed on and sheltered areas for insects to accumulate.

Dry stone wall showing diversity of micro-habitats.

Photo credit: Gary Grant

Key messages for foraging:

- Bats are insectivores. Create and enhance features that will attract nocturnal flying insects.
- Plant mixtures of flowering plants, vegetables, trees and shrubs, to encourage a diversity of insects.
- Woodlands are valuable sources of insect prey. Don't over tidy; leave some areas of the wood unmanaged.
- Retain dense understorey (at least 50% cover).
- Retain standing and fallen dead wood.
- Native and veteran trees support more insects.
- Urban trees provide many benefits including filtering pollutants, storing carbon, reducing flooding and reducing temperatures.
- In open areas increase feeding opportunities by the presence of flower rich meadows, scrub and groups of trees.
- Establish un-mown areas.
- Create or maintain freshwater sources such as ponds, canals, ditches and rivers.
- Create pond complexes with a range of pond types and sizes.
- Retain bankside trees and encourage growth of aquatic plants.
- Rain gardens, swales and green roofs are important features for capturing surface water runoff in built up areas. They can also be planted to attract insects and act as stepping stone habitats.
- Living walls should be placed in shady orientations and consideration given to how they will be irrigated (preferably with rain water or grey water).
- Climbing plants and creepers are simple and inexpensive ways to enhance vertical surfaces.

Natterer's bat.
Photo credit: Hugh Clark

Roosting

The resting or sheltering places used by bats are known as roosts. Bats need a variety of places in which to roost, as they select and use different types of roosts at different times of the year, in order to suit their metabolic and social requirements. Bat roosts are either defined by their location, such as trees, buildings or underground roosts, or by their function, such as maternity, hibernation, swarming or feeding roosts, or by the time of year/day used, such as summer, winter, day or night roosts. All bat roosts are protected by law from damage or disturbance, even if bats are not present. It is possible to damage/destroy a roost by carrying out activities close to the roost (e.g. building maintenance) or away from the roost itself (e.g. preventing bats from reaching their roost by lighting or by interfering with flight lines).

Trees

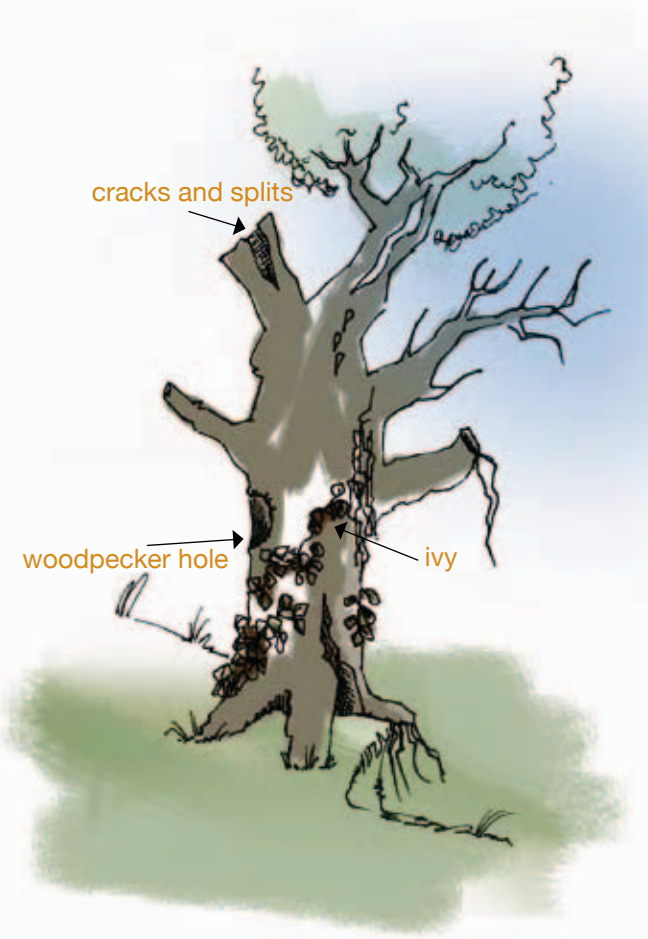
All British bats are dependent in some way on trees. One important aspect of bats reliance on trees is their use as roosting sites. A range of features can be used for roosts, in summer and winter. Many of the features that make trees suitable for roosting bats are found in more mature and particularly veteran trees. These trees may be found in a woodland setting or in hedgerows, large gardens, wood pasture, parkland and churchyards. However, it is important to note that bats will use any tree of any age if it has suitable cavities or crevices.

A range of features in trees are used by bats, such as:

- Woodpecker holes
- Hollows and cavities
- Bird, dormouse and bat boxes
- Cracks and splits in limbs
- Damaged limbs
- Entangled large limbs that form a cavity
- Loose bark
- Behind dense ivy
- Older trees—especially those more than 80 years old

Tree species such as oak, pine, willow and sweet chestnut are prone to developing splits in their branches and trunks. Ash, beech, poplar and sycamore tend to offer opportunities in the form of cavities.

The key roost types and species that use them are shown in table 3 opposite.



Tree features used by bats for roosting

Table 3. Tree hole types used by bats.[13]

● *represent high preference;* ❍ *indicate less preference of use.*

Species	Roost type			
	Woodpecker	Crevices	Bough damage	Behind loose bark
Greater horseshoe bat				
Lesser horseshoe bat				
Daubenton's bat	●	●	❍	
Bechstein's bat	●	❍		❍
Whiskered bat		❍		●
Brandt's bat		●		●
Alcathoe bat		●		●
Common pipistrelle		❍		❍
Soprano pipistrelle		❍		❍
Nathusius' pipistrelle	●	●	❍	●
Serotine		❍		
Noctule	●	●	❍	
Leisler's bat	●	●	❍	❍
Brown long-eared bat	●	●		
Grey long-eared bat				
Barbastelle		❍		●
Natterer's bat		●	❍	❍

Maintaining trees for roosting bats

- Clearly mark any trees that have high potential for, or exhibit signs of, bat roosts being present. Trees can be used as roosts all year round including as breeding sites in summer and for hibernation in winter.
- Maintain a buffer of trees and understorey around these marked trees where these occur in woodland.
- Retain as many trees as possible that have potential for roosting bats.
- Ensure that no artificial lighting will impact on trees used or with potential for roosting use by bats. Light falling on a roost will make it unlikely for a potential roost to be used and could disturb an existing roost.

Buffer trees

Roost trees or potential roost trees should have a buffer area, composed of other woodland trees and shrubs, at least 1.5 times the canopy diameter of the roost tree as these help to maintain the micro-climate of the host tree.[14] These trees should be left undisturbed to age and to develop old growth habitat naturally.

13 Adapted from: Boye, F. & Dietz, M. 2005. Development of good practice guidelines for woodland management for bats. English Nature Research Report 661. English Nature.

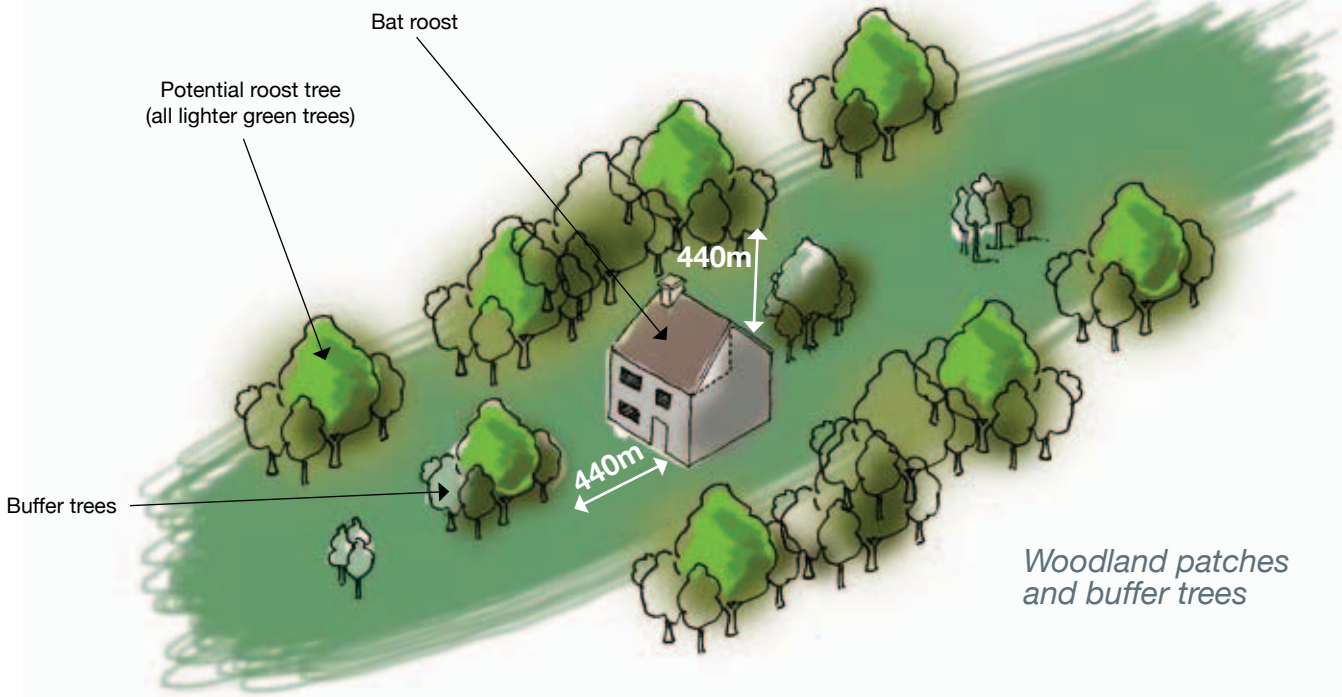
14 Woodland management for bats. 2005. Forestry Commission.

