Natural England Commissioned Report NECR181

Green Bridges

A literature review

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Natural England has statutory purposes under the Natural Environment and Rural Communities Act 2006 regarding:

- promoting nature conservation and protecting biodiversity;
- conserving and enhancing the landscape;
- promoting access to the countryside and open spaces; and
- encouraging open-air recreation.

Green bridges can be used to address the severance effects of linear transport infrastructure on wildlife, landscape and access.

They have the potential to:

- Better integrate roads and railways into their surrounding landscape and reduce the visual impact of transport infrastructure by retaining continuity of important landscape features.
- Mitigate the severance impacts of road and rail networks on walkers, cyclists and horse riders and enhance the user experience by make crossings more attractive.
- Mitigate the severance impacts of road and rail networks on wildlife by providing crossing points for a range of species such as deer, bats, birds, and dormice.
- Be a wildlife home in their own right through the incorporation of design features such as bat roosts and water features, and if managed appropriately, provide a resource for certain species such as pollinators.

Natural England commissioned this study to identify and analyse evidence to inform our understanding of the cost effective design and positioning of green bridges and similar infrastructure (including retro-fitting green features to existing grey bridges) to:

- address landscape, access and ecological severance, connectivity and integration issues on the road and rail transport network; and
- maximise the delivery of landscape benefits and ecosystem services.

The findings will be used to inform the advice we give on the planning and design of green bridges. The review will be of particular relevance to our work with national transport bodies and local authorities, but could also be of interest more widely to planners, architects and design professionals from a range of disciplines.

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Further information
This report can be downloaded from the Natural England website: **www.gov.uk/government/organisations/natural-england**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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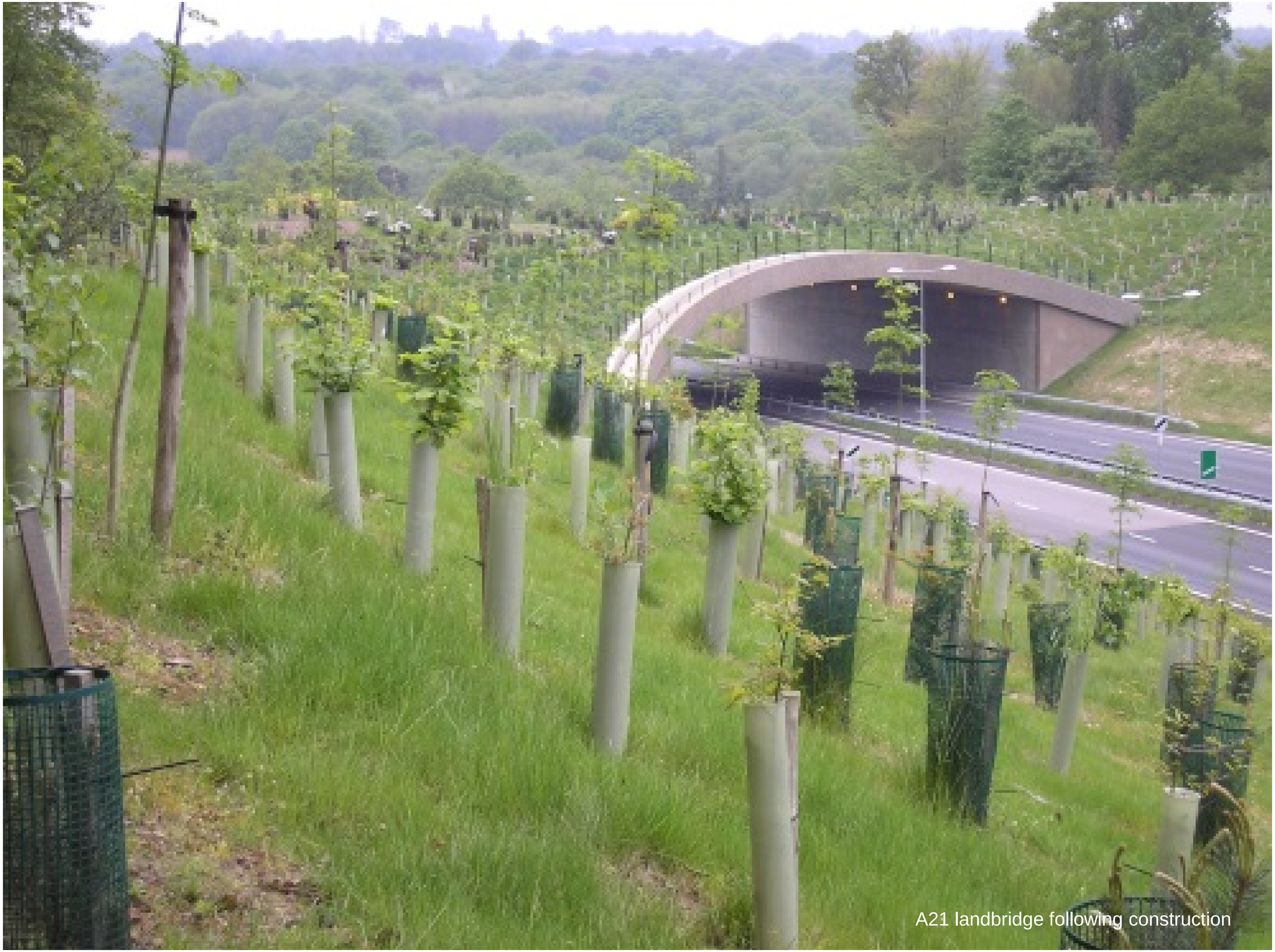

A21 landbridge following construction

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Executive Summary

It is well documented that transport infrastructure can have a negative impact on the environment. Road and rail schemes can fragment habitats, create barriers to species movement and can sever and fragment areas of valued landscape affecting both visual enjoyment and our ability to access greenspace. However, research has shown that when managed appropriately existing road and rail corridors have the potential to be enhanced to provide connecting corridors through otherwise biodiversity poor landscapes such as intensively farmed landscapes and urban areas, providing important habitats for some species such as pollinators.

This literature review forms part of Natural England's commitment to deliver the Natural Environment White Paper's (NEWP) commitment 32 which states, "the Government will work with its transport agencies and key delivery partners to contribute to the creation of coherent and resilient ecological networks, supported, where appropriate, by organisation-specific Biodiversity Action Plans. We will host a forum with environmental stakeholders to inform future priorities for the enhancement of these green corridors."

Lawton's Making Space for Nature, identifies the need for greater joined up thinking and provisions of connections across our landscape for wildlife to function. Lawton identifies that "the essence of what needs to be done to enhance the resilience and coherence of England's ecological network can be summarised in four words: more, bigger, better and joined". One of the five key approaches identified in the review is to enhance connections between, or join up, sites, either through physical corridors, or through 'stepping stones'. Green bridges may be a key step in achieving this vision to prioritise biodiversity networks.

A previous review on behalf of Natural England into how transport's soft estate has enhanced green infrastructure, ecosystem services, and transport resilience in the EU (Davis et al. 2014) identified with respect to green bridges that work is required to better understand the contexts in which these features are most effective. This study aims to build on this previous review, focusing solely on green bridges.

Wildlife crossing structures have been used in Europe and North America to facilitate movement through landscapes fragmented by roads. These structures include wildlife overpasses and green bridges, bridges, culverts, and pipes. Green bridges are relatively new within the UK, with only a small number in existence. It is from such projects that the UK can draw knowledge to inform our understanding of the effective design and positioning of green bridges. This review looks to widen our knowledge of green bridges and aims to answer the following questions:

a) How effective are green bridges in addressing landscape, access and ecological severance caused by the road and rail network;

b) How effective are green bridges at providing habitats in their own right; and

c) How effective are green bridges at delivering wider ecosystem services?

The review identified a total of 56 green bridges currently in existence (although this is unlikely to be a comprehensive list), the majority of which were located over roads and appeared to have been constructed for wildlife purposes to reduce fragmentation impacts. It is of note that the only structures identified which were designed with a primary amenity or historical landscape purposes were located within the UK. The majority of literature found focuses around wildlife crossings, and the terms wildlife bridge and wildlife crossing structure are commonly used rather the term green bridge. Other language terms commonly used are landscape bridge and ecoduct.

Limited information was found on the cost of green bridges, but of the costs found they ranged from around £1.1 million to £10 million. One example was found where the cost of 'greening' a grey bridge was estimated to be in the order of £366,000. However, it is largely unknown what percentage of this is of the overall project costs, and also if the data found provides the cost of the green bridge as a standalone element or if this includes other aspects.

Within the literature several guidance documents on planning a green bridge, along with recommendations on design were found. From these and from the case studies identified, a number of key design principles have been identified. In general from the literature it is clear that when planning a green bridge, this should not be done in isolation, but should form part of a wider mitigation strategy. Particularly of relevance for long linear schemes a green bridge may be used in combination with underpasses, tunnels and ledges to increase the overall permeability of the landscape around the road or railway to wildlife.

Looking at the main objects of the literature review the following has been found:

Objective 1

It has been found that green bridges do provide effective mitigation in addressing ecological fragmentation, with evidence of wildlife use recorded on a large number of bridges. However from the evidence currently recorded there is limited information regarding their effectiveness at a population level. For a green bridge to be truly effective at minimising the barrier effect of transport infrastructure it must be used sufficiently by species to preserve population size and viability. Only one study was found that reviewed genetic connectivity, which found that the crossing structures over and under the Trans Canadian Highway allow sufficient gene flow to prevent genetic isolation in bears. It is also noted that very few studies undertake comparison of pre, during and post construction crossings and therefore in the main, conclusions are based on post construction use alone. As such this review recommends further research to determine effectiveness, particularly in relation to mitigation for impacts on specific species.

In terms of effectiveness in addressing severance to landscape and access, no data was found to demonstrate this. Studies on an ecoduct in the Netherlands recorded use by 500 people/ day, and while this demonstrates a clear use, no data was presented on activity before and after the bridge construction to assess effectiveness. The A21 Scotney Bridge and Mile End green bridge were identified as bridges built to address landscape and access severance but no specific studies were found to demonstrate how successful they have been in delivering their original aims. However, from the 'grey literature' available there is much to suggest that Scotney Bridge has achieved its original objectives and functions well.

Objective 2

The second objective was to assess if green bridges were effective in providing habitats in their own right. Whilst the majority of literature focused on faunal use, information was also found relating to habitats. Evidence has been recorded to confirm amphibian and dragonfly use of ponds on green bridge structures, along with evidence showing that habitats on green bridge structures can closely resemble the surrounding habitats.

Objective 3

The third objective was to assess the effectiveness of green bridges to deliver wider ecosystem services. There was very little information within the literature regarding potential wider ecosystem services of green bridges. However with the exception of pollination the literature did provide evidence to demonstrate bridges can provide ecosystem services. For example, of the bridges identified, the bridge structure at Mile End provides a wider ecosystem service in terms of water recycling. Rainwater runs off the bridge and down into tanks on either side, it is then pumped back onto the bridge and recycled.

It is considered that green bridges can contribute to the following ecosystem services: pollination, trees and standing vegetation, water cycling, cultural heritage, recreation and tourism, aesthetic experience and wild species diversity.

From the findings of this review, a number of recommendations have been made. This includes the adoption of green bridges as a mitigation strategy as the evidence found demonstrates that such structures can be successful in providing biodiversity benefits. Given this it is recommended that a design guide is produced based on the findings of this review, to aid the development of green bridges within the UK. The information within this review may also have wider applications, for example there may be opportunities to apply information from this literature review in practical guidance, such as contributing to Design Manual for Roads and Bridges.

1 Introduction

Background

1.1 This literature review forms part of Natural England's commitment to deliver the Natural Environment White Paper's (NEWP) commitment 32 which states, "the Government will work with its transport agencies and key delivery partners to contribute to the creation of coherent and resilient ecological networks, supported, where appropriate, by organisation-specific Biodiversity Action Plans. We will host a forum with environmental stakeholders to inform future priorities for the enhancement of these green corridors." Natural England also has statutory purposes regarding promoting nature conservation and protecting biodiversity, conserving and enhancing the landscape, and promoting access to the countryside and open spaces and encouraging open-air recreation (Natural Environment and Rural Communities Act 2006).

1.2 Lawton's Making Space for Nature, identifies the need for greater joined up thinking and provisions of connections across our landscape for wildlife to function. Lawton identifies that "the essence of what needs to be done to enhance the resilience and coherence of England's ecological network can be summarised in four words: more, bigger, better and joined". One of the five key approaches identified in the review is to *enhance connections between, or join up, sites, either through physical corridors, or through 'stepping stones'*. Green bridges may be a key step in achieving this vision to prioritise biodiversity networks.

1.3 A previous review on behalf of Natural England into how transport's soft estate has enhanced green infrastructure, ecosystem services, and transport resilience in the EU (Davis *et al.* 2014) identified with respect to green bridges that work is required to better understand the contexts in which these features are most effective. This study aims to build on this previous review, focusing solely on green bridges.

1.4 Transport infrastructure and its operations can have significant adverse effects on biodiversity and landscape, including fragmentation and wildlife-vehicle collisions (Bennett *et al*., 2011). The overall impact of infrastructure on natural environments is termed 'fragmentation'; being the separation of ecosystems and/or habitats of plant and animal populations into smaller, more isolated units. Whilst green bridges are relatively new in the UK, with only a small number constructed, across Europe they are becoming increasingly common feature. It is from such projects that the UK can draw knowledge to inform our understanding of the effective design and positioning of green bridges.

For the purposes of this report a green bridge is defined as an: *Artificial structure over road or rail infrastructure which is either vegetated or provides some wildlife function*

Objectives

1.5 The objectives of this review were to address the following research questions:

a) How effective are green bridges in addressing landscape, access and ecological severance caused by the road and rail network;

b) How effective are green bridges at providing habitats in their own right; and

c) How effective are green bridges at delivering wider ecosystem services?

