Natural England Commissioned Report NECR169

Review of literature - how transport's soft estate has enhanced green infrastructure, ecosystem services, and transport resilience in the EU

First published 15 December 2014

www.gov.uk/natural-england

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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

This report and the accompanying report on options and opportunities were commissioned as part of the 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'*

The reports contribute to a project to pilot new approaches to maximising the potential of linear transport networks, especially road and rail, to deliver biodiversity, ecological connectivity and ecosystem services, in particular to:

- Carry out a literature review in relation to the role of the transport soft estate (the land owned by the transport providers that lies either side of the actual roads or rails themselves) for biodiversity, ecological connectivity, ecosystems services provision and infrastructure resilience, (this report).
- Apply the findings to the transport network within two Nature Improvement Area (NIA) locations: at Humberhead Levels and Morecambe Bay (NECR168).

This report addresses the specific questions:

- How has land within or adjacent to the transport corridor been used or enhanced for green infrastructure that delivers biodiversity gain, ecological connectivity, and ecosystem services?
- How has green infrastructure been used or enhanced to deliver ecosystem services both within and adjacent to the transport corridors to increase transport infrastructure resilience to climate change (ie green solutions that help better protect these networks)?

The project outputs are being used to inform a three year programme of work within each NIA. This next stage will pilot different approaches to land management of the transport soft estate and neighbouring land holdings with a view to developing and informing best practice that can be employed more widely.

This report should be cited as:

DAVIES, H., IMAGE, M., CALROW, L., FOULKES, C., FRANDSEN, M. & DUIGNAN, M. 2014. *Review of literature - how transport's soft estate has enhanced green infrastructure, ecosystem services, and transport resilience in the EU*. Natural England Commissioned Reports, Number 169.

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Keywords - climate change, climate change adaptation, climate change resilience, ecological connectivity, ecosystem approach, ecosystem services, green infrastructure (gi), landscape scale, transport, transport infrastructure

Further information
This report can be downloaded from the Natural England website: **www.gov.uk/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**.

ISBN 978-1-78354-149-2

Review of literature - how transport's soft estate has enhanced green infrastructure, ecosystem services, and transport resilience in the EU

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Abstract

Transport networks can have significant adverse impacts on biodiversity as well as being a source of pollution for human communities. In addition these networks are also vulnerable to the uncertain impacts of climate change. However, if managed appropriately, transport soft estate has the potential to mitigate these impacts and actually deliver ecological benefits and ecosystem services, as well as making the network more resilient to climate change. This review investigates two research questions considering: i) how transport soft estate has been used to deliver biodiversity gain, ecological connectivity, and ecosystem services; and ii) how green infrastructure has been used to make the transport network more resilient towards climate change. The results suggest that transport soft estate can deliver biodiversity gains and ecological connectivity, but this is very species and context dependent, with success depending on the management regime. Ecosystem service delivery is very promising with soft estate already delivering a variety of services and with the potential to deliver considerably more. The role of green infrastructure in climate change resilience is well developed in other contexts and findings could be transposed to transport networks but more work is required to assess the applicability. Further research could investigate the extent to which transport networks are transitioning from grey engineered to green infrastructure solutions and what hurdles hinder this process.

Disclaimer

The present document has been produced and adopted by the bodies identified above as author(s). This task has been carried out exclusively by the author(s) in the context of a contract between Natural England and the author(s), awarded following a tender procedure.

Contents

Summary

Transport infrastructure can have a significant environmental impact. Road and rail networks are associated with direct and indirect adverse impacts on biodiversity whilst also causing localised and generalised pollution issues which affect human communities. However, there is a considerable area of 'transport soft estate' in England that is under the management of the Highways Agency, Network Rail and other local transport authorities. This is land which is owned by these agencies, and is situated between the land boundaries and the road or track. The soft estate has considerable potential to mitigate the adverse impacts of the road or rail network and actually deliver biodiversity gains, improvement in ecological connectivity, and ecosystem services. In addition, the soft estate can be managed to help the transport network become more resilient in the face of climate change.

This review was commissioned to address two key research questions:

a. How has land within or adjacent to the transport corridor been used or enhanced for green infrastructure that delivers biodiversity gain, ecological connectivity, and ecosystem services?

b. How has green infrastructure been used or enhanced to deliver ecosystem services both within and adjacent to the transport corridors to increase transport infrastructure resilience to climate change (i.e. green solutions to network resilience)?