Future tree roosts in all settings

Even in cases where there are already bat roosts in trees, it is always important to consider future availability. Although most tree species can house bat roosts, oak is most suitable with beech often used too. Ash, elm and Scot's pine are also favoured. The tree species selected will also depend on the part of the country in question and local conditions. If planting a tree to increase future roosting potential, ensure that it is likely to be in a location with long-term security and away from artificial lighting. Also consider where the nearest foraging areas for bats would be and the route by which they would get to them (see foraging above and commuting below). In an urban setting it is still possible that trees will be used for roosting if they are in suitable locations.

Woodland patches and roost location

Bat species have been shown to benefit from the creation of an extensive network of woodland patches, including small patches, even in landscapes with little existing woodland cover.[15] For a number of bat species (common and soprano pipistrelle, lesser horseshoe bat, serotine, Natterer's bat and brown long-eared bat) a positive association has been shown between the extent and proximity of broadleaved woodland and roost locations. Overall, **90% of roosts are found less than 440 m from a woodland patch**, irrespective of the size of the nearest patch of woodland.



Woodland patches and buffer trees

Buildings

Buildings often make very suitable roosting sites as they are usually warm and safe. All the UK bat species have been known to use buildings but some have come to depend on buildings for their survival. Generally bats prefer older buildings (such as barns, farm buildings, churches and those with attics and lofts) that provide lots of cracks, gaps and openings. However, modern buildings can be used by bats, especially if they are close to good habitat.

- Check for bat signs before repairing or closing any cracks, gaps and openings in buildings. Stop works if presence of bats is suspected and immediately contact the National Bat Helpline or an accredited ecologist (for a development in progress).
- Bats do not damage or destroy buildings, makes nests, chew wires or spread disease.

New build

New buildings tend to be well sealed and thus have few roosting opportunities for bats. This makes deliberate provision of roosting spaces in buildings an important conservation action. If possible, spaces and access points should be designed into new buildings. Different bat species use buildings in different ways so consideration needs to be given for the particular needs of each species.

15 Boughey, K. et al, 2011. Effects of landscape-scale broadleaved woodland configuration and extent on roost location for six bat species across the UK

Bats that use buildings can generally be divided into four categories.[16]

- **Crevice dwellers** - prefer tight spaces (about 20mm) and are often hidden from view. Typical spaces include gaps behind barge boards, fascia, roof tiles, wall coatings, hollow mortice joints, rain gutters, chimneys, window frames and cavity walls.
- **Roof-void dwellers** - like to cluster together in tight spaces but may also use roof timbers.
- **Bats that need flight space** - need uncluttered space in the roost (at least 5m x 5m x 2.8m high) to fly around before emergence.
- **Bats that need flight space and fly-in access** - these are the horseshoe bats (only found in SW England and Wales); they cannot crawl into roosts and need large access gaps, as well as uncluttered flight space (at least 5m x 5m x 2.8m high) within the roost.

If possible, retain or preserve existing buildings on site that may provide roosting potential for bats. If bats are already using a building structure for a roost, the roost cannot be disturbed or damaged in any way unless under licence, even if bats are not present. If it is necessary to alter a building in a way which may impact the bats or the roost, the proper licensing procedures need to be followed with the help of a suitably qualified/experienced ecologist.

Purpose-built roosts

Bat boxes

Providing bat boxes can increase opportunities for roosting and they are often used as enhancement features. However, it may take a long time for bats to make use of them and in some cases they may never be used. Therefore bat boxes have limited relevance in mitigation schemes and should not be considered in this context as they are rarely able to replicate the roost conditions that will have been lost.

In urban areas we recommend the use of integrated bat boxes, which are built into the structure of the building, or the use of bat lofts, as these tend to be more permanent and less subject to disturbance than externally sited bat boxes.

Microclimate within a new roost is a very important factor in terms of increasing the chance of successful uptake by bats. Bat boxes should be draught-proof and made from a thermally stable material such as untreated wood, woodcrete, brick or stone. If possible, it is better to provide several internal chambers so that the bats can move around as their needs change. All boxes should have a small entry slit at the bottom (20 mm in width) with a roughened landing strip to allow the bats to crawl up into the box. The entry slit should be positioned so that accumulated bat waste can drop out the box or be pushed out as bats emerge.

Although it can take bats a long time to make use of artificial roosts, roost location seems to be the most important factor influencing successful uptake.

Bat box positioning considerations:

Orientation

One of the most important ways to optimise internal roost microclimate is to carefully locate the new roost. In general, bats seek warm spaces to help them with rearing young. **For this reason, bat boxes should be located where they will receive full/partial sunlight.** In the northern hemisphere this will be a southerly orientation (facing south, south-west or south-east). However, it is helpful to install bat boxes in more than one orientation to allow for a choice of roosting conditions.