Intended Audience

1.6 This document will provide information for a range of users, including ecologists, landscape planners, access, landscape architects, greenspace and green infrastructure officers, highways and rail designers and engineers and local authority planners. In particular key users are likely to be:

- Those involved in assessing impacts from road and rail schemes and identifying appropriate mitigation measures;
- Engineers responsible for designing new bridges over road and rail schemes, and modifying existing bridges; and
- Those with an interest in promoting biodiversity and with a responsibility for meeting biodiversity targets.

2 Desk Study Methodology

Aim

2.1 The desk study has been designed to collect information on the following:

- What type of green bridge structures exist (including retrofitted grey bridges);
- Examples of green bridges (UK, European and Worldwide);
- Principles of green bridge design (including examples of successful and less successful structures);
- Purposes of green bridges (i.e. wildlife, habitats, landscape, access, ecosystem services) and evidence demonstrating their usage;
- Costs associated with building green bridges; and
- Alternative options to green bridges.

Approach to data search

2.2 The methodology for the literature review follows the principles detailed by the Collaboration for Environmental Evidence partnership (Collaboration for Environmental Evidence, 2013).

2.3 The following actions were taken to identify relevant documents and information.

- Searching of online literature databases and catalogues. This search was undertaken using an extensive list of search terms, this is provided in Appendix 1. The following locations were searched:
  - Web of Science
  - Natural England library catalogue
  - http://www.britishecologicalsociety.org/journals_publications
- Searching of websites of organisations and professional networks. This search was undertaken manually using the list of search terms in Appendix 1. The following locations were searched:
  - Infra Eco Network Europe (IENE)
  - International Conference on Ecology and Transportation (ICOET)
  - Chartered Institute of Ecology and Environmental Management (CIEEM)
  - Landscape Institute
  - Highways England/ Transport Scotland
  - Natural England/ Scottish Natural Heritage/ Countryside Council for Wales
  - Environment Agency/ Scottish Environmental Protection Agency
  - Construction Industry Research and Information Association (CIRIA)
- Searching the World Wide Web. This search was undertaken manually using the list of search terms in Appendix 1. The search was undertaken using the Google search engine. The first two pages of returned results were reviewed for relevant information.
- Searching bibliographies of key articles – all bibliographies from key articles identified were scanned to identify further relevant text, based on title relevance to the literature review aims.
- Contact with individuals who work in the area (as identified from publications identified through searches). This was limited to 10 key individuals.

2.4 In order to keep a record of the search process, a spreadsheet was developed to ensure that the search strategy was transparent and repeatable. This spreadsheet was used for recording the outcomes of the searches. The spreadsheet contains multiple tabs to record information collected from the various types of searches. A copy of the completed spreadsheet is provided in Appendix 2.

Approach to data screening

2.5 In order to identify relevant material to review from the data search, documents have been screened for relevance. A three stage approach was taken for this:

- Review of article titles to remove irrelevant hits; followed by
- Review of article abstracts to remove irrelevant hits; followed by
- An assessment of the full text.

During the full text screening, documents have been excluded if they:

- Were not relevant to the aims of the review.
- Did not contain any relevant outcomes.
- Contained insufficient quality data.

2.6 Given the anticipated limited amount of available literature, "grey literature" (e.g. consultancy reports, industry reports) has also been considered within the review.

2.7 Following the title screening, documents of relevant documents were saved to the project library and recorded.

2.8 Where documents subject to a full text review were found to be of relevance to the study, details of the documents were recorded within the Findings Summary Spreadsheet (see Appendix 2). These documents were saved to the project library. This spreadsheet provides a summary of the key themes of the document and identifies if any green bridge examples are detailed in the document. This spreadsheet also ranks the confidence in the data in terms of its quality and its strength, considering the following:

- is it peer reviewed?;
- is it based on a clear evidence trail (i.e. is evidence statistically significant)?; and
- is the data evidence based or subjective?

2.9 In order to provide a transparent assessment of the data quality the scoring system detailed in Table 2.1 was used. This scoring system was only applied to those articles that were reviewed in full following an initial screening for relevance. For example, confidence in data ranked as 1aT is considered to be high.

2.10 A number of foreign language documents were identified during the literature review. Where abstracts of these were available in English, these were reviewed to identify any useful information. Where English papers refer to these foreign language papers and provide information regarding their content, the detail was taken from the secondary paper.

Table 2.1: Data quality assessment methodology

Type of study	Description
1	Organised scientific methods/ experiments. Using statistical analysis.
2	Non-analytical studies e.g. case reports, case series studies
3	Expert opinion, formal consensus
Ranking	**Description**
a	Peer reviewed journal articles
b	International organisation reports (IENE)
c	Government reports
d	Grey literature (e.g. consultancy reports, industry reports)
Transferability	**Rating description**
T	Conclusions can be transferred to other sites
No	Conclusions are unlikely to be able to be transferred

Definition of terms

2.11 In terms of this project a green bridge is defined as an artificial structure over road or rail which is either vegetated or provides a wildlife function.

2.12 For the purposes of this study green bridges were not taken to include the following; cut and cover tunnels, rope bridges, wire bridges, bat gantries. However, literature regarding such structures was reviewed when it provided useful information on how species use them, and where it could potentially inform the design of a green bridge.

2.13 This guide does not consider the visual impacts of green bridges on landscape, but more specifically relates to the way they mitigate for landscape severance from road and railway infrastructure.

3 Literature review findings

3.1 In total 105 documents where subject to full review and are detailed in the Findings Summary Spreadsheet in Appendix 2. In general the documents can be split into three categories; research papers, government guidance and international panel guidance. The text below is set out using the aims of the literature review as headings.

What types of green bridge structures exist

3.2 This aim looked to identify the types of green bridge structures which exist and the review findings draw on handbooks which give details of structure types. It is noted that all of the material that was found related to wildlife/ faunal passage and did not discuss structure types for other purposes such as landscape or access, other than mention of multiuse structures.

3.3 The COST[1] handbook (2003) identifies four types of 'over structure' to provide faunal passage; landscape bridges, wildlife bridges, modified bridges/ multi use bridges and tree top overpasses. A clear distinction between landscape bridges and wildlife bridges is not given, but in terms of design this appears to be based on scale aspects, with landscape bridges being larger structures over 80m wide and wildlife bridges being small in width with a recommendation of between 40 and 50m. The handbook does not use the term 'green bridge' to describe these structures.

3.4 The US Department for Transport (Clevenger and Huijser 2011) has produced a Wildlife Crossings Structures Handbook. This guide identifies four types of crossing which can be used to help connect wildlife and habitats, and which it defines as follows (again, the handbook does not use the term 'green bridge' to describe these structures):

- *Landscape bridge:* Designed exclusively for wildlife use. Due to their large size these are used by the greatest diversity of wildlife and can be adapted for amphibian and reptile passage.
- *Wildlife overpass:* Smaller than landscape bridges, these overpass structures are designed exclusively to meet needs of a wide range of wildlife from small to large species.
- *Multi-use overpass:* Generally the smallest of the wildlife overpasses. Designed for mixed wildlife–human use. This wildlife crossing type is best adapted in human disturbed environments and will benefit generalist type species adapted to regular amounts of human activity and disturbance.
- *Canopy crossing:* Designed exclusively for semi-arboreal and arboreal species that commonly use canopy cover for travel. Meets the needs of species not built for terrestrial travel and generally have difficulties crossing open, non-forested areas.

3.5 Clevenger and Ford (2010) note that landscape bridges are defined as being generally more than 100m wide, and due to their size enable habitat restoration, especially if well integrated to enable habitat continuity between either side of the bridge.

3.6 The Trans-European Wildlife Networks (TEWN) Project Manual (EuroNatur Foundation 2010) differentiates between wildlife overpasses and green bridges and uses the term 'landscape bridge' in reference to green bridges and ecoducts. It details that the width of most wildlife overpasses built in Europe varies from 25-80m. The manual states that big animals (although no examples of what constitutes a big animal are given) use only underpasses, overpasses and landscape bridges, whereas only a few individuals of a certain species will use smaller structures which will not guarantee the long term survival of those species. However, it is noted that smaller structures may save whole populations of smaller animals if the structures are well maintained. In terms of green bridges, the report states that all representatives of fauna cross them, from insects to large carnivores.

[1] European Cooperation of the of field Science and Technical Research

Examples of green bridges (UK, European and Worldwide)

3.7 The second aim looked to gather examples of green bridge structures. The review identified a larger number of structures, especially from Europe, however the level of detail available for each one varies considerably. As with the details on the types of green bridge structures detailed above, the majority of bridge structures appear to have been built for wildlife purposes, although clear information in bridge aims was not widely recorded. This section details case studies from around the world, a summary of these is provided in Table 3.2 which includes weblinks to photographs of these bridges where available.

UK

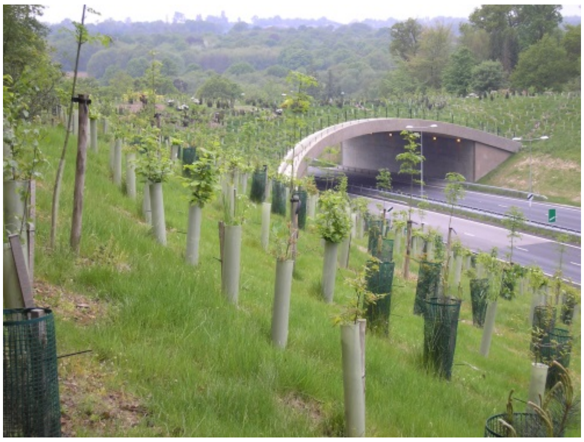
3.8 The A21 Scotney Castle green bridge was constructed as part of a Highways England improvement scheme for a new dual carriageway by-pass around Lamberhurst village, near Tunbridge Wells, Kent. The bridge is located within the High Weald Area of Natural Beauty (AONB). The proposals concerned a 3.2km section of new road passing to the East of Lamberhurst village across open countryside, crossing the Teise valley and rejoining the existing A21 just below Spray Hill and Ruffets Wood. The original proposals would have severed the historic West Drive which was laid out in 1842 and still used as the main entrance to Scotney Castle, which is now owned by the National Trust. The National Trust objected to the initial proposals due to the impact on the historic drive and then, through its consultants, worked with the HA to modify the scheme with the inclusion of a “landbridge”. The landbridge enabled the West Drive to be reinstated on its original line providing landscape and habitat connectivity.

3.9 Scotney Castle is widely recognised as one of the most important and complete ‘Picturesque’ landscapes of England, shaped by Edward Hussey III, incorporating the ancient castle and the ‘new house’ of 1837 - 43, and managed by his successors. In planning the new house, Edward also laid out his grounds and the new West Drive with the assistance of William Sawrey Gilpin – apostle of the Picturesque movement. The landbridge provided the opportunity to avoid severance and the dislocation of the West Lodge and to maintain the presentation of the historic drive. The photographs below show the construction of this bridge and its appearance following construction. The bridge is 92m long, 29m at narrowest point, 55m at widest.

3.10 In addition to the historic landscape purpose, the bridge also provides wider ecological benefits and evidence has been recorded of dormice using the bridge. Dormice were known to occupy land directly to the west and a small wooded area 400m south east of the bridge. Nest boxes were placed on the bridge and 6 years after construction dormice were recorded using the bridge, including a female with young (Peoples Trust for Endangered Species, 2012).

3.11 The cost of the landbridge has not been separately identified. It formed part of the £22 million (including Public Inquiry) spent on the 3.2km section of single and dual carriageway of the Lamberhurst by-pass scheme. Of note from all of the structures identified within this review, this was the only green bridge which appeared to have a clear aim with respect to maintaining landscape character/ historical purpose rather than wildlife aims.

Photographs taking during the construction phase of the A21 landbridge

Photographs of the A21 landbridge following construction

3.12 Also within London is the Mile End green bridge, which was constructed to overcome conflict between Mile End Park and the traffic of the Mile End Road. Although the park was 90 acres, it was perceived as a series of smaller parks due to its dissection by a number of major and minor roads and railway lines. In order to join up the park a green bridge was built to increase connectivity. The structure cost £5,800,000 (http://www.czwg.com/works/green-bridge). The green bridge spans five lanes of the Mile End Road, with 25m width of landscaped parkland. Rainwater runs off the bridge and down into tanks on either side. It is then pumped back onto it and recycled.

3.13 Sheena Crombie from Highways England provided details of two green bridge examples where farm accommodation bridges have been used (*pers comm*). On the A66 at Temple Sowby a green strip was provided on one side of the bridge. However on completion of the project the bridge was handed over to the farmer, who owned the land either side of the bridge. The farmer when moving cattle over the bridge, shut the gates either side and as such the verge became heavily trampled and grazed. On the A556 a new accommodation overbridge is planned, this will be a 11m green bridge, with a farm track and a 7m green verge. The verge is to be planted with grasses and trees in large tubs. The driver for the project was the presence of amphibians, bats and badgers in the area. This bridge has not yet been constructed.

3.14 Limited details were found on green bridges constructed as part of the Weymouth Relief Road project (Dorset County Council). Three bridges, the Lorton Lane bridge, the Ridgeway bridge and the South Down bridge were constructed in 2010. They are adapted road or farm access bridges and were 'greened' to enhance ecological connectivity rather than in response to a need for specific species or habitat mitigation for severance. The South Down bridge has been landscaped to blend into the surroundings and is to be used for pedestrian and equestrian access. The Ridgeway bridge allows continuation of the South West Coastal Path and the Lorton Lane bridge allows access to be retained to the Lorton House and Meadows visitors centre. The Ridgeway bridge is within the Dorset AONB and includes a dry stone wall.

3.15 The Lorton Lane bridge has been planted with hawthorn, blackthorn and various wild rose species. The bridge connects to footpaths and bridleways in Lorton Meadows Nature Reserve, which in turn connect to Southdown Ridge, Two Mile Coppice and the conservation area near Horselynch Plantation which is being created as part of the relief road project. The bridge is constructed from arches 'stitched' together at the top with reinforcing steel and concrete, the outside of the arches are backfilled with earth.