A standard literature review methodology identified 160 studies which were used to help address these questions. However, the research and guidance was not evenly distributed. A far greater proportion of the papers identified covered road as opposed to rail networks. In addition the majority of the green infrastructure literature was framed in an urban rather than transport context. A third research question which considered the opportunities and constraints on transport network operators in moving from grey engineered to green infrastructure solutions was also investigated but was not pursued further due to lack of published material.

Overall, the review has found that transport soft estate has the potential to provide biodiversity gain for a variety of flora and fauna though this is highly species and context dependent. The main beneficiaries would be vulnerable grassland species restored to roadside verges as well as the insects and pollinators which rely on them. Its impact on other fauna is more mixed with some birds and mammals benefiting from the soft estate whilst posing a significant risk to others. The management of verges and design of vegetation cover are important factors in enhancing species richness as well as minimising safety risks associated with the transport network. Some recommendations have been made to take into account these factors.

Similarly, the transport soft estate can both enhance and reduce ecological connectivity depending on the species and context. The benefits of verges as corridors for species movement are primarily for less demanding, generalist species that are tolerant of disturbance and pollution and are resilient to increased mortality risk associated with traffic. For other species the barrier/fragmentation and mortality risks associated with such corridors can be significant. Project level solutions to these problems include green bridges and other wildlife crossings. In addition, bridges and overpasses are often a major barrier feature and ecological considerations should be factored into their design. There are also risks associated

with spreading of certain invasive species. GIS methods offer a means for transport planners to take a strategic approach, taking landscape-level factors into consideration when designing and modifying infrastructure networks. Networks of recreational greenways could be an effective means of compensating for habitat fragmentation resulting from new transport networks.

There is considerable evidence that the transport soft estate can provide a range of ecosystem services which would benefit communities. Provisioning services include the use of road or trackside biomass for fuel. Regulating services include the use of vegetation strips to improve local air quality, reduce local heat effects, provide a wind and noise shield and sequester carbon. The Sustainable Drainage Systems (SuDS) along transport corridors could also improve water quality and mitigate flood risk. In addition, the restoration of grassland on the transport soft estate can provide important habitat for pollinators. Well managed vegetation on the soft estate can improve the visual amenity of the road for local residents, and in some instances reduce driver stress, and has the potential to enhance the role of transport networks as gateways for visitor destinations. The soft estate can also be designed and managed to improve the biodiversity value and attractiveness of non-motorised routes linked to the transport network, with associated benefits for mental and physical health.

Transport networks will be severely affected by climate change, though the extent, location and frequency of its impacts will be hard to predict at this juncture. The evidence suggests that green infrastructure can provide a resilient adaptation to some of these effects, such as increased storm and wind damage, summer heat effects, subsidence and landslides, flood risk and sea level rise, as well as increased leaf and branch fall. However, many of the studies of green infrastructure application for these purposes were carried out in a non-transport context and there is a need for further work to investigate their applicability to road and rail networks. Vegetation strips and SuDS would appear to offer the best potential. Management of vegetation, such as trees and woody vegetation, will also be important, especially as transport operators will also need to consider health and safety factors.

A number of recommendations were suggested for transport operators to consider when designing or modifying infrastructure for biodiversity gain, ecological connectivity and ecosystem service delivery. These include: specific management plans for roadside verges and hedges to promote species richness; mosaic management approaches to create a variety of habitats and corresponding habitat niches and features i.e. woodland rides and glades, variation in grassland sward height, creation of shrub layer etc; managing holistically with the surrounding habitat and landscape context; and considering green infrastructure solutions which offer a broad range of ecosystem services such as SuDS and vegetation strips.

Because green infrastructure has only been used and studied sporadically in a transport context, the main recommendations were for further work to investigate its applicability in this arena. A particular consideration is how to balance the delivery of ecosystem services, biodiversity and transport infrastructure resilience with the requirements of safety and transport operations. The review has found a that it is possible to balance these requirements, for example through the management of woody vegetation and the restoration and management of species rich grassland, which can help reduce operational safety risks from leaf / branch fall and increase the network's resilience to extreme weather, whilst also acting as a valuable species rich habitat for pollinators. The review also recommends further investigation into the commercial viability of biomass extraction from transport soft estate. Finally, the management of the soft estate should also consider the management of adjacent land to identify potential synergies to deliver more resilient infrastructure with greater biodiversity, ecological connectivity, and ecosystem service potential.