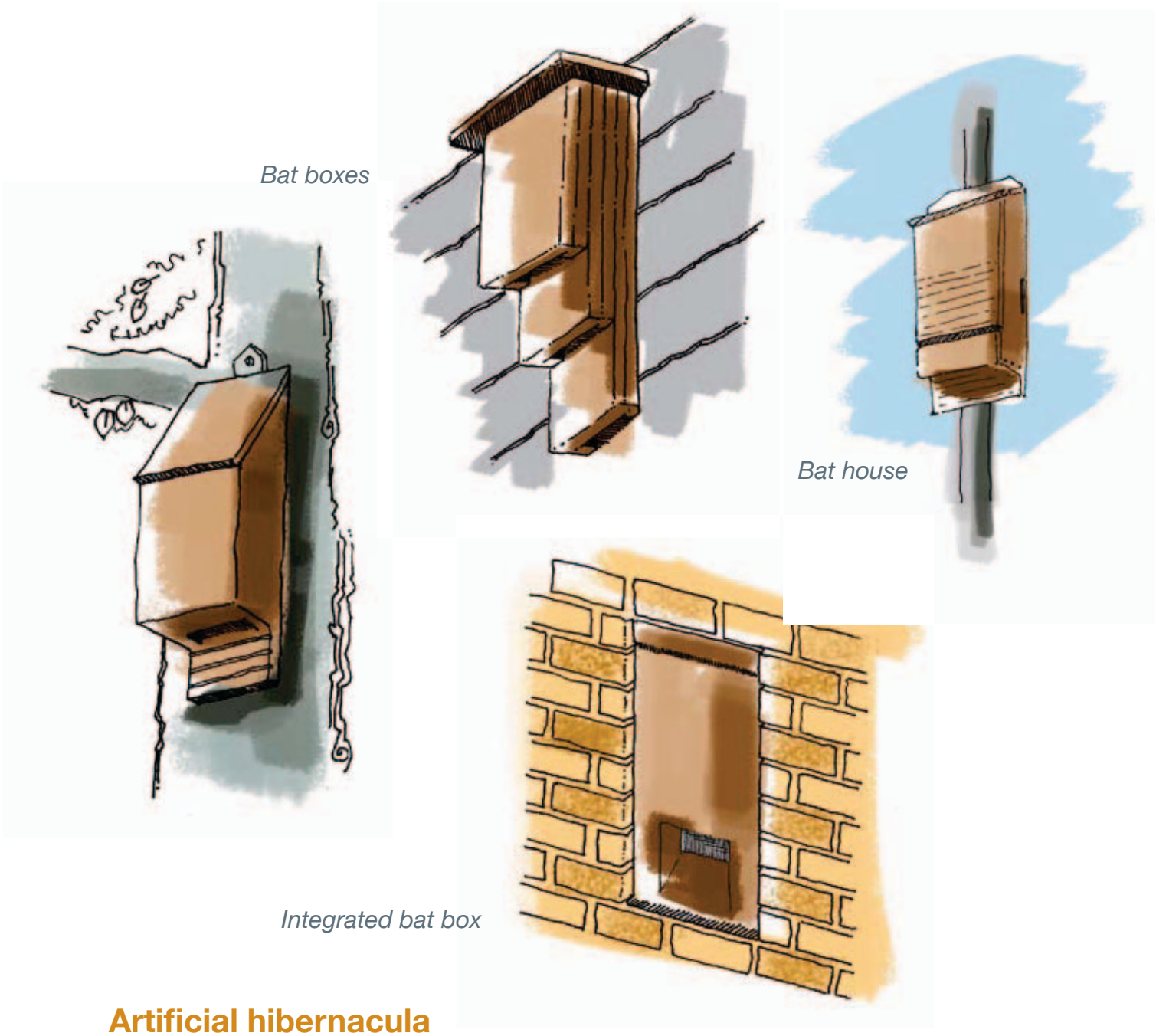
Height

Position the bat boxes a minimum of 2 m above ground, although 5-7 m is better to prevent disturbance from people and/or predators. Avoid placing boxes above windows, doors and climbing plants, or other features that might provide access for cats. Keeping boxes away from windows and doors also prevents bat droppings from accumulating and reduces the chances of learner fliers entering open windows or doors. Position near the eaves or gable apex of a building to minimise disturbance.

Surrounding habitat

To increase the chances of bats roosting in a bat box, it should be placed adjacent to vegetation features such as hedges and treelines. Some bat species use these features for navigation between their roosting site and feeding grounds and to avoid flying in open and exposed areas. Bats will be more likely to discover the artificial roost if it is placed close to an existing flight path.

16 Williams, C. 2010. Biodiversity for low and zero carbon buildings: a technical guide for new build. RIBA Publishing.



Bat boxes

Bat house

Integrated bat box

Artificial hibernacula

Bats hibernate to conserve energy during the winter months when their insect food is in short supply. Hibernation roosts (hibernacula) are characterised by thick walls that insulate the interior from fluctuating external temperatures and humidity. However, some bats will also hibernate in gaps on the outside of structures. Natural sites include caves and deep rock and tree fissures. Man-made sites include a wide range of structures that have fallen into disuse, such as worked-out mines and dene-holes, cellars, tunnels, ice houses and pillboxes. Dry stone walls and gabion-stacks may also be used by some bat species. If accessible to humans, structures such as these are often disturbed and this can preclude their use by bats. The installation of horizontal grilles at entrances (of the correct spacing) may be needed to control access.

There are examples of tailor-made artificial hibernacula. These usually take the form of an artificial cave, created in the simplest case by burying large-bore concrete pipes. Experience to date suggests that these take even longer than boxes to be discovered by bats and patience is required.

The most important features of an effective hibernation site are.[17]

- Location and access (to ensure bats will find it during summer or autumn).
- High humidity (close to 100%).
- Stable winter temperatures (within the range 2-6°C, depending upon the species).
- Suitable crevices for bats to hide in or surfaces to hang from.
- Protection from predators and people.

17 Waite, M. 2005. Bat roost creation opportunities in Greater London. London Biodiversity Partnership.

Key messages for roosting:

- All bat roosts are protected by law from damage or disturbance, even if bats are not present.
- Bats rely on crevices, cracks and holes in trees as roosts.
- Mature and veteran trees have many features that make them suitable for roosting bats and should be retained.
- Clearly mark any trees that have high potential for, or exhibit signs of, bat roosts being present.
- Maintain a buffer of trees and understorey around roost trees or potential roost trees at least 1.5 times the canopy diameter of the roost tree.
- Try creating or maintaining even small woodland patches, even in urban areas, as most bat roosts tend to be found less than 440m from a woodland patch.
- All types of buildings can be used by bats as roosts, particularly if close to good habitat.
- Even small gaps 15 to 20 mm in size can be accessed by bats.
- New buildings should make deliberate roosting provision for bats in the appropriate location and size for the specific bat species.
- Bat boxes can be used as an enhancement measure. Boxes should be placed in a warm location (preferably more than one aspect), at least 2m above the ground and away from possible disturbance.
- Artificial hibernacula should be constructed to provide cool stable microclimate with high humidity.

Brown long-eared bat.
Photo credit: Hugh Clark

Commuting and landscape connectivity

The activity of flying between the roost and foraging area is known as commuting. Bats are known to use set routes for commuting which are known as commuting corridors, flight paths or fly-ways. These routes tend to make use of features such as avenues of street trees, treelines along waterways, hedgerows, vegetated railway corridors, gardens and woodland edges as linkages in the landscape. These features are thought to act as navigation structures, provide cover from weather and predators, and also provide en-route foraging resources. The provision of commuting features is important for overall connectivity of the landscape, and will benefit many animals in addition to bats.

Linear features in the built environment

It is important that linear or linking features (in the form of trees, hedges, tall shrubs, woods, parks, railway lines, green roofs and waterways) are provided in the urban landscape to provide safe, dark corridors at night for bats to fly through otherwise well-lit areas. If the vegetation is native it will also attract more insects, allowing the bats to feed too. **In urban areas special attention should be given to providing unlit areas,** especially in and around parks and treelined lanes and roads, and bridges that cross streams and rivers.

Street trees

Street trees are single specimens typically planted along streets, roads and avenues in cities, towns and villages. **Street trees are particularly important in the role of providing corridors for wildlife**, allowing species to move between the larger areas of green space within the city, as well as being available as a food source or home. Street trees are also vital in their role of regulating urban temperatures, being a barrier for noise pollution and capturing pollutants out of the air; all of which benefit the local wildlife as well as the human population. Street trees that are of particular benefit to wildlife include native species such as silver birches, large canopy trees or fruiting species such as the various cherry varieties.

This linear tree feature in Victoria, London provides shade and seating for people, visual relief in a built up area and habitat for wildlife. It is also adjacent to a biodiverse green roof thus providing good linkages for bats which are known to use the area.

Photo credit: Huma Pearce

Riparian corridors

Water networks in the form of rivers, streams, canals and irrigation ditches are often used by bats as navigation features in the environment. Care should be taken not to artificially light these features. Where lighting is necessary for operational reasons the lighting should only be used when needed.

Hedges and trees

Although hedges are usually associated with rural settings they can be important linking and transition features in built up areas. Many of our bat species are reluctant to leave the cover of features such as treelines, hedges and woodland as they move between their roost and foraging grounds. Fragmentation of the landscape can therefore be a serious issue for bats. However, if smaller habitat patches are connected by treelines and hedges it is possible for these separate patches of habitat to operate as if they are a continuous habitat.

- Ensure connectivity is maintained between foraging areas and roosts using hedges, water bodies and other linear features. This will form part of the broader green infrastructure network.
- Connecting features are especially important when they are between separate blocks of habitats in urban environments. This allows small fragmented blocks of habitat to operate as one bigger block.
- **Avoid opening up gaps greater than 10 m** along linear features.[18] Some bat species will avoid even small gaps.
- **Encourage flowers and grasses at the base and margins.** Hedges and trees with plenty of vegetation at the base support lots of wildlife. Flowers like primroses and knapweed provide nectar and pollen for bees and other beneficial invertebrates, while tussocky grasses provide safe places for beetles, spiders and the like during the winter[19]. Frogs, toads, newts and lizards like dense growth at the base of hedgerows for food, cover and places to hibernate.