3.16 The South Down bridge is an arch construction, which is backfilled with earth behind the bridge arches. The backfilling builds up the level of the ground either side of the bridge to make sure that the cycleway and bridleway is level. Vegetation has been planted across to create a continuous line. The bridge was hydro-seeded and then added to with hand sowing of a local mix of wild flowers seeds.

3.17 Although not a green bridge, also of relevance to this review is a study by Berthinussen and Altringham (2012) which looked to assess the effectiveness of bat gantries constructed in Northern England. The study looked at bat gantries which consisted of metal or wooden pylons, with 2 or 3 pairs of wires spanning the road with plastic spheres on. The study recommended that further investigation is needed into natural crossing structures over roads, such as green bridges and tree 'hop-overs'.

3.18 An example of a different type of green bridge is the Thames Garden Bridge. Details of this have been taken from the Environmental Statement for the project which is yet to be constructed (Garden Bridge Trust, 2014). This proposed garden bridge over the Thames will measure 366m long and 30m wide, with around 270 trees and landscape beds. This is quoted within the press as costing £175million to construct and running costs of £3.5million a year (Guardian, 2014).

Europe

3.19 In the Netherlands, green bridges are commonly referred to as 'ecoducts'. The Netherlands leads the way in terms of the number of ecoducts constructed; since the first one constructed in 1988 there are now at least 47 ecoducts present (See Table 3.1), which from the literature available all appear to have been built for biodiversity purposes (http://nl.wikipedia.org/wiki/Ecoduct). Dutch literature states that in Holland it almost goes without saying the crossings will be constructed for fauna when new road and railway infrastructure is built (Bekker *at al* 2011). These ecoducts have been subject to various studies, and although much of the literature is in Dutch there are also a number of articles in English.

Table 3.1: List of Built and Planned Ecoducts in the Netherlands

Information taken from http://nl.wikipedia.org/wiki/Ecoduct

Road	Bridge name	Length	Width	Cost[2]	Notes of interest
A1	Ecoduct Laarder Hoogt	70 m and 30 m	40 m and 30 m	£8.2 million (EUR 11.5 million)	Opening 2015, two separate bridges
A1	Ecoduct Harm van de Veen	~ 50 m			Kootwijk - Hoge Veluwe National Park for Red Deer. Opened 1999
A1	Ecoduct High Buurlo	~50 m			Just west of Apeldoorn. Opened 2011
A1	Ecoduct The Borkeld	~ 17 m	relatively narrow		The ecoduct connects the nature reserve De Borkeld where A1 deepened passes. Opened 2003
A1	Ecoduct Boerskotten	~ 15 m			Completed in 1992
A2	Ecoduct Autena	15 m	15 m		
A2	Ecoduct Beesdsche Veld	~20 m			Built 2010
A2	Natuurbrug Het Groene Woud	~50 m			Built 2003
A2	Ecoduct Groote Heide	~ 50 m			Built 2014
A2	Natuurbrug Weerterbergen	24 / 75 m	40 / 40 m		2014 Nature bridge consists of two structures. The ecoduct over the railway is 24m long and 40m wide, the section over the road is 75m long and 40m wide.

[2] http://www.xe.com/ - Conversion at a rate of 1 GBP = 1.40112 EUR (13/03/2015)

Road	Bridge name	Length	Width	Cost[2]	Notes of interest
A2	Ecoducten Bunderbosch/Kalverbosch	Kalverbosch:37m Bunder Bosch:25m	27 / 25 m		2013 Ecoduct Kalverbosch, with a length of approximately 37m and a width of 27m, spans the lane northbound. The ecoduct Bunder Bosch with a length of approximately 25m and a width of 25m spans the southbound carriageway. There are screens installed to prevent disturbance by street and car lights.
A4	Eco-aquaduct Zweth	100 m			Combination of a wildlife crossing and aqueduct planned for 2015
A12	Ecoduct Mollebos	79 m	53 m		Built 2012
A12	Ecoduct Rumelaar				Built 2012
A12	Ecoduct Jac. P. Thijsse	~ 50 m			Built 2011
A27 / N417	Ecocorridor Zwaluwenberg	30 m			2013 wildlife crossing over the A27 and the parallel railway line. The Gooi Nature owns a portion of the land and manages the nature reserve. Crossings by deer, badger, pine marten, sand lizard, and studded blue beetle.
A28	Ecoduct Leusderheide	53 m			Built 2005
A28	Ecoduct Huis ter Heide	~ 50 m			Built 2012
A28	Ecoduct Hulshorst	50 m			Built 2011
A28	Ecoduct Dwingelderveld		60 m		Built 2013
N35	Ecoduct Twilhaar	30 m			Built 2011
N48	Ecoduct Suthwalda				
N48	Ecoduct Stiggeltie				
A50	Wildwissel Woeste Hoeve	72 m			Built 1988, this was the first ecoduct in the Netherlands
A50	Wildwissel Terlet	65 m			Built 1988
A50	Ecoduct Slabroek				The bridge is 10m wide with a bicycle path. Landscaped to compensate for the extension of the A50, regular use by badgers and deer.
A50	Ecoduct Tolhuis	40 m			Built 2011
A50	Ecoduct Wolfhezerheide	71 m	46 m		Built 2011
A50	Ecoduct Herperduin	50 m			Built 2014

Road	Bridge name	Length	Width	Cost[2]	Notes of interest
A67	Ecoduct Kempengrens	60 m			Built 2014 The ecoduct connects two forest areas in the Kempen together with five ecotypes; moist to wet vegetation with pools and screened with stumps for amphibians and insects; wetlands, flowery brushwood for insects; grassy vegetation for large herbivores; species-rich vegetation with open sand and small bushes on the edges for insects and reptiles and secluded thicket vegetation for mammals.
A73	Ecoduct Waterloo				Built 2007
A74	Ecoduct Ulingsheide	36 m	58 m		Built 2012 The ecoduct Wambach, which was initially known as the ecoduct Ulingsheide
N200	Natuurbrug Zeepoort			£3.9 million (EUR 5.5 million)	Scheduled for 2016
N201	Natuurbrug Zandpoort	40m	13m		Built 2013
N227	Ecoduct Treeker Wissel				
N236	Lutrapassage/ Natrixpassage	2 x 80 m			Built 2013, 2 viaducts
N237	Ecoduct Boele Staal	40m	60m		Planned 2015
N237	Ecoduct Beukbergen	19 m	30 m		Built 2009
N297	Ecombiduct Op de Kievit				
N310	Ecoduct Oud Reemst	50 m			Built 2012
N324	Ecoduct Maashorst	40 m			Built 2014
A348	Ecopassage Middachten				
N350	Ecoduct De Grimberg				Built 2013
N396	Ecoduct Leenderbos				Built 2014
N417	Ecoduct Zwaluwenberg	30 m			Built 2013 The Gooi Nature owns a portion of the land and manages the nature reserve. Deer, badger, pine marten, sand lizard, and studded blue beetle recorded using.
N524	Natuurbrug Zanderij Crailo	300 m	50 m	£10.5 million (EUR 14.75 million)	Built 2006

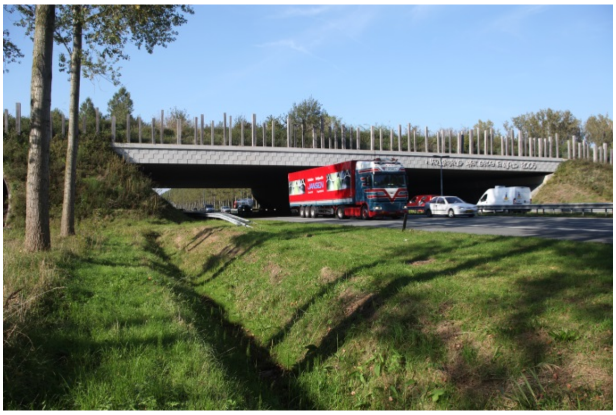
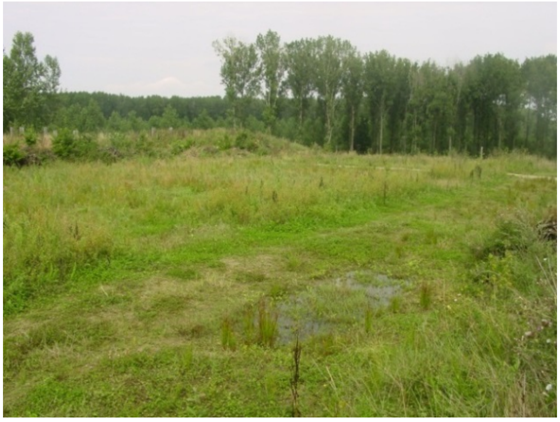
3.20 Further details were found on a number of the green bridges in the Netherlands are detailed as follows:

3.21 Van Wieren and Worm (2001) undertook monitoring on the Terlet, an overpass in the Netherlands which is 50m wide and 95m long and planted with tree species. This was built at an historical crossing point for red deer. The road either side of the overpass is fenced. This bridge was monitored in 1989 and 1994/5 using sand traps to record footprints and in 1995 small mammal trapping was also undertaken. Evidence of use by red deer, roe deer, fallow deer, wild boar, red fox, badger and wood mice, common shrew and common vole was recorded. The level of bridge use was higher in the 1994/5 study, which the author considered was due to species' increased familiarity with the bridge. The paper also references a study by Pfister and Birrir (1991) which compared overbridges of different widths in Switzerland and concluded that bridges around 5m wide were hardly used by roe deer and usage increased substantially when they were wider than 30m (the original paper of this study is in German).

3.22 Van der Grift *et al.* (2010) discusses the Groene Woud ecoduct in the Netherlands, which is an overpass designed and managed to create optimal humid conditions for amphibians. This structure includes a chain of small pools across the overpass and its access ramps. It is located in the National Landscape Groene Woud and connects wetland areas which are bisected by a motorway. In terms of design, the wildlife overpass is 50m wide and 65m long and crosses the motorway 7m above ground level. The access ramps are 110m (west) and 85m (east) long and have a gradient ratio of 1:14 and 1:10 respectively. The overpass is covered by a layer of 0.5m topsoil. On the access ramps the topsoil depth is 1m. The topsoil layer on the overpass and access ramps consists of soil that originates from the immediate vicinity of the overpass. The topsoil has been put in place in such a way that the original sequence of soil layers is maintained. Along the edges of the overpass 2.5m high embankments have been constructed to reduce disturbance from light and noise emitted by passing traffic. The overpass is closed to the public.

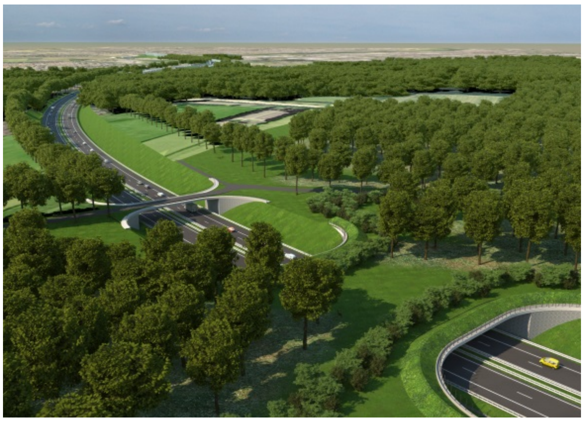
3.23 To create the conditions for amphibians, there is a controllable groundwater level on top of the overpass, across the whole length of the overpass and its access ramps, with a wetland zone of a chain of small pools. Water is pumped up to the top of the overpass and slowly released through the cascade of small pools towards bigger pools at the feet of the access ramps. The overpass was monitored for 3 years, which found the number of observations of amphibians in the wetland zone on the overpass was at least 1.5 times higher than the number of observations in other locations on the bridge. Six amphibian species were recorded on the bridge; common toad, common frog, marsh frog, edible frog, smooth newt and great crested newt.

Photograph of Groene Woud – courtesy of Rijkswaterstaat

Photographs showing the Groene Woud - courtesy of ALTERRA / E.A. van der Grift

3.24 Another Dutch bridge which is designed with water in mind is the Ecoduct Wambach, constructed 2011-12 (2012 IENE). This is the first green bridge designed with climate change resilience. The design considered climate change resilience to match the water management on the green bridge with Intergovernmental Panel on Climate Change based climate scenarios of the Royal Dutch Meteorological Institute. Concrete ridges are glued to the deck of the green bridge which forms basins to retain water available for drought periods. Polystyrene bases of embankments retain water through raised edges covered with foil. To avoid excess water during rainfall peaks, an oversized drainage system has been designed to channel water to two ponds. The drainage system may also be used in a reversed fashion, to supplement the green bridge with water.




Photographs of the Ecoduct Wanbach, courtesy of Victor Loehr, Rijkswaterstaat

Left photo shows design plan, right photo shows construction stage

3.25 Van der Grift *et al.* (2011) discusses a monitoring study over one year of two ecoducts in the Netherlands with shared usage, mammals and humans. The two ecoducts studied were Zanderji Crailoo (a 300m long, 50m wide, landscaped ecoduct with a mosaic of shrubs, heath, grassland, open sand, tree stumps and a loamy ditch) and Slabroek (a 100m long, 15m wide and landscaped ecoduct with a mosaic of grassland, ruderal[3] vegetation and a loamy ditch). Both structures are open to the public between sunrise and sunset. The study compared mammal usage on days with frequent public use with days with low-level public use and found no strong differences in mammal use. When comparing with wildlife overpasses without human co-use elsewhere in the Netherlands, the crossing frequencies at overpass Zanderij Crailoo and overpass Slabroek were not necessarily lower. At Zanderij Crailoo the mean number of crossings per year of roe deer, red fox, pine marten, stoat and red squirrel exceeded the national mean. At overpass Slabroek the mean number of crossings per year of badger and polecat exceeded the national mean. However, crossing frequencies which were lower than the national mean were recorded for roe deer, red fox, European hare, rabbit and red squirrel, despite their occurrence in relatively high densities in the area. The data suggests that Slabroek did not function properly for these species.