1. Introduction and Objectives

1.1. Background

The existing transport network includes a significant area of 'soft estate'. This is defined by Defra as 'the area of land owned by the Highways Agency between highway fences but not occupied by the road' (Defra, 2007) though this definition can also be extended to land owned by Network Rail. The Highways Agency manages approximately 30,000 hectares of land, supporting a wide range of habitats, including over 40 million trees (Highways Agency, n.d. website). The Strategic Road Network (SRN) is 6.900 km long and makes up only 2.4% of the surfaced road network (House of Commons, 2014). Hence a large area of road network and associated soft estate is under the management of local transport authorities. Network Rail manages over 32,000 km of track and has an interest in over 200 SSSIs in England covering over 650 hectares of land (Network Rail SSSI register; Network Rail, 2014 website).

Transport infrastructure and its operations can have significant adverse effects on biodiversity and landscape, including fragmentation and wildlife-vehicle collisions (Bennett *et al*., 2011). However, transport's soft estate also has the potential to deliver a range of ecosystems services through its green infrastructure (GI). With appropriate design and management, the soft estate and its green infrastructure has the potential to deliver multiple ecosystem services which could benefit biodiversity and ecological connectivity as well as increasing transport infrastructure's resilience to climate change.

This review seeks to explore further the potential for enhancing the transport's green infrastructure and the ecosystem services it provides for the benefit of biodiversity and transport infrastructure resilience. Enhancing the soft estate could make an important contribution towards the delivery of outcomes as set out in Biodiversity 2020 (Defra, 2011a) , It could also contribute towards local social and economic developments and make an important contribution to the debate around short and long term resilience of the nation's transport infrastructure (DfT, 2014).

1.2. Objectives

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

a) How has land within or adjacent to the transport corridor been used or enhanced for green infrastructure that delivers biodiversity gain, ecological connectivity, and ecosystem services?

b) How has green infrastructure been used or enhanced to deliver ecosystem services both within and adjacent to the transport corridors to increase transport infrastructure resilience to climate change (i.e. green solutions to network resilience)?

The review of literature aims to investigate the evidence base for the above research questions. The review will be used to inform a parallel study, which will make recommendations for land management options to enhance the transport soft estate within two selected study areas, Morecambe Bay Nature Improvement Area (NIA) and Humberhead Levels NIA.

2. Methodology

2.1. Approach

This literature review of the role and function of transport corridors soft estate in relation to ecosystem services and resilience to climate change followed the principles of a systematic review as set out by the Collaboration for Environmental Evidence partnership (Eycott *et al*. 2010).

2.2. Data sources

The following web databases were searched for scientific papers: Science Direct, Scopus and Google Scholar. For railway and highway management plans the websites of Network Rail and Highways Agency were used. Other publicly available databases were searched including the Forestry Commission, Natural England, Green Infrastructure North West, CIRIA and Institute of Civil Engineers. Additional citations referred to in papers, books and reports located during these searches were sourced through Science Direct. Some documents were provided directly by Natural England, Highways Agency, Network Rail and other parties.

2.3. Scope

The literature review focused primarily on studies within the UK, but also included relevant studies from Europe and beyond. All documents reviewed were written in the English language.

The search for relevant literature was constrained by a limited timeframe, and was therefore not comprehensive. Furthermore, the review covered a very broad topic area, and therefore only a sample of studies could be included in each topic. Ecosystem services, transport resilience to climate change, and green ecosystem solutions to civil engineering structures were found to contain a wide range of subtopics. These sub-topics were identified and literature searches were made based on key words set out in section 2.4.

Search terms were used to search within titles, keywords and abstracts and were limited to publications from 1995 onwards.

2.4. Search terms

The search terms in the table below were used in the first phase of the literature review. Each search was recorded in a spreadsheet with the search terms used, database and number of hits, shown in full in Appendix 1.