Hedgerow structure and management

- Management of hedgerows for bats should aim to **produce tall (ideally at least 2.5m high)**,[20] **wide and continuous hedges**, comprising **native species**.
- **Include a range of different hedge species** to provide food throughout the year – willows and blackthorn for early season nectar; hawthorn, bramble and rose for summer flowers and autumn berries; ivy for autumn nectar and late winter berries.[26]
- **Keep it thick and dense.** Close interwoven branches in your hedge provide safe nesting and roosting places for small birds like thrushes, finches, robins, hedge sparrows and wrens. Open hedges expose nests to predatorymagpies, crows, pigeons and squirrels. Holly is a very good hedging plant, forming compact dense bushes that give excellent protection during the winter.
- **Cut at the right time. Never cut during the bird breeding season (1 March to 31 August)** unless you have to, for safety reasons. **Leave trimming your hedge until late winter after most of the berries are gone.** Hedgerow berries and other fruit provide vital food for birds like fieldfares, redwings and other thrushes throughout the winter. However, attention must be given to the fact that many insects have stages that over-winter in hedgerows, both on the twigs and on the herbage.
- **Don't cut too often or too tight.** Hedges should not be cut annually unless there is an access issue, such as with those alongside roads and footpaths. Cutting every three or more years will allow hedge plants to produce flowers and berries and achieve a better structure. Annual flailing has had a severe impact on many species of butterfly and moth.[21]
- **Adopt rotational management.** Only a proportion of the total hedgerow in any given area should be cut in a single year, to ensure that over-wintering invertebrate species are not completely eliminated. This could involve cutting only one side of a hedge to allow invertebrates to recolonise, or managing different sections of a hedge in different years.
- Place standard trees within hedgerows (i.e. hedgerow trees).

18 Entwistle, A.C. et al. 2001.Habitat management for bats: A guide for land managers, land owners and their advisors. Joint Nature Conservation Committee.

19 http://www.hedgelink.org.uk/hedgerow-management.htm

20 Wickramasinghe, L.P. et al.2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. Journal of Applied Ecology. 40: 984-993

21 Hedgelink: http://www.hedgelink.org.uk/wildlife-and-hedgerows.htm

Hedgerow trees

The presence of trees in a hedgerow has been found to attract soprano pipistrelle bats, and is likely to benefit other bat species.[22] Hedgerow trees may benefit bats by providing increased shelter from predators and the elements. They also increase prey availability, as insect accumulation in the lee of hedgerows increases with increasing feature height. Hedgerow trees have been shown to increase the abundance and diversity of moths which are found in the diet of many bats and are the main prey item for some species including the greater horseshoe bat and brown long-eared bat. Hedgerow trees can also provide additional microhabitats, such as decaying and dead wood, that increase invertebrate abundance and diversity.

Examples of native hedgerow trees are: elm, oak, ash, beech, field maple, hornbeam and holly. Fruit and nut trees such as crab apple, wild cherry, hazel, elder, damson and pear can also be encouraged.

Urban biodiversity enhancements

Built up areas can be improved for biodiversity by adding a combination of the following features:

1. Biodiverse green roof
2. Integrated bat boxes (majority located on sunny orientations)
3. Habitat walls (sunny orientation)
4. Green / Living walls (shady orientation easier to establish)
5. Sustainable Urban Drainage features (combine hard and soft landscape to create rain gardens, rills and swales, filter strips, detention and retention ponds)
6. Climbing plants and creepers
7. Large native trees
8. Planters

The orientation of the features and proximity to artificial lighting should be carefully considered.

22 Boughey, K et al. 2011. Improving the biodiversity benefits of hedgerows: How physical characteristics and the proximity of foraging habitat affect the use of linear features by bats. Biological Conservation. 144 (6): 1790-1798

Key messages for commuting:

- Commuting between the roost and foraging areas is an essential requirement for bats. All known bat commuting routes should be retained and enhanced.
- Commuting routes tend to make use of features such as avenues of street trees, treelines along waterways, hedgerows, railway lines, gardens and woodland edges.
- Hedges and treelines help connect fragmented habitats and can function to turn small habitat patches into larger continuous habitat areas.
- Avoid creating gaps in linear features such as hedges and treelines, as some bats avoid even small gaps.
- Aim to produce tall, wide and continuous hedgerows with vegetation planted around the base.
- Install or maintain standard trees (hedgerow trees) within hedgerows.
- Provide un-lit linear or linking features in the landscape, particularly urban areas, in the form of trees, hedges, tall shrubs, woods, parks, railway lines, waterways and green roofs.
- Street trees and riparian corridors provide important corridors for wildlife in urban areas. Care should be taken to ensure that they are not artificially lit.

Daubenton's bat.
Photo credit: Kevin Durose

Landscape connectivity: corridors and linkages

It is important to try to maintain existing flight paths and where possible, to improve the overall permeability of the landscape to bats by providing connectivity. Structural landscape connectivity is essential for the movement of some species,[23] but may be undermined if artificial lighting is present.[24] Green corridors that link habitats should include the use of linking features such as tree networks, stepping stones such as green spaces, and effective road crossings such as underpasses and overpasses.

Urban green spaces: pocket parks, gardens and squares

It is important to recognise that even small green spaces can be an important refuge for native wildlife in urban areas. Urban patios, gardens, balconies, vegetated pavements and even traffic roundabouts can comprise a major part of the total green space in a city. These features form habitat patches within cities that are often small, fragmented and isolated. Efforts should be made to improve the size, connectivity and heterogeneity of these urban habitat patches.

Pocket parks

Pocket parks are small parks accessible to the general public, frequently created on small, irregular pieces of land, and generally in built up areas. They vary in size and are found in all types of locations from town centres to quiet villages. Pocket Parks serve many purposes; they make a valuable contribution to the protection and conservation of landscape, heritage and wildlife, as well as giving local people the opportunity to enjoy the place in which they live or work. In addition, Pocket Parks can assist in the regeneration of areas as well as help to maintain existing features.

Gardens

Private domestic gardens are known to constitute a considerable proportion of "green space" in urban areas and are of potential significance for maintaining biodiversity and ecosystem service provision in such areas. Gardens create considerable habitat and improve connectivity by functioning as corridors or by enlarging the size of other urban habitats. Studies have shown that in addition to the high cultivated floral diversity, the three dimensional structure of garden vegetation is an important predictor of vertebrate and invertebrate abundance and diversity.[25 26]

- **Gardens should not be treated as individual units but rather as patches of interconnected habitat.** If possible they should be managed collectively as '**habitat gardens**'.[27]
- The presence of adjacent gardens can increase the species richness of urban parks.
- Private gardens and other green spaces should be spatially arranged to maximise total habitat patch size and minimise isolation.
- **Vegetation complexity needs to be maximised** throughout the residential ecosystem – especially where social resources are lacking for 'wildlife-friendly' garden management.
- Wildlife-friendly gardening practices need to be tailored to the wider landscape context.
- Green space strategies and planning documents that promote the creation and maintenance of green infrastructure, such as habitat corridors or stepping stones, should be structured according to the creation of 'habitat zones', which increase the extent of a specific **habitat type**, such as woodland or wetland.

23 Hale JD, Fairbrass AJ, Matthews TJ, Sadler JP (2012) Habitat Composition and Connectivity Predicts Bat Presence and Activity at Foraging Sites in a Large UK Conurbation. PLoS ONE 7(3): e33300. doi:10.1371/journal.pone.0033300
24 Stone, E.L., Jones, G., & Harris, S. 2009. Street lighting disturbs commuting bats. Current Biology 19:1-5
25 Smith, R.M. et al. 2006. Urban domestic gardens (VIII):environmental correlates of invertebrate abundance. Biodiv.Conserv. 15, 2515–2545
26 Smith, R.M. et al. 2006. Urban domestic gardens (VI): environmental correlates of invertebrate species richness. Biodiv. Conserv. 15, 2415–2438
27 Goddard, M.A., Dougill, A.J. and Benton, T.G. 2010. Scaling up from gardens: biodiversity conservation in urban environments. TREE (25) 2:90-98

Squares, paved areas and balconies

Urban squares offer a great opportunity to create “green oases” in the city. They are usually open spaces, with hard surfaces, surrounded by shops and cafes and provide informal public gathering areas.

- If possible reduce the amount of impermeable surfaces by using permeable paving, sections of lawn, and flower beds. This re-establishes natural processes such as nutrient and water cycling.
- Make use of planters and raised beds where paving cannot be removed and where they can be irrigated naturally.
- Use signature trees to provide focal points and potential roost sites for bats.
- Link to other green features by using courtyard trees, low level shrubs and hedges.
- Soften walls and railings by using climbing plants and creepers.
- Create water features.
- Install bird and bat boxes onto the surrounding building surfaces in the appropriate position.

Large native trees in urban squares, such as these in Crawley, create focal points as well as habitat and connectivity.

Photo credit: Gary Grant

The use of climbing plants can transform vertical spaces in urban environments.