[3] Plant species which typically grow in waste ground and early colonisers

3.26 A further paper by Van der Grift *et al.* (2010) details that the Zanderij Crailoo is used by walkers, cyclists and horse riders. A study into its use recorded 180,000 walkers and cyclists and 17,000 horse riders between Jan 2008 and Jan 2009, with daily averages 500 walkers and cyclists and 5 horse riders. Species use was monitored between 2007 and 2008, with 13 species recorded. Roe deer and rabbit were found to use the bridge daily and fox and hare were also recorded. A total of 6 species of amphibians and 2 species reptiles were found, with brown frog being the most common and then smooth newt.

3.27 A further Ecoduct near Kootwijk in the Netherlands (http://www.iees.ch/cs/cs_3.html) crosses a 4-lane motorway. This 150m long structure has an hour glass shape structure and is 80m wide at its entrances and 30m wide in the middle. Walls have been constructed on the edges of the ecoduct in order to reduce traffic disturbance. The walls are 1.5m in height and planted with trees and shrubs; in the centre the vegetation is more open. The design aimed to create passage for both fauna species associated with forests and fauna species associated with heathland and drifting sand. Various mammals have been recorded using the structure, including common shrew, wood mouse, roe deer, white-toothed shrew, pine marten, wild boar, field vole and red deer.

3.28 The Kikbeek ecoduct, constructed in 2006 is 70m in length, and 40m wide at its narrowest point. This is another ecoduct with wetland habitat, with a pond on the bridge, that fills with rain water and stagnates to create a temporary water source. Monitoring of the ecoduct recorded 21 species of dragonfly in the first year, 12 of which were reproducing. Other details about this ecoduct were found in an English abstract of a Dutch paper (Lambrechts 2010 and 2008). The ecoduct connects two parts of the National Park "Hoge Kempen", which contains dry and wet heathland and coniferous forest. Pitfall trap surveys recorded 78 spider species (23 Flemish red data list), two years following construction was completed, including typical woodland and heathland species and wetland species along the pool edge.

3.29 A second study by Lambrechts (2007) looked at the use of a Flemish ecoduct, built within the Meerdaal Forest. This was constructed between 2004 and 2005 and was then surveyed for fauna the following year. Pitfall trapping for spiders was undertaken, which recorded a total of 67 species (13 Flemish red list). The study identified a hedge of tree trunks as being important for spiders.

3.30 Outside of the Netherlands, a number of other countries are known to have green bridges. A US Department of Transport paper which discusses wildlife habitat connectivity across European highways, informed by the department's fact finding trip to Europe (Bank *et al*. 2002), provides a useful summary of these, although only limited details on the bridges are given. The report details that there are 125 overpasses in France and 32 in Germany (with more in construction). Examples of green bridges in France are provided, noting that these usually have an hour glass shape, being constricted in the area of the road to reduce costs. The A87 in France has four smaller overpasses as these were considered more effective than one larger crossing, with the aim of facilitating enough crossing to maintain genetic diversity rather than to provide total connectivity. The structures built were 12m at the narrowest point with 50cm of soil, with a pond built at one end and large boulders placed at each end to stop vehicle use. For those in Germany, the paper details that widths range 8.5m to 870m. Reference is made to a research project looking at a crossing over the A1 in Grauholz, Switzerland, where a 23m crossing was considered too narrow as 'alarm behaviour' was recorded in roe deer using the structure. However, in comparison a 17m wide crossing at Brienzwiler was regularly used by badger, fox, marten and red and roe deer. (The research papers for these studies are not in English).

3.31 The Trans-European Wildlife Networks (TEWN) Project Manual (EuroNatur Foundation 2010) details two ecoduct examples in Switzerland which were built to prevent fragmentation of larger forest complexes, Aspiholz being 140m wide, and Fuchswies 200m wide. No detailed information on costs is given, although the report does state that they cost about 5% of the overall construction costs. Limited details on the design are provided: the bridges were formed with concrete of 0.4m and a minimum soil layer of 1.5m, which allows the growth of forest vegetation without watering. At Aspiholz, native bushes were planted only at critical spots (it does not define what these were) and the rest has been left for natural succession. Two years after its construction 60 plant species were recorded, as well as some rare insect species. Small ponds on the bridge attract amphibians during migration and reproduction. No raw data is provided or details of monitoring studies. The report also detailed a new motorway to the south of Croatia (to

Split and Dubrovnik towns), which has ten dedicated overpasses (green bridges in widths of 120 m, 150m and 200m), although no additional details are given on these.

3.32 A study by Kusak *et al* (2009) looked at a green bridge called Dedin on the Zagreb – Rijeka motorway. This bridge is 100.5m wide and has been monitored since its construction in 1999. The monitoring recorded that fox, badger, hare and roe deer use the bridge for foraging, either grazing grass or hunting small mammals and other vertebrates (amphibians and reptiles).

3.33 Olsson *et al*. (2008) undertook a study to investigate the effectiveness of a highway overpass to promote landscape connectivity and movement of moose and roe deer in Sweden. After the construction of exclusion fences and highway crossings, there was a 70% reduction in roe deer-vehicle collisions, and a total reduction of moose-vehicle collisions during the first 31 months post-fencing, compared to the same amount of time prior to fencing. The structure which was monitored during this study was completed in June 2000. The structure was hourglass-shaped, 80m long, 17m wide at the centre, and 29m wide at the entrances. The sides were covered with 2m high grey tempered glass-shields intended to reduce the noise and light from headlights of cars. The surface of the overpass was covered with sand (track plates) except for a 4m wide gravel road with low traffic volume rather than being a vegetated green bridge.

Worldwide

3.34 One of the most famous locations with green bridges, that is regularly cited in articles, are those over the Trans Canadian Highway in Banff. Clevenger (2003, 2009) has produced multiple papers regarding the work undertaken to study these two 50m wide structures, which have been monitored since 1996 using infrared cameras and raked track beds. The amount of both wildlife and human use has been recorded. Annual monitoring of the overpasses found a general pattern of increased use at overpasses for grizzly bears, wolves, and black bears during the first five years of monitoring. Increased annual passage frequencies were found for large carnivore species between years three and five of monitoring, i.e., 4 to 25 times greater than the average use during the first two years. Consistent annual increases in use were also observed for deer; use increased steeply and linearly from approximately 200 passes in year one to roughly 1,100 passes in year five. The data provides evidence that there is a learning curve or adaptation period for all wildlife using the overpass (this was also found to be the case in the study of the underpasses on the scheme). Clevenger advises that small sampling windows, typical of one- or two-year monitoring programs are too brief and can provide spurious results. Clevenger advocates the need to remember in the planning process that crossing structure systems are permanently embedded in the landscape, but the ecological processes going on around them are dynamic.

3.35 Another green bridge example is the Compton Road faunal overpass in Brisbane, Australia. The bridge is hour-glass in shape and 70m long, with its width ranging from 20m to 15m at the centre. The height of the surface of the structure is 8m with a 5.4m clearance within both tunnels. In terms of soil there is between 30cm to 1.3m topped with hydromulch and planted at a density of 70 shrubs and 6 trees per 100m^2. The bridge was studied four years after construction; this study recorded 45 vegetation species, most of which had been planted with the remainder self-propagating (Jones *et al*. 2011). The structure of the vegetation now closely resembles the dense understory of the surrounding subtropical eucalyptus forest and is remarkably similar in species richness. The use of this bridge by birds has been studied; which found there was a significant difference in the mean species richness of birds detected using the overpass compared to flying over the road, with almost twice as many species being detected on the overpass (Jones 2013).

3.36 Table 3.2 below provides a summary of the green bridge examples obtained. Included within this table are website links to photographs of these bridges where available.

Table 3.2: Summary of Green Bridge Examples

Bridge Name	Location	Cost[4]	Design Information	Usage data	Source and Photograph reference
A21 Scotney Bridge	Kent, UK		92m long, 29m at narrowest point, 55m at widest. Mixed use. Designed for landscape purposes	Dormice recorded on bridge	LUC
Mile End	London, UK	£5.8 million	Mixed use, amenity		http://www.czwg.com/works/green-bridge
A66 Temple Sowby	UK		Mixed use – Farmers Accommodation Bridge with a green verge either side. The verges were each less than 1m	The bridge was heavily used by farmer, who shut cattle on bridge. Cattle over grazed and trampled verges.	*Pers comm* S.Crombie – Highways England
A556, Cheshire	UK	Estimated cost of 'greening' the access bridge £366,000, with total bridge cost estimated at £1.14 million.	Under construction. Mixed use bridge. 11m green bridge, with a farm track and a 7m green verge, to be planted with grasses and trees in tub planters. The driver for the project was to provide connections for amphibians, bats and badgers.	Under construction.	*Pers comm* S.Crombie – Highways England
Banff wildlife crossings	Banff, Canada		50m wide	Monitored since construction using infra-red and track beds.	Clevenger (2003)
Terlet	Netherlands		50m wide and 95m long and planted with tree species and road fenced either side	Monitored in 1989 and 1994/5	Van Wieren and Worm (2001)
Groene Woud ecoduct	Netherlands		50m wide and 65m long Crosses the motorway 7m above ground level. Access ramps are 110m (west) and 85m (east) long and have a gradient ratio of 1:14 and 1:10 respectively.	Used by common toad, common frog, marsh frog, edible frog, smooth newt and great crested newt	Van der Grift *et al.* (2010) http://www.wegenwiki.nl/Natuurbrug_Het_Groene_Woud

[4] http://www.xe.com/ - Conversion at a rate of 1 GBP = 1.40112 EUR (13/03/2015)

Bridge Name	Location	Cost[4]	Design Information	Usage data	Source and Photograph reference
			0.5m topsoil. Access ramps: 1m topsoil. The topsoil layer on overpass and access ramps consists of soil that originates from the immediate vicinity of the overpass. The topsoil placed to maintain original sequence of soil layers is maintained. Along the edges of the overpass 2.5m high embankments have been constructed to reduce disturbance from light and noise emitted by passing traffic. Closed to public. Controllable groundwater level on top of the overpass, across the whole length of the overpass and its access ramps a wetland zone has been constructed existing of a chain of small pools. Water is pumped up to the top of the overpass and slowly released through the cascade of small pools towards bigger pools at the feet of the access ramps.		
Zanderjo Cariloo	Netherlands	£10.5 million (EUR 14.75 million)	300m long, 50m wide, landscaped ecoduct with a mosaic of shrubs, heath, grassland, open sand, tree stumps and a loamy ditch. Mixed use.	Used by roe deer, red fox, pine marten, stoat and red squirrel. Average people use, 500 walkers/ cyclists daily and 5 horse riders.	Van der Grift *et al.* (2010) Van der Grift *et al.* (2011) http://www.wageningenur.nl/nl/Dossiers/dossier/Ecoducten.htm
Slabroek	Netherlands		100m long, 15m wide and landscaped ecoduct with a mosaic of grassland, ruderal vegetation and a loamy ditch. Mixed use.	Used by polecat and badger	Van der Grift *et al.* (2011)

Bridge Name	Location	Cost[4]	Design Information	Usage data	Source and Photograph reference
Wamback Ecoduct	Netherlands		Design considered climate change resilience. Concrete ridges are glued to the deck of the green bridge which forms basins to retain water available for drought periods. To avoid excess water during rainfall peaks, an oversized drainage system has been designed to channel water to two ponds. The drainage system may also be used in a reversed fashion, to supplement the green bridge with water.		
Ecoduct near Kootwijk	Netherlands	£2.1 million (EUR 3 million)	150m long, hour glass shape structure, 80m wide at its entrances and 30m wide in the middle. 1.5m walls planted with trees and shrubs have been constructed in order to reduce traffic disturbance.		http://www.iees.ch/cs/cs_3.html
Kikbeek ecoduct	Netherlands		70m long, 40m wide. Built to connect two parts of a National Park	Used by 78 species of spider and 12 dragonflies.	Van der Grift (2005), Lambrechts (2010)
A87 bridges	France		12m at the narrowest point with 50cm of soil, with a pond built at one end and large boulders placed at each end to stop vehicle use		Bank *et al.* 2002
Aspiholz and Fuchswies	Switzerland	5% of project cost	Concrete of 0.4 m and a minimum soil layer of 1.5 m. Autochthonous bushes were planted only at critical spots and the rest has been left for natural succession.	Two years after its construction 60 plant species were recorded	TWEN manual
Dedin on the Zagreb - Rijeka motorway	Croatia		100.5m wide	Fox, badger, hare, roe deer and other vertebrates (amphibians and reptiles) recorded.	Kusak at al (2009)

Bridge Name	Location	Cost[4]	Design Information	Usage data	Source and Photograph reference
Compton Bridge	Brisbane, Australia		70m long, 20-15m wide. Soil depth 30cm to 1.3m. Planting density 70 shrubs and 6 trees per 100m^2	45 species of vegetation established after 4 years.	Jones *et al*. (2008, 2010, 2011, 2013)

Principles of green bridge design

3.37 In terms of green bridge design, the literature provides a number of texts that describe the processes that can be taken to identify if a green bridge is the most appropriate structure and aspects to consider when planning the construction of a bridge. A number of papers work through a screening approach to determine if a green bridge is the best option and detail the considerations to take into account. In terms of design principles, details on planning approaches are given first, followed by design specifics. A number of papers also identify the need for a monitoring plan to be put in place post construction.

Planning

3.38 The papers reviewed provided some advice regarding planning bridges within existing transport networks and planning green bridges for new schemes.

3.39 Looking at existing road networks in a region, Clevenger and Ford (2010) discuss taking a landscape based approach, key habitat linkages or zones of important connectivity for wildlife should be identified, then potential crossing locations should be prioritised based on future planned projects, scheduling and ecological criteria. This approach helps to strategically plan mitigation schemes at a regional or ecosystem level. The paper identifies the key benefits of this approach to be an ability to prioritise objectives, incorporate landscape patterns and processes into planning and to address stakeholder concerns. By taking a regional level approach, project specific work will consider the larger ecological network.