Photo credit: Gary Grant

Eco-passages

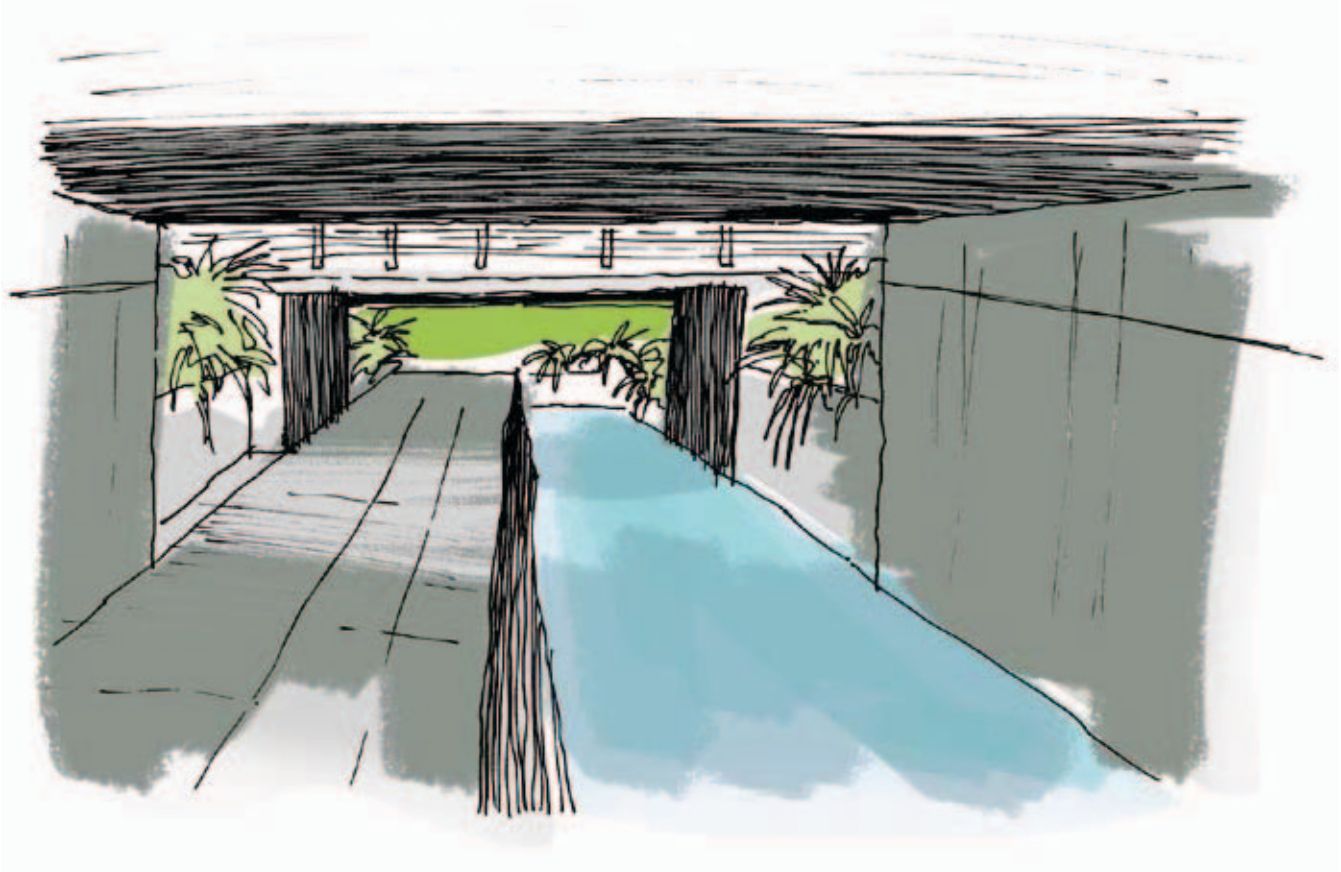
New developments, and in particular the construction of roads, have the potential to sever landscape elements used as commuting routes by bats. In addition to creating an open area, which most bat species are reluctant to cross, road traffic further increases the barrier effect due to sudden movement, noise, headlamps, street lighting and the risk of collision. Recent research shows that roads have a major negative impact on bat foraging activity and diversity.[28]
Eco-passages in the form of different types of under- and over-passes are important for providing crossing points for all types of wildlife and mitigating for habitat fragmentation.

Underpasses: culverts and tunnels

Bats regularly use underpasses such as tunnels and culverts. Underpasses are readily accepted and used frequently by the slow and low-flying bat species but are less likely to be used by fast hawking bats adapted to flying in open areas. In general, the higher and broader an underpass the more likely bats are to use it.[29] [30] In particular, height has been shown to be the most important cross sectional factor that determines bat use of underpasses, while length appears to be less significant. Ideally an underpass with a width/height ratio of one would be preferable to a wide and low underpass. Underpasses designed for lesser horseshoe bats should be at least 2.5m in diameter. Natterer's bat is known to use smaller conduits.

Underpass entrances can also be planted in order to create a 'funnel' effect where bats are encouraged to fly into the tunnel rather than up and over the road. However, it is important that it remains unlit and has vegetation at either end.

Culverts can provide valuable underpasses for bats as they are generally not illuminated and do not have vehicular traffic. Many bat species associated with water are likely to follow the streams and canals that lead through them.[31]

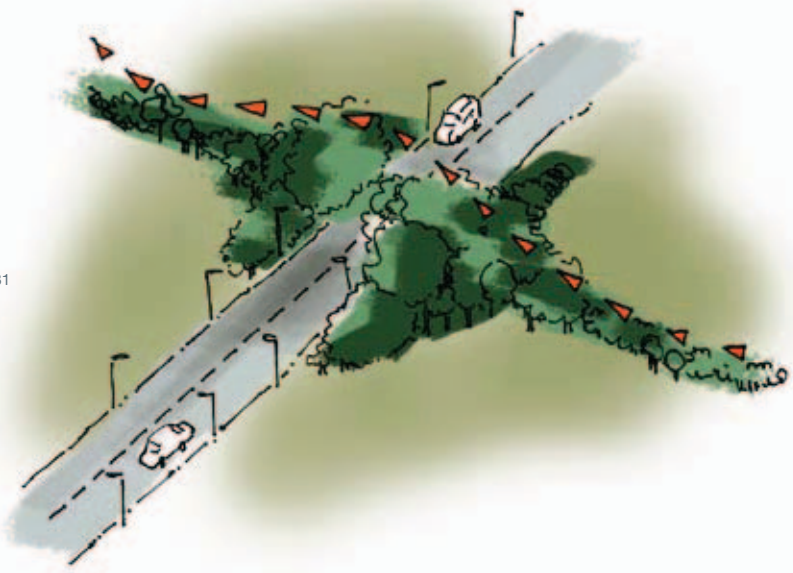


Underpasses

28 Berthinussen, A. and Altringham, J. 2011. The effect of a major road on bat activity and diversity. Journal of Applied Ecology 49 (1): 82-89
29 Bach, L. et al. 2004. Tunnels as a possibility to connect bat habitats. Mammalia 68 (4): 411-420
30 Boonman, M. 2011. Factors determining the use of culverts underneath highways and railway tracks by bats in lowland areas. Lutra 54 (1):3-16
31 Limpens H.J.G.A., Twisk P. and Veenbaas G., 2005. Bats and road construction. DWW-2005-033, ISBN 90-369-5588-2

Overpasses: hop-overs and bridges

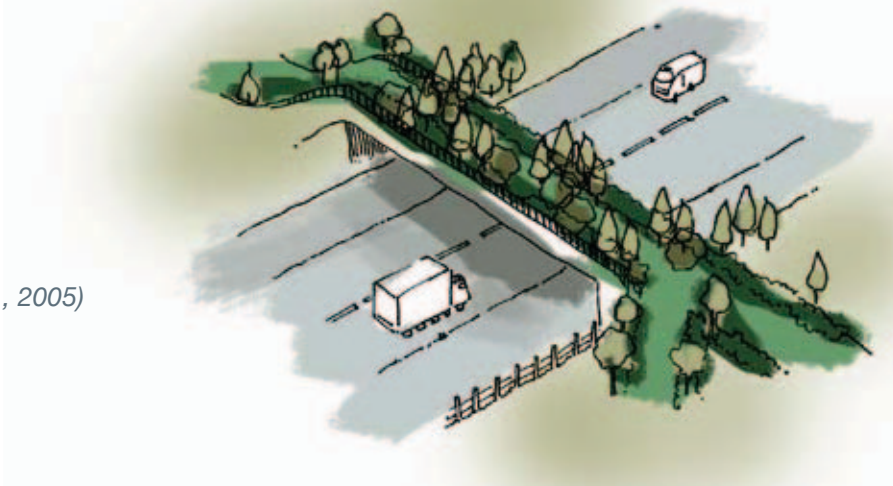
Measures to create passing-over opportunities for bats include hop-overs (using crowns of trees) as well as green bridges and viaducts.



Hop-overs
(adapted from Limpens et al., 2005)[31]

Partially or completely vegetated bridges, called *green bridges* or *habitat bridges*, can be built to assist animals with dispersal across roads. These can range from pedestrian bridges with one side adapted to provide a grass verge, to substantial bridges with mature trees and grassland. The provision of green bridges may allow bat movement from a nearby roost to feeding areas and alternative roosts.

The most critical element to encourage use of a green bridge by bats is the absence of lighting both from the bridge itself and from the traffic below. Bridge walls must be solid to prevent light penetration. Green bridges with linear trees and shrub features tend to be used more frequently than those with scattered tree and shrub features.[32]



Green bridge
(adapted from Limpens et al., 2005)

Wire or mesh structures, known as bat gantries or bat bridges, have been proposed as artificial road crossing structures for bats. However, evidence from research is not supporting bat gantries as effective mitigation for the impact of roads.[33] The Bat Conservation Trust advises caution in the use and siting of bat gantries. Further robust and comparable pre- and post-construction monitoring of the use of bat gantries needs to be carried out to objectively assess their effectiveness as mitigation. Prior to specifying such structures, all other options should be examined and advice sought from the Highways Agency. We encourage more investigation of natural crossing points such as hop-overs, elevated verges and green bridges that could deliver a benefit for the bat species involved, and also for other wildlife impacted by such developments.

See Table 4 for a summary of suitable features to facilitate the movement of bats.

32 Georgii, B. et al 2011. Use of wildlife passages by invertebrate and vertebrate species. MJPO.

33 Berthinussen, A. and Altringham, J. 2012. Do bat gantries and underpasses help bats cross roads safely? PLoS ONE 7(6): e38775. Doi:10.1371/journal.pone.0038775

Outdoor lighting

Bats are nocturnal animals, adapted to low-light conditions. This means that most bat species find artificial lighting to be very disturbing. We know that some bat species will not cross lines of street lights.[34] Such light acts as a barrier, disrupting flight paths and restricting access to otherwise suitable habitat. In addition, lighting close to roost access points disturbs bats within a roost, delays emergence times and may result in the abandonment and loss of roosts.

With smarter lighting, rather than less lighting, it is possible to reduce the effects of light pollution. Lighting should only be erected where it is needed, illuminated during the time period it will be used, and only to levels that enhance visibility. Artificial light shining on bat roosts, their access points and the flight paths leading to and from the roost must always be avoided.

Where lighting is unavoidable, consideration should focus on the design. Design strategies that reduce the potential impact of lighting on bats include the following:

- Do not provide excessive lighting. Use only the minimum amount of light needed for safety.
- Minimise light spill. Eliminate any bare bulbs and any upward pointing light. **The spread of light should be kept near to or below the horizontal.** Flat cut-off lanterns are best.
- Use narrow spectrum bulbs to lower the range of species affected by lighting. Use light sources that emit minimal ultra-violet light and avoid the white and blue wavelengths of the light spectrum **to avoid attracting lots of insects**. Lighting regimes that attract lots of insects result in a reduction of insects in other areas like parks and gardens that bats may be using for foraging.
- **Lights should peak higher than 550 nm**[35] or use glass lantern covers to filter UV light. White LED lights do not emit UV but have still been shown to disturb slow-flying bat species.[36]
- Reduce the height of lighting columns. Light at a low level reduces impact. However, higher mounting heights allow lower main beam angles, which can assist in reducing glare.
- For pedestrian lighting, use low level lighting that is as directional as possible and below 3 lux at ground level but preferably below 1 lux.
- Increase the spacing of lanterns.
- Use embedded road lights to illuminate the roadway and light only high-risk stretches of roads, such as crossings and junctions, allowing headlights to provide any necessary illumination at other times.
- Limit the times that lights are on to provide some dark periods.
- Use lighting design software and professional lighting designers to predict where light spill will occur.
- Avoid using reflective surfaces under lights.
- Use temporary close-boarded fencing until vegetation matures to shield sensitive areas from lighting.

34 Stone, E.L., Jones, G., & Harris, S. 2009. Street lighting disturbs commuting bats. Current Biology 19:1-5

35 Van Langevelde, F eta l. 2011. Effect of spectral composition of artificial light on the attraction of moths. Biol. Conserv. doi:10.1016/j.biocon.2011.06.004

36 Stone, E.L., Jones, G., & Harris, S. 2012. Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. Global Change Biology doi: 10.1111/j.1365-2486.2012.02705.x

Table 4. Summary of suitable features to facilitate the movement of bats (adapted from Limpens et al., 2005)

Lesser horseshoe bats in roof space.

Photo credit: John Black

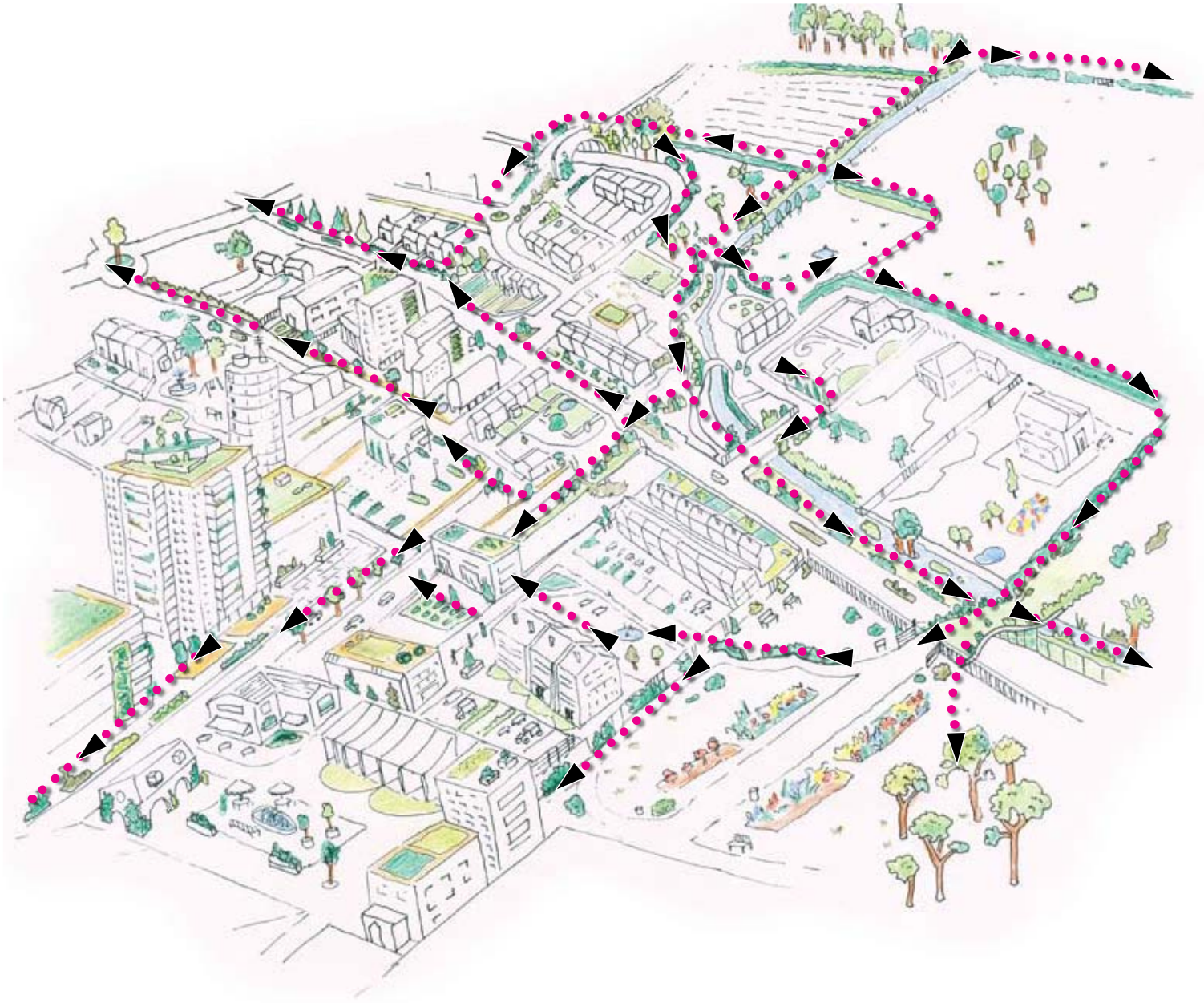
Brown long-eared bat on tree.