3.40 In terms of planning specifics, the paper identifies that the following resources should be used to identify wildlife habitat linkages and movement corridors; aerial photographs, landcover vegetation maps, topographic maps, landownership maps, wildlife habitat maps and wildlife movement data, field research, road kill data and road network data. This paper then provides specific information on how this data is best used, noting that overlaying in GIS is useful for identifying habitat linkages. This landscape level assessment will identify areas of wildlife conflict over a large area. Once identified, specific placement of crossings can then be done at a project level taking into account local conditions such as topography. It is noted that this paper is based on US species, which will range over a greater geographic area due to their migratory nature than species in England.

3.41 A report prepared for the Colorado Department of Transport (Felsburg Holt & Ullevig, 2013) discusses a screening process used to identify potential locations to install a wildlife crossing over an existing road, Interstate 70 in Colorado. The report is specific to that project; however some of the criteria used for screening provide a useful framework for consideration on other projects. The report uses the following factors to create a shortlist of locations: frequency and severity of animal/vehicle collisions; habitat and movement areas for the species likely to use a wildlife overpass; Average Annual Daily Traffic Count (AADT) Range; Natural and protected habitat on both sides of the highway; and relationship with existing and proposed wildlife crossing structures. The shortlist was then subject to further screening based on: topography, obstacles present, geology/geography, maintenance, safety, flood hazard zone and utilities.

3.42 It is noted that the approach taken in planning at a regional and project level are largely the same in terms of data collection, although when planning at a project level, collecting data on species movements at a regional level is likely to enable a more informed decision to be made on the best location to position a bridge.

3.43 COST (2003) details that selecting the most appropriate type of fauna passage requires consideration of the landscape, habitats affected and target species, and evaluating the importance of the habitats and species at a local, regional, national and international scale. Where an internationally important corridor for the movements of large mammals is cut by an infrastructure development, then a large landscape bridge may be the only measure which can help maintain functional connectivity and landscape permeability. The report details general rules to determine which is more suitable, an overpass or underpass, stating that this is partly determined by the topography. The paper also details that the density of faunal passages required to effectively maintain habitat connectivity is a major decision in planning mitigation measures; for example in some instances one or more wide passages will be appropriate, whereas other problems will be better tackled by a larger number of smaller-scale measures. Bridges should be well connected to their surroundings, either by way of habitat corridors leading towards passages for small animals or with guiding lines for larger animals.

3.44 The US Department for Transport (Clevenger and Huijser 2011) has produced a Wildlife Crossings Structures Handbook. This handbook is 223 pages and as such only a brief summary is provided here; the handbook should be referred to directly for further information. The handbook discusses both project and landscape level approaches to wildlife crossings. In terms of planning for wildlife crossings, the handbook identifies the need for aerial photographs, land cover vegetation maps, landownership maps, wildlife habitat maps, wildlife movement model data, ecological field data, road kill data and road network data and suggests the use of GIS for identifying habitat linkages and siting wildlife crossings. The handbook also discusses the need to consider topographical features, multiple species use, adjacent land management and the wider corridor network. The handbook notes that as the lifespan of wildlife crossing structures is around 70–80 years, the location and design of the crossings needs to accommodate the changing dynamics of habitat and climatic conditions and their wildlife populations over time.

3.45 The document provides guidance on when to consider each structure type, based on the potential of a site to provide habitat connectivity. For sites with high potential as key habitat linkages at a local or regional scale a landscape bridge is recommended and mixed use crossings should not be used. For sites with low potential (i.e. habitats with human disturbance) overpasses are not recommended, but underpasses should still be considered.

3.46 Clevenger and Ford (2010) provide general details on how wildlife habitat connectivity can be incorporated into transportation projects and how this can be planned. They discuss both project based approaches and system (landscape) level approaches, noting there is a risk that a project level focus may not consider how a crossing structure fits into the larger landscape and regional wildlife corridor network. It is noted that this is a paper is from the US and, as such, species requirements at regional levels differ from the UK in terms of migration. For project based crossings it notes that structures must link to larger functional landscapes and habitat complexes and not lead to ecological “dead-ends”. This requires large spatial scale considerations and should include for potential future land-use changes.

3.47 Another guide produced in the US is Safe Passage, A Guide to Developing Effective Crossings for Carnivores and Wildlife (Ruediger, 2007). This guide lists the key tools for connectivity planning to be; aerial photographs, landownership maps, vegetation maps, topographic maps, wildlife habitat/ range maps and road kill information. The guide details that overpasses are often the most effective means to provide wildlife crossing, although does not detail any data to support this statement. The guide states than an overpass can cost $5million[5] (£3.4 million) or more, but again does not provide any data to support this. In comparison a 13’h x 23’w multi-plate arch style culvert may cost $250,000[5] (£170,000).

3.48 In terms of planning for a bridge, a paper by Ahern *et al.* (2009) considers issues and methods for transdisciplinary planning of combined wildlife and pedestrian highway crossings. This discusses the need to identify the type of wildlife usage, considering individual species from the perspective of road kill, to the requirements of populations and metapopulations[6]. It identifies that, at a population level, issues include maintaining population continuity or providing access to vital habitats required by a population; and, at a metapopulation level, issues include maintaining

[5] http://www.xe.com/ at rate of 1 USD = 0.678760 GBP (13/03/2015)
[6] A metapopulation consists of a group of spatially separated populations of the same species which interact at some level.

gene flow, supporting individuals mixing between populations, and providing sufficient opportunities to recolonize habitat fragments after local extinction events.

3.49 In planning a mixed use bridge, the paper identifies the following aspects for consideration; community planning, cultural landscape issues and health and safety. The paper notes that issues related to the interactions of cultural landscapes and highways include; potential trail linkages, historic preservation, preserving views, architectural design control, and tourism. It details that a mixed use crossing has the potential to complement or detract from cultural landscape character and should be carefully analysed and considered in the planning process. The paper notes that the planning process for a combined wildlife crossing should be transdisciplinary, defined as a collaborative process in which knowledge, information and decision-making responsibility flows between professionals and stakeholders, and vice versa. The paper provides recommendations on how this can be achieved, which includes establishing a diverse steering group and holding public meetings. A flow diagram is provided for identifying if a wildlife crossing is required; this is from the perspective of constructing a crossing across an existing road.

3.50 Ahern also discusses elements to consider as part of the design, including issues surrounding the load of the bridge and the effect this may have on the design, aesthetic considerations and cultural landscape factors. Principal themes and periods of a region's history should be identified to consider how historical and cultural values inform potential locations for a crossing; drawing from relevant literature, archival research, interviews and public meetings.

3.51 A study by Downs and Horner (2011) identifies that 'spatial decision models' can be used to select optimal locations for crossing structures that best enhance habitat connectivity in fragmented landscapes, to help animal movements and reduce traffic mortality rates.

Bridge design

European guidelines

3.52 The COST European handbook (Iuell, B *et al.* 2003) uses the terms landscape and wildlife bridges to describe green bridges. A landscape bridge is defined as one that provides connections at a landscape/ ecosystem level, a wildlife bridge is defined as one that provides connections at a population/ meta-population level, although it is acknowledged that there is a continuum between the two. The handbook notes that due to the cost of overpass construction, they should not be built for one or two target species, but rather the aim should be to connect habitats at an ecosystem level, which requires the simulation of habitats either side of the infrastructure on the bridge. This should take account of local environmental factors such as soil, humidity and light.

3.53 The handbook also provides guidance on locating bridges and gives details on recommended dimensions. In terms of landscape bridges a width of greater than 80m is recommended, to allow the establishment of habitats to provide a connection at an ecosystem level. For wildlife bridges a width between 40-50m is recommended, with a generalisation given that larger mammals require a wider bridge than small vertebrates, but to create the specific habitats that small vertebrates require a wider structure may still be required. It is assumed that this may apply when creating wetland habitat for amphibians. Where the local topography naturally channels animals directly to the structure or the target species are not very sensitive (e.g. roe deer) then the width may be lowered to 20m. A width below 20m is not recommended as although evidence shows that species will still use these bridges, the frequency of use is reduced. In terms of width to length ratio, it is advised that with should be greater than 0.8.

3.54 The handbook covers other design aspects, with recommended soil depths for grass (0.3m), shrubs (0.6m) and trees (1.5m) and planting advice. It advocates the use of plant species native to the local area, and that the local seed bank may be used, from topsoil or a hay cut. In addition to planting, it states that natural establishment can lead to good results.

3.55 The Trans-European Wildlife Networks (TEWN) Project Manual (EuroNatur Foundation 2010) provides case studies from Europe and focuses on Balkan Peninsula and the Carpathian region (Croatia, Slovakia, Poland and Bulgaria). The section of the manual which deals with overpasses states that animals may use local roads as an overpass if there is some space left on each side of the overpass, this recommendeds a minimum width of about 2m for small mammals, and at least 15m for bigger mammals, combined with directing fences to prevent access to the road and to indicate the passage. Important factors for wildlife passage are identified as:

- Appropriate location and density;
- Correct selection of types and parameters for various wildlife species;
- Appropriate arrangement of the passage and its surroundings;
- Maintenance and protection of the crossing structure; and
- Preservation of the ecological function of the landscape on both sides of the road/railway.

3.56 The report also gives a summary of green bridges in Europe and details that widths very from 25m to 80m, with a soil layer of 0.5m to 2m deep, lengths between 30 to 70m and that access slopes may be more than 100m long. The text also comments that green bridges may have artificial screens or earth embankments on both edges to decrease the effect of noise and night lights and some bridges have small water ponds and fences to lead animals along the road to the overpass entrance.

3.57 The report differentiates between wildlife overbridges and green bridges (ecoducts, landscape bridges) and states that green bridges are large structures that allow unobstructed crossing and natural migrations over an infrastructure barrier. In terms of size, the text states that the minimal width is hard to determine but it seems that structures of less than 100m do not serve as real ecoducts. In terms of the finished structure the report details that a green bridge should be overgrown by native vegetation to fit into the landscape without open and exposed spaces for animals; while the crossing and the edges of the bridge should have banks about 1.5m high as visual and sound barrier from the road, with the motorway fence on the ridge of the bank.

3.58 In Germany overpasses can vary in width from 8.5m to 870m, and as guidance soil depths used are around 0.3m for grass, 0.6m for shrubs and 1.5m to 2m for trees (Bank *et al*. 2002).

3.59 Van der Grift *et al*. (2011) provides guidelines for designing mixed use crossings. These guidelines detail that the recreational zone (containing trails and screening measures) should be located on one side of the bridge. Screening/ fencing should be placed between the recreational zone and the nature zone, with a minimum height of 1m. This should be permeable for wildlife, but provide a visual barrier with sufficient vegetation cover to provide cover for passing animals. The width of the bridge should take the minimum width of the natural zone (based on literature, i.e 40-60m) with the additional width of the recreational zone. It is recommended to reserve at least 10m for the recreational zone if it is located immediately adjacent and on the inside of the screening measure at the edge of the overpass; or, if located on the outside of this screening measure, less space – approximately 5m.

3.60 A paper by Georgiiet *et al*. (2011) identified eight aspects that affect green bridge use by wildlife; width, age, vegetation, traffic noise, position and human presence. The use was found to increase according to the width of the bridge. Bridges at forest edges and nearer to canopies were found to be more extensively used (although the difference in use was not statistically significant) than bridges in more open habitats. Animals were found to use the open parts of green bridges more, with data showing that hares, badgers and foxes preferred to walk on gravel areas. This information should be taking into account in the design.

3.61 Bach (2014) provides a summary of a study of 15 crossovers, including nine green bridges for bats, and the findings of this study are then used to provide design recommendations. The paper obtained does not provide any detailed results, but does detail that a higher level of bat activity was recorded on green bridges compared to road bridges; however tunnels showed the greatest activity. The paper also states that the most important factors for a well-built green bridge for bats are to have good guiding structures on the bridge and a good connection to the surroundings. The paper suggests that an optimal green bridge should contain at least a double row of hedges and good connections on both sides to preserve an established flight path.

3.62 Edgar *at al* (2009) discussed the use of the LARCH (Landscape ecological Analysis and Rules for Configuring Habitat) model which can be used to identify bottlenecks where wildlife crossings should be placed. It is a spatially explicit expert-based GIS model that allows for analysis of the configuration and persistence of habitat networks that can lead to viable wildlife populations. LARCH was used in Bulgaria to study the impact of existing and planned transport corridors on the population viability of twelve indicator species. The LARCH study identified sites where de-fragmentation measures may lead to a shift in population viability from non-viable (i.e. population with an extinction probability of >5% in 100 years) to either viable (i.e. population with an extinction probability of 1-5% in 100 years) or highly viable (i.e. population with an extinction probability of <1% in 100 years); and where population viability shifts from viable to highly viable, solely due to constructing wildlife crossing structures. However, on reviewing the data the majority of bottlenecks were identified by experts rather than the LARCH model.

3.63 O'Connor and Green (2011) in a Review of Bat Mitigation in Relation to Highways Severance identify a study by Bach *et al*. (2005) which compared usage by bats of green bridges to road bridges that did not include any specific ecological measures. Results from the study were not statistically analysed but indicated that green bridges had a higher usage rate than road bridges, and that wider green bridges (> 50m) had the highest usage. There were exceptions to this, as bridges differed in connecting habitat and their usage between foraging and commuting (the primary source study is in German and has not been reviewed as part of the literature review).

International

3.64 The Wildlife Crossings Structures Handbook (Clevenger and Huijser 2011) provides design guidelines for structures in terms of dimensions, detail are provided in table 3.3.

Table 3.3: Summary of structure dimensions from the Wildlife Crossing Structure Handbook Design and Evaluation in North America, 2011

Type	Usage	Species	Minimum dimensions	Recommended dimensions
Landscape	Wildlife only	All wildlife species Amphibians (if adapted)	70m	>100m
Wildlife	Wildlife only	Large mammals, High-mobility medium-sized mammals, Low mobility medium-sized mammals, Small mammals, Reptiles, Amphibians (if adapted)	40-50m	50-70m
Mixed Use	Mixed use; Wildlife and human activity	Large mammals, High-mobility medium-sized mammals, Low mobility medium-sized mammals, Small mammals, Reptiles, Amphibians (if adapted)	10m	15-40m
Canopy	Wildlife only	Semi-arboreal mammals	-	-

3.65 The handbook also provides a series of "hot sheets" which provide guidance on the design of each of these structure types. Below is a brief summary of the details each sheet contains that are relevant to green bridge design. These hot sheets should be referred to directly for further details on each bridge type.

Table 3.4: Summary of details contained within the "hot sheets"

Information taken from Wildlife Crossing Structure Handbook Design and Evaluation in North America, 2011

Type	General guidelines	Dimensions	Suggested design details
Landscape	Vegetative composition should be similar to adjacent habitat to facilitate use by largest no. of species. Should be situated at known wildlife corridor	Min width: 70m, recommended 100m. Fence/ berm height: 2.4m Soil depth: 1.5-2m	Be a 'heterogeneous environment' (i.e. diverse in character), combining open areas with shrubs and trees. Use species taxonomically close to existing adjacent trees (note site and environmental conditions may require hardy drought tolerant species). Trees and dense shrubs should be

Type	General guidelines	Dimensions	Suggested design details
	with minimal human disturbance and closed to public. Maximise continuity of native soils adjacent to and on bridge. Reduce light and noise by using earth berms, solid walls and dense vegetation.		planted on edges of structure to provide cover. Centre section to be left open with low lying or herbaceous vegetation. Drainage should slope slightly from central longitudinal axis to sides. Amphibian habitat can be created as stepping stones or isolated ponds. Vegetation at edges should guide wildlife to the entrance of the structure. Best sited in areas bordered by elevated terrain, enabling approach ramps and surface of structure to be at the same level. Large boulders can be used to block vehicle passage. Wildlife fencing is most effective way to guide wildlife to the structure. Mechanically stabilized earth walls can substitute fencing and are less visible. During first few years may need to irrigate vegetation. Bridge should be monitored for human use that may affect wildlife use.
Wildlife	Same as landscape bridge but narrower so the ability to restore habitats is more limited.	Minimum width: 40-50m Recommended width: 50-70m Fence/ berm height: 2.4m Soil depth: 1.5-2.4m	Design similar to landscape bridge. Parabolic arch design is better for wildlife approaching ramps, but higher in cost than rectangular or straight edged construction. Vegetate with native trees, shrubs, grasses (may require hardy/ drought tolerant species). Centre should be left open with low lying or herbaceous vegetation. Use shrubs, woody debris and rock piles to create microhabitats. Amphibian habitat can be created as stepping stones or isolated ponds. Best sited in areas bordered by elevated terrain, enabling approach ramps and surface of structure to be at the same level. Wildlife fencing is most effective way to guide wildlife to the structure. Mechanically stabilized earth walls can substitute fencing and are less visible. During first few years may need to irrigate vegetation. Bridge should be monitoring for human use that may affect wildlife use.

Type	General guidelines	Dimensions	Suggested design details
Mixed Use	Design is generally narrower.[7] Generally near human use areas. Human use should be confined to one side, vegetation can be used to shield human use from wildlife. Maximize continuity of native soils adjacent to and on overpass. Reduce light and noise by using earth berms, solid walls and dense vegetation.	Minimum width: 10m Recommended width: 15-25m Fence/ berm height: 2.4m Soil depth: 0.5m-1.0m	If has one lane road (gravel or paved), sides should be vegetated. Interface between human lane and wildlife pathway should be as natural as possible. Plant species to match or be taxonomically close to existing vegetation. Best sited in areas bordered by elevated terrain, enabling approach ramps and surface of structure to be at the same level. Large boulders can be used to block vehicle passage. Wildlife fencing is most effective way to guide wildlife to the structure and to prevent intrusions onto the right of way. During first few years may need to irrigate vegetation.

3.66 Safe Passage (Ruediger, 2007) provides recommended dimensions for bridges depending on target species. However, with the exception of deer, the target species are not present in the UK and as such this data is not transferable. A width of 75 feet (22.86m) is recommended for deer.

3.67 The U.S Department of Transportation, Federal Highway Administration (2008) recommends a width of at least 50-70m if large species are involved that are sensitive to human disturbance, or if multiple habitats are to be provided. Further rationale for this width is provided by Pfister (2002) and others, who showed that the use of wildlife overpasses increases linearly until a width of about 50m at which point the increase in wildlife use starts to taper off (the primary source by Pfister is in German and has not been reviewed as part of this study).

3.68 Given the number of texts that provide recommendations or details on bridge width, a summary is provided in table 3.5.

Table 3.5: Summary of recommended bridge widths

Bridge type	Width	Source
Landscape	>80m	Iuell, B *et al.* (2003)
Landscape	70-100m	Clevenger and Huijser (2011)
Landscape	100m	EuroNatur Foundation (2010)
Wildlife	40-50m	Iuell, B *et al.* (2003)
Wildlife	40-50m	Clevenger and Huijser (2011)
Wildlife	50-70m	U.S Department of Transportation – Federal Highway Administration (2008)

[7] It is noted that this guidance differs from the European guidance on mixed use bridges which states that mixed use bridges should take the width required for wildlife passage (e.g 40m, but target species dependant) and then add on the width of the human use.

Bridge type	Width	Source
Wildlife	25-80m	EuroNatur Foundation (2010)
Mixed use	15-25m	Clevenger and Huijser (2011)
Mixed use	Minimum width of the natural zone (based on literature, i.e 40-60m) with the additional width of the recreational zone (~10m)	Van der Grift *et al.* (2011)

3.69 In terms of converting a grey bridge to a green bridge, Dolan (2003) notes that in Holland two 'land traffic flyovers' have been modified by closing one lane and covering it with soil for vegetation to create a green bridge running alongside a traffic bridge.

3.70 From the information reviewed a summary of key design features is provided in table 3.6 below.

Table 3.6: Summary of design information obtained for known green bridges

	Soil depth	Dimensions	Planting Details	Access ramps	Other details
A21 Scotney Castle	Minimum 0.6m to 1.5m (using locally won subsoils and topsoils)	Deck span 29m (narrowest point N/S) x 55m (widest on east side) x 43m (E/W). Total length 92m (48m in centre).	Old trees stumps and sections of moss bank. Continuous thicket of varied width between 3m and 10m. Species managed to a 5m growth height.	18m and 25m run ins	Drive across is 3.5m wide and 33m long. Arrangement in ground to east and west of desk to collect rainwater and to deliver into soil layers and a ribbed central reservoir.
Groene Would	0.5m topsoil on bridge, 1m on access ramps	50m wide x 65m long	No details	110m and 85m long, at gradient ratio of 1:14 and 1:10	Soil placed to maintain original sequence of soil layers. 2.5m high embankments along edge of structure to reduced light and noise. Controllable ground water level on top.
Zanderji Crailoo		50m wide x 300m long	Mosaic of shrubs, heath, grassland, open sand, tree stumps and a loamy ditch.		Mixed use

Slabroek		15m wide x 100m long	Mosaic of grassland, ruderals and a loamy ditch		Mixed use
Kooywijk		Hourglass shape – 80m wide- 50m wide x 150m	Planted with trees and shrubs and open vegetation in centre		
Kikbeek		70m x 40m at narrowest point	Wetland habitat and pond on bridge		
A87 French bridges	0.5m at narrowest point	12m at narrowest point	Pond at one end		
Aspiholz	Minimum 1.5m		Small ponds on bridge		
Compton	30cm to 1.3m	Hourglass shape, 70m long, 20m wide to 15m in centre	Planted at density of 70 shrubs and 6 trees per $100m^2$		

Monitoring

3.71 Following green bridge construction, several papers advocate monitoring studies to assess their use. Guzvica *et al*. (2014) studied different methods for monitoring green bridges for wildlife uses. In summary the paper details that animal activity on the wildlife crossings can be monitored using a range of methods including genetic sampling (using hair/DNA snagging devices), radio and satellite telemetry tracking, road-kill or vehicle collision data, snow tracking, tracking beds, tracking plates, digital camera and video monitoring, active and passive infrared (IR) tracking systems. Of these track-pads, digital camera traps and infrared (IR) trail monitoring systems offer an indirect approach. The study results found camera traps to be highly reliable (although noting they may not capture fast moving species) and track pads were reliable, although work best using a high proportion of fine grained material. The study recommended a combination of methods.

3.72 Monitoring of the Banff overbridges suggests that wildlife can habituate[8] to some types of disturbance (e.g., vehicle traffic) but remain sensitive to others (e.g., foot traffic at the wildlife crossings). The adaptive response by wildlife to use overpasses supports the need for long-term monitoring (e.g. greater than 4 years) to fully understand the effectiveness of mitigation (Barrueto *et al*. 2014).

3.73 Corlatti (2009) reviews data gathered on the effectiveness of green bridges in terms of their ability to provide connectivity and prevent genetic isolation. This paper identifies a lack of sufficient evidence due to the nature of the studies undertaken on overpasses to date. This study identifies the need for before and after comparisons and long term monitoring projects with fieldwork and genetic analysis to assess if green bridges prevent genetic isolation.

[8] become accustomed to

Purposes of green bridges (i.e. wildlife, habitats, landscape, access, ecosystem services) and evidence demonstrating their usage

3.74 From the majority of the literature reviewed, there was very little information given about the original aim of a green bridge or the specific reason for its construction. The majority of texts related to the wildlife function of green bridges, and for the bridge examples found this appeared to be their main purpose. A number of mixed use bridges were also identified, which clearly had an amenity purpose, although details on this purpose was limited. Only one bridge was clearly identified as being built for historical landscape purposes, that being the A21 Scotney Castle Bridge in Kent. The Mile End Bridge in London was also built for amenity and landscape purposes to join up fragments of an urban park.

3.75 Of the bridges identified, the bridge structure at Mile End provides a wider ecosystem service in terms of water recycling. Rainwater runs off the bridge and down into tanks on either side, it is then pumped back onto the bridge and recycled. The A21 Scotney Castle bridge also has a catchment collection system for rainwater, using the ground to the east and west of the bridge to collect local rainwater runoff and deliver this into a ribbed central reservoir on the land bridge. It is considered likely that many of the other green bridges identified use a water collection system to provide irrigation for the vegetation planted on the bridge. Whilst this does provide a wider ecosystem service in terms of water management, it is a secondary function of the bridge allowing the vegetation and habitats to survive.

3.76 In terms of ecosystem services, the UK National Ecosystem Services Assessment identifies the following types of services; provisioning services regulating services, supporting services and cultural services. Table 3.7 provides details of each of these service types. It is noted that there are no specific details in the literature discussing green bridges and the ecosystem services they can provide; however based on the information reviewed it is considered that green bridges provide those services highlighted in green within the table.

Table 3.7: Ecosystem Services

Provisioning services:	Regulating services:	Supporting services:	Cultural services:
Food (crops livestock and fish) Fibre Fresh water Genetic resources **Trees, standing vegetation and peat** **Wild species diversity**	Climate regulation Noise regulation **Pollination** Disease and pest regulation Regulation of water, air and soil quality	Soil formation Nutrient cycling **Water cycling** Primary production	Spiritual or religious enrichment **Cultural heritage** **Recreation and tourism** **Aesthetic experience**

3.77 Based on the information in the case studies found, an assessment of the ecosystem services that these bridges are likely to make is provided below in table 3.8. This is based on a review of the literature relating to these bridges, but it is noted that within this literature no specific references to ecosystem services are made.

Table 3.8: Examples of bridges providing ecosystem services

Ecosystem service	Bridges
Pollination	No details are provided in the literature regarding this ecosystem service and green bridges, however it is considered likely that all green bridges planted with vegetation will provide some plants that can be used by pollinating insects.

Ecosystem service	Bridges
Trees, standing vegetation and peat	Both trees and standing vegetation are features of all of the green bridge case studies identified above.
Water cycling	Mile End – here rainwater runs off the bridge into tanks either side and then is pumped back onto the bridge and recycled. Groene Woud – water on this bridge is pumped to the top and then cascades down in series of pools which are used by amphibians. Kikbeek – pools have been created on this bridge to collect rainwater, these pools are then used by wetland species. Wamback Ecoduct – water management of the bridge is designed with climate change resilience. Concrete ridges are glued to the deck of the green bridge which form basins to retain water available for drought periods. The drainage system may also be used in a reversed fashion, to supplement the green bridge with water.
Cultural heritage	A21 Scotney Castle – here the line of a historic drive was maintained through the installation of the green bridge.
Recreation and tourism	Mile End, A21 Scotney Bridge, Zanderji Crailoo, Slabroek – all of these bridges are mixed use bridges.
Aesthetic experience	A21 Scotney Castle – here the historic drive way was maintained to provide an aesthetic experience. Mile End Bridge – here the bridge is used to link up fragments of the Mile End Park to improve the users enjoyment of the park.
Wild species diversity	A21 Scotney Castle, Terlet, Groene Woud, Zanderji Crailoo, Slabroek, Kikbeek, Aspiholz, Banff, Compon Road, Dedin. Specific details of species use on the bridge structures identified are given above in table 3.2.

Costs associated with building green bridges

3.78 Details on costings were limited with only broad costings available for a small number of bridges. Also, it cannot be stated with certainty that the cost is purely that of the bridge structure or the wider road scheme. The information gathered does not allow for any accurate cost comparisons of different structure types and insufficient detail was found to provide any meaningful analysis. Table 3.9 provides a summary of the known bridge costs and details of these structures.