Photo credit: Eric Hardy

Bat species	Passing over					Passing under						
	High over landscape	Hop-over at crown height	Hop-over vegetation	Hop-over vegetation + wall	Over or along viaduct/bridge	Culverts (h x w = 1 x 2m	Bridge over water (h <1m)	Tunnels (h x w = 4 x 4 m)	Bridge over water (h >2m)	Tunnels (h x w = 6 x 6 m)	Under viaduct (h > 6m)	Bridge over water (h > 6m)
Lesser horseshoe bat				•	•	•	•	•	•	•	•	•
Natterer's bat				•	•	•	•	•	•	•	•	•
Bechstein's bat				•	•		•	•	•	•	•	•
Brown long-eared bat				•	•		•	•	•	•	•	•
Grey long-eared bat				•	•		•	•	•	•	•	•
Greater horseshoe bat				•	•			•	•	•	•	•
Whiskered bat			•	•	•			•	•	•	•	•
Brandt's bat			•	•	•			•	•	•	•	•
Barbastelle bat			•	•	•			•	•	•	•	•
Daubenton's bat			•	•		•	•	•	•	•	•	•
Soprano pipistrelle		•	•	•	•			•	•	•	•	•
Common pipistrelle		•	•	•	•			•	•	•	•	•
Nathusius' pipistrelle		•	•	•	•			•	•	•	•	•
Serotine bat	•	•	•	•	•					•	•	•
Noctule bat	•	•	•	•	•					•	•	•
Leisler's bat	•	•	•	•	•					•	•	•

Ecological networks

The arrows in the diagram below show how a bat could use green infrastructure features in the urban landscape to move from one part of the landscape to another.



Summary of key messages for landscape connectivity

- Improve the overall permeability of the landscape to bats by providing green corridors that link habitats such as tree networks, stepping stones such as green spaces, and effective crossings such as underpasses and overpasses.
- Efforts should be made to improve the size, connectivity and heterogeneity of urban habitat patches.
- Gardens create considerable habitat and improve connectivity by functioning as corridors or by enlarging the size of other urban habitats.
    - Improve the three dimensional structure of garden vegetation to increase vertebrate and invertebrate abundance and diversity.
    - Private gardens and other green spaces should be spatially arranged to maximise total habitat patch size and minimise isolation.
    - Better integrate the design and management of private gardens into city-wide biodiversity strategies.
- Squares, paved areas and balconies - If possible reduce the amount of impermeable surfaces by using permeable paving, sections of lawn, and flower beds.
    - Make use of planters and raised beds where paving cannot be removed
    - Link to other green features by using courtyard trees, low level shrubs and hedges
    - Soften walls and railings by using climbing plants and creepers
- Eco-passages in the form of different types of under- and over-passes are important for providing safe crossing points for all types of wildlife
- The higher and broader an underpass the more likely bats are to use it. Underpass entrances should be planted along the edges and remain unlit.
- The provision of green bridges may allow bat movement from a nearby roost to feeding areas and alternative roosts. The most critical element to encourage use of a green bridge by bats is the absence of lighting both from the bridge itself and from the traffic below.
- Most bat species and other wildlife find artificial lighting to be very disturbing.
- Avoid artificial lights shining on bat roosts, their access points and their flight paths.
- Prevent light spill, decrease light intensity, avoid the UV spectrum and light only where and when it is needed.

Resilient landscape design for bats

By following the guidance outlined here, urban planners and designers should be able to develop landscapes that could support healthy bat communities. However, this assumes that the key features of the landscape (roosts, feeding areas and commuting routes) persist indefinitely into the future. It is clear that funding for maintenance, land ownership, land use and landscape structure are not fixed – they can change over time. As a result, we recommend that future proofing is considered as part of any intervention.[37] Maintenance requirements should be minimised, with its funding ring-fenced. Putting in place a variety of roosting opportunities, tree networks and feeding areas can provide some useful excess, should some be lost. In addition, features should be located in areas less likely to be subject to future disturbance.

37 http://www.icevirtuallibrary.com/content/article/10.1680/ensu.2012.165.1.59

Appendix: Plant species list for encouraging bats

The following table is a suggested species list of plants that can provide benefit for bats either by providing a food source for insects [38] [39] or roost potential. The plants listed are predominately native to Britain. The small group of non-native plants is included for their documented value for wildlife. This list has been checked against Natural England's list of invasive non-native plants.[40] Also see the Non-Native Species Secretariat (NNSS) website.[41]

Plant species	Common name	Native (N)	Type	Benefit	Soil	Light	Extensive Green Roofs	Living walls	Rain gardens	Hedges /Trees	Beds /Borders
Acer campestre	Field maple	N	T/S	C	Any	Sun/shade				Y	
Acer platanoides	Norway maple		T	S	Well drained / alkaline	Sun/shade				Y	
Acer saccharum	Sugar maple		T	S	Any	Sun/shade				Y	
Achillea millefolium	Yarrow	N	HP	C,F	Well drained	Sun	Y				
Ajuga reptans	Bugle	N	HP	C,F	Any	Sun/shade	Y		Y		
Anthyllis vulneraria	Kidney vetch	N	HP	F	Well drained	Sun	Y				
Aubrieta deltoidea	Aubrieta		H	F	Well drained	Sun/shade		Y			
Betula pendula	Silver birch	N	T	C	Sandy/Acid	Sun				Y	
Cardamine pratensis	Cuckoo-flower	N	HP	F	Moist	Sun/shade			Y		Y
Carpinus betulus	Hornbeam	N	T	C	Clay	Sun				Y	
Centaurea nigra	Common knapweed	N	HP	C,F	Dry, not acid	Sun	Y				Y
Centranthus ruber	Red valerian		HP	F	Well drained / alkaline	Sun	Y				Y
Clematis vitalba	Old man's beard	N	C	F	Well drained / alkaline	Sun				Y	
Corylus avellana	Hazel	N	S	C	Any dry	Sun/shade		Y		Y	
Crataegus monogyna	Hawthorn	N	S	S,C	Any	Sun/shade				Y	
Daucus carota	Wild carrot	N	Bi	S,C,F	Any	Sun	Y				Y
Dianthus spp.	Pinks	N	A-Bi	F	Well drained	Sun	Y	Y			Y
Digitalis purpurea	Foxglove	N	Bi	C	Well drained	Shade / partial shade				Y	Y
Erica cinerea	Bell heather	N	S	F	Sandy	Full sun					Y
Erysimum cheiri	Wallflower		Bi-P	F	Well drained	Sun		Y			
Eupatorium cannabinum	Hemp agrimony	N	H	F	Moist	Sun/shade			Y		Y
Fagus sylvatica	Beech	N	T	C,R	Well drained alkaline	Sun/shade				Y	
Foeniculum vulgare	Fennel		H	F	Well drained	Sun					Y
Fraxinus excelsior	Common ash	N	T	C,R	Any	Sun/shade				Y	
Hebe spp.	Hebe species		S	F	Well drained	Sun/shade				Y	Y
Hedera helix	Ivy	N	C	F,C	Any	Sun/shade		Y	Y	Y	Y
Hesperis matrionalis	Sweet rocket		H	F	Well drained / dry	Sun/shade					Y
Hyacinthoides non-scripta	Bluebell	N	B	F	Loam	Shade/ partial shade		Y		Y	Y
Ilex aquifolium	Holly	N	T	C	Any	Sun/shade				Y	
Jasminum officinale	Common jasmine		C	F	Well drained	Sun		Y			Y
Lavandula spp.	Lavender species		S	F	Well drained / sandy	Sun		Y			Y
Linaria vulgaris	Toadflax	N	HP	C	Well drained /alkaline	Sun	Y				Y
Lonicera periclymenum	Honeysuckle	N	C	F	Well drained	Sun		Y		Y	
Lotus corniculatus	Bird's foot trefoil	N	HP	F	Well drained /dry	Sun	Y				Y

38 Nectar plants for moths (Butterfly Conservation website) ttp://www.mothscount.org/text/64/nectar_plants.html
39 Moth caterpillar food plants (Butterfly Conservation website) http://www.mothscount.org/text/65/caterpillar_foodplants.html
40 Natural England: http://www.naturalengland.org.uk/ourwork/conservation/biodiversity/threats/Horizon-scanning-plants.aspx
41 NNSS: https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm

Plant species	Common name	Native (N)	Type	Benefit	Soil	Light	Extensive Green Roofs	Living walls	Rain gardens	Hedges /Trees	Beds /Borders
Lunaria annua	Honesty		Bi	F	Any	Sun/ partial shade	Y				Y
Malus spp.	Apple		T	C	Any	Sun				Y	Y
Matthiola longipetala	Night-scented stock		A	F	Well drained /moist	Sun			Y		Y
Myosotis spp	Forget-me-not species	N	A	F	Any	Sun	Y	Y			Y
Nicotiania alata	Ornamental tobacco		A	F	Well drained /moist	Sun/ partial shade			Y		Y
Oenothera spp.	Evening primrose species		Bi	F	Well drained /dry	Sun	Y				Y
Origanum vulgare	Marjoram	N	HP	F	Well drained /dry	Sun	Y	Y			Y
Populus alba	White poplar	N	T	C	Clay loam	Sun				Y	
Primula veris	Cowslip	N	HP	F	Well drained /moist	Sun/ partial shade	Y				Y
Primula vulgaris	Primrose	N	HP	F	Moist	Partial shade	Y	Y		Y	Y
Prunus avium	Wild cherry	N	T	C	Any	Sun				Y	Y
Prunus domestica	Plum		T	C	Well drained /moist	Sun				Y	Y
Prunus spinosa	Blackthorn	N	S	C	Any	Sun/ partial shade				Y	
Quercis petraea	Sessile oak	N	T	C,R	Sandy loam	Sun/shade				Y	
Quercus robur	Common oak	N	T	C,R	Clay loam	Sun/shade				Y	
Rosa canina	Dog rose	N	S	C	Any	Sun			Y	Y	Y
Salix spp.	Willow species	N	S	S,C	Moist	Sun/shade			Y	Y	
Sambucus nigra	Elder	N	T	C	Clay loam	Sun				Y	
Saponaria officinalis	Soapwort	N	HP	F	Any	Sun					Y
Saxifraga oppositifolia	Saxifrage	N	HP	C	Well drained	Sun	Y	Y			Y
Scabiosa columbaria	Small scabious	N	HP	F	Well drained /alkaline	Sun	Y				Y
Sedum spectabile	Ice plant		HP	F	Well drained /dry	Sun	Y				Y
Silene dioecia	Red campion	N	HP	F	Any	Shade/ partial shade		Y	Y	Y	Y
Sorbus aucuparia	Rowan	N	T	C	Well drained	Sun				Y	
Stachys lanata	Lamb's ears		HP	F	Well drained /dry	Sun	Y				Y
Symphotrichum spp.	Michaelmas daisies		HP	F	Any	Sun					Y
Tagetes patula	French marigold		A	F	Well drained /moist	Sun					Y
Thymus serpyllum	Creeping thyme	N	HP/S	F	Well drained /dry	Sun	Y	Y			Y
Tilia x europaea	Common lime		T	C	Any	Sun/shade				Y	
Trifolium spp.	Clover species	N	H	F	Any	Sun	Y				Y
Valeriana spp.	Valerian species	N	HP	F	Moist	Sun/ partial shade			Y		Y
Verbascum spp	Mulleins	N	Bi,HP	C	Well drained	Sun	Y				Y
Verbena bonariensis	Verbena		HP	F	Well drained /moist	Sun					Y
Viburnum lantana	Wayfaring tree	N	S	C	Any	Sun/shade				Y	Y
Viburnum opulus	Guelder rose	N	S	C	Moist	Sun/shade			Y	Y	
Viola tricolor	Pansy	N	A	F	Well drained /moist		Y	Y			Y

Type

HP - Herbaceous perennial
Bi - Biennial
BiP - Biennial perrenial
T - Tree
S - Shrub
H - Herb
A - Annual
B - Bulb
C - Creeper/ climber

Benefit

C - Moth caterpillar food plant
S - Sap sucking insects (eg whiteflies)
F - Flowers attract adult moths
R - Good roost potential

Resources

- Bats and road construction. 2005. Vereniging voor Zoogdierkunde en Zoogdierbescherming
- Bats: from evolution to conservation. 2011.OUP Oxford
- Biodiversity By Design: A Guide for Sustainable Communities. 2004. Town and Country Planning Association
- Biodiversity for low and zero carbon buildings. 2010. RIBA Publishing
- Biodiversity Positive: Eco-towns Biodiversity Worksheet. 2009. Town and Country Planning Association http://www.tcpa.org.uk/data/files/biodiversity.pdf
- Creating green roofs for invertebrates: A best practice guide. 2012. Buglife http://www.buglife.org.uk/Resources/Buglife/GreenRoofGuide_P5.pdf
- Designing resilient cities: A guide for good practice. 2012. BRE
- Ecosystem Services Come To Town: Greening Cities by Working with Nature. 2012. Wiley-Blackwell
- Green Infrastructure Valuation Toolkit (http://www.greeninfrastructurenw.co.uk/html/index.php?page=projects&GreenInfrastructureValuationToolkit=true)
- Planting beds in the city of Stockholm: A handbook. 2009. City of Stockholm. http://international.stockholm.se/PageFiles/279007/100322%20GH_HB%20STHLM%20-%20Engelsk%20version.pdf
- Rain Garden Guide: http://raingardens.info/wp-content/uploads/2012/07/UK-Rain-Garden-Guide.pdf
- Seattle Green Factor (http://www.seattle.gov/dpd/Permits/GreenFactor/Overview/default.asp)
- Trees in the Townscape. 2012. Tree Design Action Group. http://www.tdag.org.uk/uploads/4/2/8/0/4280686/tdag_treesinthetownscape.pdf

Principles

- **Ecosystem services**
  The United Nations Convention on Biological Diversity (the Earth Summit), which met in Rio de Janeiro in 1992, introduced to governments the powerful idea of ecosystem services, whereby we acknowledge that nature provides us with the clean air, clean water and food that we need to survive. Ecosystems also moderate the climate and protect us from erosion, flood, disease and pests. The modern view is that nature not only belongs in cities, but that restoring nature in man-made environments is essential if city dwellers are to enjoy a full range of ecosystem services and adapt to climate change.

- **Biodiversity**
  Biodiversity is the variability among living organisms from all sources and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.[42] Biodiversity has key roles at all levels of the ecosystem service hierarchy: as a regulator of underpinning ecosystem processes, as a final ecosystem service (that directly affects the delivery of some ecosystem services) and it may also be the good itself that is valued.[43]

  In general, **biodiverse habitats are more resilient, robust and cheaper to maintain** than species-poor open spaces and provide more and better ecosystem services. For example, watercourses that retain a full range of species have been shown to be more effective in improving water quality. A mixed-woodland is more resilient to pests and diseases and extremes of weather like flooding and drought than a single-species plantation.

- **Green infrastructure and green grids**
  Green infrastructure is a generic term used to describe networks of green spaces, which provide ecosystem services within man-made landscapes. Green infrastructure includes playing fields, parks, gardens, squares, verges, rivers, canals and street trees as well as vegetation on buildings including green roofs and living walls. By creating networks of green infrastructure cities can be made more permeable to both wildlife and people. An example of a green infrastructure network is the All London Green Grid.[44]

  In order to ensure that green infrastructure is biodiverse, designers and managers need to consider the setting for and the situation of each scheme. **A multi-functional approach to design means that each scheme seeks to provide a full range of ecosystem services and does not concentrate on amenity alone.**

- **Water sensitive urbanism**
  Water Sensitive Urban Design (WSUD) seeks to integrate wise use of water into urban design and management in order to collect water in the urban catchment, reduce demand and waste, reduce flooding and protect watercourses and the wider environment.[45] This approach recognises the importance of working with the grain of nature and using green infrastructure wherever possible. WSUD involves the restoration of watercourses and the use of features like green roofs, rain gardens, swales and ponds, resulting in an increase in the area of wildlife habitats in cities. Sustainable urban drainage (SUDS), which is recognised by the Flood and Water Management Act 2010, is equivalent to the drainage aspect of WSUD.[46]

42 Convention on Biological Diversity (CBD)
43 Mace, G., Norris, K.,and Fitter, A.H. 2011. Biodiversity and ecosystem services: a multilayered relationship. TREE: 27(1): 19-26
44 http://www.designforlondon.gov.uk/what-we-do/all/all-london-green-grid/
45 http://waterbydesign.com.au/whatiswsud/
46 http://www.ciria.com/suds/

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