Table 3.9: Costs of green bridges

Bridge name, location	Cost[9]	Details on structure	Source
Mile End, UK	£5,800,000	25 m width of landscaped parkland. Rainwater runs off the bridge and down into tanks on either side. It is then pumped back onto it and recycled.	http://www.czwg.com/works/green-bridge

[9] Exchange rate calculated using www.xe.com on 27/02/15 rate of 1 GBP = 1.37209 EUR, 1 USD = 0.678844 GBP

Bridge name, location	Cost[9]	Details on structure	Source
Kootwijk, Netherlands	£2,187,621 (3 million euros)	150m long, hour glass shape structure, 80m wide at its entrances and 30m wide in the middle. 1.5m walls planted with trees and shrubs.	http://www.iees.ch/cs/cs_3.html
Laarder Hoogt, Netherlands	£8,385,588 (11.5 million euros)	Not yet constructed. Two bridges, one 70x40m and one 40x30m	http://nl.wikipedia.org/wiki/Ecoduct
Natuurburg Zeepoort	£4,008,493 (5.5 million euros)	Scheduled for construction in 2016	http://nl.wikipedia.org/wiki/Ecoduct
Zanderij Crailio	£10,569,588 (14.75 million euros)	300m long, 50m wide	Van der Grift *et al.* (2010) Van der Grift *et al.* (2011)
Aspiholz and Fuchswies, Switzerland	5% of project cost	Concrete of 0.4 m and a minimum soil layer of 1.5 m. Native bushes were planted only at critical spots and the rest has been left for natural succession.	TWEN manual (2010)
A556, Cheshire, UK	Estimated cost of 'greening' the access bridge £366,000, with total bridge cost estimated at £1.14 million.	Not yet constructed. Proposal is for a 11m green bridge, with a farm track and a 7m green verge.	Highways England (2015)

3.79 The US Department of Transport Wildlife Vehicle Collison Reduction Study (Huijser *et al*. 2008) provides some details on the costs of green bridges along with details on direct and indirect benefits of wildlife crossings. In terms of direct benefits the study states that wildlife overpasses increase the effectiveness of wildlife fencing or other barriers alongside the road in reducing collisions, as if there are no safe crossing structures animals are more likely to break through the wildlife fencing (or other barrier) and thereby reduce the effectiveness of the wildlife fencing. In terms of indirect benefits it states that wildlife crossings can mitigate the habitat fragmentation effects of roads and maintain viable populations over the long term. Example costs for overpasses are given, citing that a proposed overpass across Montana Highway 83 near Salmon Lake (two-lane road) is estimated to cost $1,500,000–2,400,000 (£1million - £1.6million)[9] and the costs for seven wildlife overpasses in the Netherlands ranged between €1,400,000 and €5,600,000 (£1million – £4million).

Alternative options to green bridges

3.80 The COST handbook (2003) details that modifying proposed designs is often the most appropriate way to reduce the barrier effect of existing roads and railway lines. This approach can be less costly and can significantly increase the permeability of the infrastructure.

3.81 The COST handbook looks at the two purposes of wildlife crossings with respect to an emphasis on maintaining linkages, or an emphasis on reducing mortality. Depending on the aim of the crossing, different solutions to green bridges may be more applicable, with a flow diagram provided to identify the most suitable solution.

3.82 Where the aim is to provide links across a road or railway then the following alternative options to green bridges are given:

- Modified bridges/ Multifunctional overpasses;
- Viaducts and river crossings;
- Underpasses for medium-sized and large animals;
- Underpasses for small animals;
- Modified and multifunctional underpasses;
- Modified culverts;
- Fish passages; and
- Amphibian tunnels.

3.83 Where the aim is to reduce species mortality then the following alternative options to green bridges are given:

- Fences;
- Artificial deterrents;
- Warning signs/ warning systems with sensors;
- Clearing vegetation/ Planting vegetation;
- Noise barriers;
- Adaptation of the kerb;
- Escape ramps from drains;
- Width of road;
- Artificial light; and
- Fauna exits in waterways.

3.84 The report notes that road bridges or culverts are mostly not used by animals to cross a road or railway line, because they don't fulfil the requirements for more demanding species. However, if the demands of animals are taken into account, these existing structures can often be adapted to serve as fauna passages. For viaducts and other large structures, often little adaptation is needed for the structures to be a genuine alternative to specific fauna passages.

3.85 The handbook details that modified structures can help to increase the permeability of infrastructure at little additional cost, taking the design principles relating to specific fauna passages and applying them to modified and joint-use passages, for example; using larger dimensions, separating the flow of animals and humans, providing shelter for animals and lowering the amount of traffic flow at certain times. In making such modifications, both the ecological and engineering requirements have to be known and possible conflicts identified.

3.86 Bank *et al*. (2002) identifies non-structural methods which can be a cost effective way of reducing wildlife mortality. These are listed as olfactory repellents, road lighting, population control and habitat modification, for example cutting a 3-10m strip of vegetation along the road to keep animals away from the infrastructure and increase driver visibility while planting cover to direct animals to available crossings.

3.87 The Trans-European Wildlife Networks (TEWN) Project Manual (EuroNatur Foundation 2010) identifies three other types of technical solutions for animal crossing structures across traffic routes, in addition to green bridges:

- Tunnel passages for amphibians;
- Tubes and underground canals for small mammals and other vertebrates; and
- Underpasses and overpasses for animals.

3.88 MacDonald *et al*. (2004) details that wildlife overpasses may accommodate more species of wildlife than underpasses as they are less confining, quieter, maintain ambient environmental conditions, and because the structure itself can serve as intervening habitat for small animals otherwise unlikely to move long distances. By contrast, underpasses are likely to be better suited for animals that prefer cover.

3.89 In terms of warning signs, the 2014 IENE conference included a discussion on the use of animal-activated electronic wildlife-crossing-system. The conference proceedings discuss the use of systems which detect animals in a defined area at the roadside and will then warn the drivers by lightening up. Six sights in Germany with such systems were looked at and in one year more than 1,700 crossing were recorded. Species identified in video analysis included fallow deer (which accounted for the majority), roe deer, fox, hare, badger and wild boar. During this period only five ungulate[10]-vehicle-collisions occurred within the crossing areas, although no information is provided for collisions prior to the use of the system. It does note that such systems are relatively inexpensive, can be integrated into existing deer fences and will only warn drivers if there is a real risk that wild animals might be on the road.

[10] Animals with hoofs

4 Summary of findings

4.1 The majority of the literature related to bridge crossings over road, with the exception of two bridges identified in the Netherlands that crossed over both road and rail. It is, however, considered that the concepts for green bridges over roads could be similarly applied over railway lines. However it is noted that positioning would need to take account of aspects associated with railway infrastructure such as overhead power lines which could have health and safety implications.

4.2 The review identified a total of 56 green bridges currently in existence (this is unlikely to be a comprehensive list), the majority of which were located in the Netherlands. Of the structures in existence, the majority appeared to have been constructed for wildlife purposes to reduce fragmentation impacts. This assumption is primarily based on the study data reviewed, which focuses on wildlife use. It is of note that the only structures identified which were designed with a primary amenity or historical landscape purposes were located within the UK. The UK also provided examples of farm bridges over roads being designed with a green verge, i.e., converting a grey bridge to a green bridge. This is not to say that those bridges identified in Europe with mixed usage were not primarily designed for an amenity purpose, with a secondary wildlife goal, but the literature reviewed focuses on the wildlife use of these structures rather than the human use. Where design information has been found for mixed use bridges, this also largely focuses on tailoring the design for wildlife use and ensuring that the use by humans does not conflict with the wildlife function of the structure. No examples in the literature were found with respect to specific approaches or designs for retrofitting existing grey bridges. No distinction was found in the literature with respect to bridges in urban and rural settings.

4.3 Within the UK, the google search only identified the green bridges at Scotney Bridge and Mile End, however a trawl for images, also identified further green bridges in Weymouth. These were not identified through the main literature search due to a lack of scientific literature on them. This highlights that fact that due to a lack of monitoring data and studies on green bridges there may be examples of green bridges that were not identified through this study.

4.4 The majority of literature focuses around wildlife crossings, and the terms wildlife bridge and wildlife crossing structure are commonly used rather the term green bridge. Other language terms commonly used are landscape bridge and ecoduct. It is noted that the term landscape bridge does not appear to relate to a bridge constructed for aesthetic landscape purposes, but the term landscape is used to create a picture of wider landscape scale connectivity. Whilst green bridge is a term more commonly used within the UK, it is not regularly used in European or international literature.

4.5 Limited information was found on the cost of green bridges, but of the costs found they ranged from around £1.1 million to £10 million. One example was found where the cost of 'greening' a grey bridge was estimated to be in the order of £366,000. However, it is largely unknown what percentage of this is of the overall project costs, and also if the data found provides the cost of the green bridge as a standalone element or if this includes other aspects.

4.6 Within the literature several guidance documents on planning a green bridge, along with recommendations of design were found. From these and from the case studies identified, a number of key design principles can be identified. In general from the literature it is clear that when planning a green bridge, this should not be done in isolation, but should form part of a wider mitigation strategy. Particularly of relevance for long linear schemes a green bridge may be used in combination with underpasses, tunnels and ledges to increase the overall permeability of the landscape around the road or railway to wildlife.

4.7 In terms of planning for a green bridge, it is recommended that a communication plan is produced to ensure engagement with stakeholders. Data gathering is also a key part of the process and should be used to select the best location to position a bridge. Within the literature the following data is recommended:

- Aerial photography;
- Landownership maps and adjacent land management;
- Potential future changes in land management;
- Phase 1 habitat maps (and where appropriate National Vegetation Classification maps);
- Species survey data;
- Road kill data;
- Topography data;
- Geology data;
- Flood risk zone;
- Utilities; and
- Amenity use.

4.8 In terms of specific design considerations the overall function of the green bridge will drive most of the decisions, as the size of the structure must be determined based on the requirements of the expected species use and need for separation between wildlife and human access. Specific design considerations will need to take account of the following:

- Shape of green bridge, e.g. hourglass or straight;
- Width;
- Length;
- Suitable vegetation to be in keeping with local landscape and habitats;
- Soil depth;
- Screening and fencing;
- Target species;
- Other users (pedestrians, equestrian, cyclists); and
- Engineering considerations.

4.9 In summary from the literature the design principals detailed below have been identified. These principles have been supplemented with additional best practice guidance taken from Natural England's Mosaic Approach: Managing Habitats for Species (B2020-009). In addition to the design, the future monitoring and management of the structure should also be considered.

Width and length

4.10 Bridges with aims to achieve connections at a landscape/ ecosystem level should be over 80m in width. Bridges which aim to achieve connections for species at a population level should be around 50m (published guidance recommendations range from 25m-80m, with an average of 50m). Bridges below 20m in width are not recommended as frequency of use has been found to be lower. A width to length ratio over 0.8 is recommended.

Habitats

4.11 The vegetation should complement the habitats either side of the structure, using plant species native to the local area. In terms of seeding, options including natural establishment and use of the local seed bank (from topsoil or hay cutting) should be considered. Hedge structures can be used to provide a guiding line. When targeting small vertebrates and invertebrates then the aim should be to resemble the habitat adjacent to the bridge as far as is possible. The planting should be designed to create a mosaic with tree and shrub planting at the end and the middle section left open with grasses and smaller vegetation. Depending on the species that may use the bridge it may also be appropriate to leave patches of bare ground or gravel. If such micro-habitats are created then within the management plan measures should be included to ensure that these remain open areas rather than allowing colonisation by vegetation. Brash, tree stumps and piles of rubble may also be used to create refuges for small animals.

4.12 To account for the time it takes for vegetation to establish, other features may be provided to provide cover following bridge construction. This may include tree stumps, piles of brash and stones (it may be possible to use leftover construction materials for this purpose).

4.13 Water features can be created on bridges to provide “stepping stones” for species using the bridge and can also provide a habitat in their own right. These have been successfully created on the continent and used by a number of amphibian species and dragonflies. This can be achieved by creating a series of wet depressions across the bridge itself, with deeper ponds either side. Water recycling can be used to transport rain water run off to the top of the bridge, which can then run down the bridge through a series of small pools/ wet depressions. It is noted that the wet habitats on the bridge may not contain water at all times, but will be dependent on rain water.

Soil

4.14 The amount of soil used will affect the bridge load. It may be possible to achieve deeper depths at the edges of the bridge with shallow depths in the centre. The variation in soil depths can be used to create a mosaic of vegetation. As a guide the following depths are recommended; Grass and herbs 0.3m, shrubs 0.6m and trees 1.5m.

Screening and fencing

4.15 Screens can be used to reduce disturbance on the bridge from light and noise. These should be located as close to the outer edge of the bridge as possible to maximise the amount of the bridge available for use.

4.16 On wider bridges, hedges on mounds may be used to provide screening. Where earth mounds are used these should be designed to extend along the transport infrastructure.

4.17 Side screens should be around 2m in height and should be connected into any other screening present along the infrastructure (such as noise barriers). If screens are not used then fencing must be placed along the outer edge of the bridge and fencing on the bridge must tie into fencing along the infrastructure.

Target species

4.18 The target species for use may be critical in determining the width, design and vegetation. For example amphibians may require a “wet zone” across the bridge. For larger animals, the width and location can be more important than the vegetation, but for smaller animals such as bats the vegetation is more important.

Other Users (Mixed use)

4.19 In general the literature focuses on bridges with a wildlife function and as such guidance recommends avoiding mixed use structures where wildlife use is the primary objective. However in two studies on mixed use bridges, where wildlife use was investigated, evidence of species use was recorded and as such it is considered in certain circumstances, mixed use bridges may be appropriate.

4.20 To determine the width of a mixed use bridge, the width of any paths should be added to the width required for faunal passage to give the total width of the bridge.

4.21 For bridges, where the main objective is species use (particularly for species sensitive to disturbance) it is recommended that any paths used should be positioned on an outer edge to ensure the width of the natural area is retained. Where the main function is to provide access, with a secondary biodiversity benefit, then it may be appropriate to consider the use of paths in other areas of the bridge

4.22 If greening a low use road bridge (e.g. an accommodation overbridge), a vegetated strip along one edge may be used. This should have a minimum width of 1m, with soil of around 0.3m. The strip may be planted or left to naturally vegetate, although it is important that a management plan is in place to ensure that the verge is maintained.

Ecosystem service benefits

4.23 In designing a green bridge consideration could also be given to what ecosystem services the structure can provide. Although this is not implicitly detailed in the literature from the functions that green bridges can provide, this study has identified a number of ecosystem services which could be linked to green bridges. For most bridges, if designed for wildlife purposes or with a secondary wildlife function, then the bridge will naturally provide the function of wild species diversity. Examples of other ecosystem services that may be provided include the use of plant species with high nectar sources to provide a resource for pollinating insects; this may be achieved through planting a wildflower meadow mix. Consideration should be given to sourcing a local seed mix from a local meadow crop, or leaving the site to reseed naturally.

4.24 The method of drainage should also consider water recycling to irrigate the bridge structure. This may also be used to provide resilience to climate change, for example by using basins within the bridge deck to retain water for use in drought periods.

4.25 Mixed use bridges and those that are designed to maintain cultural and recreational links will provide cultural heritage, recreational and tourism services. If appropriately landscaped such structures should also provide an aesthetic experience and the users viewpoint should be considered during the design process.

Engineering considerations

4.26 Load and drainage are the main engineering aspects which will influence the design of the bridge in terms of what vegetation it can support and as such should be considered at the initial design stage. The build materials will also affect the aesthetics of the bridge and how well it merges into the surrounding landscape.

Other key considerations

4.27 Costs can also be a key factor. These can be reduced or minimised by decreasing the load, span, and/or width of the structure. Shorter spans can be obtained through the provision of intermediate supports, though this can interfere with road safety and aesthetic concerns. The foundations for the structure have a significant impact on cost and requirements are related to soil conditions and topography at the site. It is important to note here, that the design is not altered to the extent that the bridge no longer achieves its original project aims. Also when considering costs, the wider benefits should be taken into account. For example a mixed use bridge may deliver multiple benefits for wildlife and public access.

4.28 Other considerations may be required, for example with respect to health and safety and on-going maintenance. For example, the location of tree planting above a railway may need to take account of leaf fall onto the tracks. Vegetation such as leaves on the line, particularly in the autumn months can lead to significant delays on the rail network by causing adhesion and track circuit problems (Natural England 2014).

Monitoring

4.29 A monitoring plan should be developed which will help assess the effectiveness of the green bridge. The nature of the plan will be determined from the original aims of the green bridge and the monitoring should look to establish if the aims have been met. The level of survey undertaken will be dependent on those aims.

4.30 For example for a bridge which has been developed for species mammal use, it may be appropriate to install camera traps on the bridge as these have found to be a successful method of monitoring green bridges. Where habitat creation has been undertaken, then botanical surveys should be undertaken.

4.31 It is important that long term monitoring is undertaken as species use may increase following a period of familiarisation, with this in mind a typical monitoring programme may survey the bridge annually for years 1-3, then year 5 and year 10 following construction.

4.32 Any misuse of the bridge identified during monitoring should be reported and if required recommendations fed into the maintenance plan to prevent further misuse.

Maintenance

4.33 A detailed maintenance plan should be developed; this should tie into the monitoring, making changes where necessary if issues are picked up during the monitoring.

4.34 The responsibility for maintenance should be agreed from the project outset. This is especially important when the organisation has not been involved in the planning process. It is important that they are aware of the purpose of the bridge along with the maintenance plan.

4.35 Maintenance should include inspection of the bridge drainage to ensure if it remains functional.

Objectives

4.36 Looking at the main objects of the literature review the following has been found:

Objective 1

4.37 From the data reviewed there is evidence of wildlife use across a range of species groups on a large number of bridges (of the 53 bridges reviewed the majority demonstrated wildlife use), and this indicates that they are mitigating the effects of ecological fragmentation. However it should be noted that very few studies undertake comparison of pre, during and post construction crossings and therefore in the main, conclusions are based on post construction use alone. Further research is therefore recommended to determine effectiveness of green bridges at the local scale using pre, during and post construction data, with the establishment of clear criteria for determining effectiveness for specific species. It is also noted that most of the evidence currently recorded on green bridge use does not evaluate effectiveness at a population level. For a green bridge to be truly effective at minimising the barrier effect of transport infrastructure it must be used sufficiently by species to preserve population size and viability. Only one study was found that reviewed genetic connectivity, which found that the crossing structures over and under the Trans Canadian Highway allow sufficient gene flow to prevent genetic isolation in bears. It is noted here that while two wildlife overpasses are present, a number of underpasses are also used and as such it is a combination of wildlife crossing types which allow this gene flow. Further research on the effectiveness of green bridges at the population level is also recommended.

4.38 In terms of measuring the effectiveness in addressing severance to landscape and access, limited data was found. Studies on the Zanderjo Cariloo ecoduct recorded use by 500 people/ day, and while this demonstrates a clear use, no data was presented on activity before the bridge construction to assess any changes in this use. Both the A21 Scotney Bridge, within the High Weald AONB, and Mile End structures were identified as bridges built to address landscape and access severance but no specific studies were found to demonstrate how successful they have been in delivering their original aims. However, from the 'grey literature' available there is much to suggest that Scotney Bridge has achieved its original objectives and functions well.

Objective 2

4.39 The second objective was to assess if green bridges were effective in providing habitats in their own right. Whilst the majority of literature focused on faunal use, information was also found relating to habitats which suggests that green bridges can function in their own right as small scale mosaics in a wider landscape. Evidence has been recorded to confirm amphibian and dragonfly use of ponds on green bridge structures, this demonstrating that these are functioning habitats (Van der Grift *et al*. (2010), Lambrechts 2010 and 2008). Vegetation studies of the Compton bridge in Australia found that the structure of the vegetation closely resembles the dense understory of the surrounding subtropical eucalyptus forest and was similar in species richness (Jones 2013).

Objective 3

4.40 The third objective was to assess the effectiveness of green bridges to deliver wider ecosystem services. There was very little information within the literature regarding potential wider ecosystem services of green bridges. With the exception of pollination the literature did provide evidence to demonstrate bridges can provide ecosystem services, however use by invertebrates has been recorded and as such it is assumed they can be used by pollinators. For example, of the bridges identified, the bridge structure at Mile End provides a wider ecosystem service in terms of water recycling. Rainwater runs off the bridge and down into tanks on either side, it is then pumped back onto the bridge and recycled.

4.41 In summary it is considered that green bridges can contribute to the following ecosystem services: pollination, trees and standing vegetation, water cycling, cultural heritage, recreation and tourism, aesthetic experience and wild species diversity. Table 4.1 provides a summary of those bridges which are considered to provide these services.

Table 4.1: Bridge examples which are considered to provide ecosystem services

Ecosystem service	Bridges
Pollination	It is likely that all green bridges planted with vegetation will provide some level plants that can be used by pollinating insects.
Trees, standing vegetation	In the majority of examples identified, trees and standing vegetation are present on the bridges.
Water cycling	Mile End, Groene Woud, Kikbeek and Wambach Ecoduct.
Cultural heritage	A21 Scotney Castle.
Recreation and tourism	Mile End, Zanderji Crailoo and Slabroek.
Aesthetic experience	A21 Scotney Castle and Mile End Bridge.
Wild species diversity	A21 Scotney Castle, Terlet, Groene Woud, Zanderji Crailoo, Slabroek, Kikbeek, Aspiholz, Banff, Compon Road and Dedin. Specific details of species use on these bridge structures are given above in table 3.2 above.

5 Recommendations

5.1 From the literature review a number of recommendations emerge:

- The literature demonstrates that green bridges are used by a wide range of species groups and can provide biodiversity benefits while helping to mitigate against ecological fragmentation. It is therefore recommended that green bridges are considered as part of the mitigation design for infrastructure schemes.
- It is noted however that very few studies undertake include a comparison of pre, during and post construction crossings and therefore in the main, conclusions are based on post construction use alone. It is therefore recommended that a best practice protocol is developed for green bridge monitoring, whereby the aims of the green bridge are clearly defined at the outset of the project and a replicable methodology for pre, during and post construction monitoring is developed, with criteria defined for effectiveness of the structure in relation to the aims.
- Given the number of green bridges (ecoducts) constructed in the Netherlands and the level of research that has been undertaken on these structures (many articles have been produced in Dutch), it is recommended that a visit (by representatives from Natural England) is made to the Netherlands to view these structures and discuss with their designers and those who study them the key aspects to consider in green bridge design. This would allow information to be gathered on what they have learnt through over 20 years of green bridge construction. Following on from this, connections should be made with those in the Netherlands designing and constructing green bridges to ensure that the UK benefits from the extensive experience that the Dutch have.
- Following on from the recommendation above, a number of foreign language articles were identified, including monitoring studies on Dutch bridges. It is recommended that these articles are translated and reviewed. Any information found, could be summarised as an Addendum to this report. Additionally it would be useful to investigate if any of the green bridges constructed around the world have been done so for landscape and access purposes (either alone or in combination with wildlife goals). This may be done by reviewing the list of structures identified within this report and searching to determine if these are located within any protected landscapes.
- Based on this literature review and the design criteria identified its recommended that a design guide is produced. This design guide could be used for key organisations such as the Highways England, Network Rail and local authorities when planning major new infrastructure projects. The guide could also be used on projects where an ability to provide biodiversity, landscape and access benefits within the existing infrastructure has been identified.
- The information identified within this literature review may also be used by other agencies when producing literature on ways to "green" current infrastructure and meet biodiversity targets as well as to provide details on green bridges as a mitigation techniques. For example there may be opportunities to apply information from this literature review in practical guidance, for example contributing to Design Manual for Roads and Bridges. It may help to inform use of the environment funds designated as part of the Roads Investment Strategy for actions above and beyond business as usual to help Highways England '*invest in retrofitting measures to improve the existing road network as well as maximising the opportunities offered by new road schemes to deliver additional improvements.'*
- The review found a number of examples of mixed use bridges, but few studies that specifically monitored their effectiveness for both access and wildlife connectivity. From the literature reviewed there is some evidence that green bridges can provide benefits for both people and wildlife, but further work is needed to develop the evidence base. Different approaches may be required depending on whether access, landscape or ecological connectivity is the principal aim. Additional information may be found if foreign papers are reviewed, but it is also recommended that for any mixed use bridges constructed a clear monitoring plan is developed to develop a

greater understanding of the effectiveness of mixed use. The literature on multiple use linear ‘greenways’ may provide further relevant transferable information.

- Limited information was found regarding the costs of green bridge structures. It is recommended that further research is undertaken to review the cost effectiveness of green bridges against other mitigation measures. This should take into account wider benefits that both green bridges and other measures can provide.
- Limited information was found on the effectiveness of green bridges for addressing landscape severance, but grey literature indicates that if designed sensitively green bridges can help to meet local landscape objectives. We would recommend that further studies are undertaken to develop the evidence base. This study did not find any literature relating to the visual impacts of green bridges and further studies are recommended to establish the evidence in relation to this.
- The information within this review could be supplemented by investigating what additional green infrastructure practices may be applicable to bridges. For example approaches used on green roofs and green walls may be transferable to bridges. This information may be particularly relevant when considering options to retrofit a grey bridge with biodiversity enhancements. It is noted that very little design information was found within this review regarding retrofitting grey bridges to create green bridges and this should be explored further.
- Due to a lack of monitoring data and studies on green bridges there may be examples of green bridges that were not identified through this study. It is recommended that monitoring of existing green bridges is undertaken in the UK to determine their usage and effectiveness with regard to their original aims and that this information is made publically available.

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Appendix 1 - Search terms

Green + bridge

Green + overbridge

Green + crossing

Green + overpass

Green + span

Eco + Bridge

Eco + overbridge

Eco + crossing

Eco + overpass

Ecoduct

Wildlife + crossing + structure

Wildlife + overpass

Wildlife + passage + structure

Wildlife + bridge

Wildlife + overbridge

Wildlife + grantry

Garden + bridge

Garden + overbridge

Landscape + crossing + structure

Landscape + overpass

Landscape + bridge

Landscape + overbridge

Landscape + grantry

Landscape + overpass

Bat + gantry

Bat + bridge

Bat + overbridge

Bat + overpass

Bat + crossing+structure

Squirrel + bridge

Squirrel + gantry

Squirrel + overbridge

Squirrel + overpass

Squirel + crossing + structure

Dormouse + bridge

Dormouse + gantry

Dormouse + overbridge

Dormouse + overpass

Dormice + crossing + structure

Amphibian + crossing + structure

Amphibian + overpass

Amphibian + bridge

Amphibian + overbridge

Reptile + crossing + structure

Reptile + overpass

Reptile + bridge

Reptile + overbridge

Deer + crossing + structure

Deer + overpass

Deer + bridge

Deer + overbridge

Mammal+ crossing + structure

Mammal + overpass

Mammal + bridge

Mammal + overbridge

Badger + crossing + structure

Badger + overpass

Badger + bridge

Badger + overbridge

Land bridge + road

Land bridge + rail

Land overpass + road

Land overpass + rail

Land crossing + road

Land crossing + rail

Mosaic approach + bridge

Mosaic approach + overbridge

Mosaic approach + overpass

Pollination + bridge

Pollination + overbridge

Pollination + overpass

Vegetated+ sustainable drainage system + bridge

Vegetated+ sustainable drainage system + overbridge

Vegetated+ sustainable drainage system + overpass

Visual amenity + bridge

Visual amenity + overbridge

Visual amenity + overpass

Green + walls + bridge

Green + walls + overbridge

Green + walls + overpass

Road + Ecological severance + Mitigation

Highway + Ecological severance + Mitigation

Rail + Ecological severance + Mitigation

Road + habitat severance + Mitigation

Highway + habitat severance + Mitigation

Rail + habitat severance + Mitigation

Road+ Landscape severance + Mitigation

Highway + Landscape severance + Mitigation

Rail + landscape severance + Mitigation

Appendix 2 - Findings Summary Spreadsheet

Planning & EIA
Design
Landscape Planning
Landscape Management
Ecology
Mapping & Visualisation

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