Table 2.1: Search terms used in search 1

Search terms
Adaptation for climate change risks
Agriculture AND Ecosystems and Environment Journal
Biodiversity
Biofuel production and road verges
Climate change
Vegetation AND Driver stress
Ecosystem services
Ecosystem-based approach
Ecosystem-based resilience AND transport corridors
GI type: Green linear routes OR linkages
GI type: Non-specific green infrastructure AND climate change adaptation / mitigation
GI type: Non-specific green infrastructure AND improving air quality
GI type: Non-specific green infrastructure AND reducing flood risk
Green infrastructure
Green transport corridors
Habitat fragmentation AND transport corridor
Highway verges AND ecosystem services
International / national/ regional / North West Region / sub region/ city region/ local/ site
Invasive species
Journal of Environmental Management
Management of vegetation types
Network Rail Biodiversity Action Plan
Network Rail Line-side Management
Rail AND ecological connectivity
Rail corridors
Road verge management
Roadside habitats
Roadside OR rail vegetation ecosystem services
Roadside vegetation ecosystem services
Roadside vegetation management
Roadside verges biomass production
Roadside verges value for species road OR rail
Species rich grassland - priority habitat
SuDS / flood resilience/ infrastructure asset management
Transport
Transport AND ecological connectivity
Transport AND environment journal
Transport AND green infrastructure
Transport corridor
Transport soft estate AND ecological benefits

Table 2.2: Search terms used in search 2 (in alphabetic order not search order. For search order see table in Appendix 1)

Search terms
Air quality
Air quality AND transport corridor
Air quality AND green infrastructure
Air quality AND ecosystem services
Biodiversity
Biofuel production and road verges
Carbon sequestration AND transport corridors
Carbon sequestration AND green infrastructure
Carbon sequestration AND ecosystem services
Ecosystem-based approach
Ecosystem-based resilience AND transport corridors
Green transport corridors
Landscape AND transport
Noise AND transport corridors
Noise AND roadside vegetation
Noise AND vegetation
Pollination AND green infrastructure
Pollination AND roadside verge
Rail AND soil retention
Roadside verges biomass production
Roadside verges value for species road OR rail
Soil retention AND transport
Soil retention AND ecosystem services
SuDS AND transport
Visual impact AND transport
Visual impact AND road
Water quality AND green infrastructure
Water quality AND buffer strips
Water quality AND ecosystem services
Water quality AND roadside verges

2.5. Study selection criteria

The selection of references to be reviewed was carried out in a two stage process. The first stage was the initial screening of references on databases. The criteria for this first stage was that all documents should be either scientific peer-reviewed journal articles or “grey literature” which included competent authority guidance, policy documents or book chapters. The references retrieved were ordered by date, with the most recent first, and then by relevance. The titles were screened and documents relevant to the study objectives were saved to the project library and catalogued in a spreadsheet. Where any apparently relevant citations or links were found they were followed one step away from the original hit. The first phase of the search produced 106 references.

The second stage of the selection process involved the categorisation of references under topic headings relating to the three study objectives. In this process some references were found to be non-relevant. The references were also categorised into general studies covering green infrastructure, ecosystem services and climate change adaptation, and those specifically related to transport corridors. The studies related specifically to transport corridors were prioritised. The references found to be applicable to the study were then reviewed in full.

Table 2.3: Topic headings used to categorise references

<table>
<tr><th>Objective 1: Transport soft estate delivering biodiversity gain, ecological connectivity and ecosystem services</th><th>Objective 2: Transport soft estate delivering green infrastructure resilience to climate change</th></tr>
<tr><td>Biodiversity gain – flora
Biodiversity gain – fauna</td><td rowspan="3">Climate resilience
Storm and wind damage
Temperature effects on road and rail track
Subsidence/land slides
Flood risk / sea level change
Leaf / branch fall
Green infrastructure</td></tr>
<tr><td>Ecological connectivity / dispersal
Habitat fragmentation
Invasive species
Green bridges / wildlife crossings
Bridge design</td></tr>
<tr><td>Ecosystem services
Biomass
Air quality
Climate regulation
Surface water and flood risk
SuDS
Water quality
Hazard regulation – soil retention / slope stability
Noise regulation
Disease and pest regulation
Pollination
Cultural services
Landscape and visual amenity
Driver stress</td></tr>
</table>

The categorisation of references enabled a gap analysis to be undertaken, to identify which topics were insufficiently covered in the initial search. The next stage was to search for relevant references within identified documents, and to search for these specific references through Science Direct. The initial review of documents also allowed the identification of significant authors, and other publications by these were identified through Science Direct.

2.6. Quality assessment

Most documents met the requirements of the first stage selection, and have been through a peer review process or other critical review in the case of competent authority guidance or policy. Grey literature has not been through the same level of quality control and has therefore been treated with more caution. All documents have been reviewed critically to evaluate the quality of the information, particularly in terms of conclusions drawn and evidence provided. The breadth of topics covered in the study does not, however, allow a full critical assessment of methodology, sampling framework etc. as this requires expert knowledge in the fields in question.

3. Literature Review Results

3.1. Presentation of results

The final literature review results are presented in Table 3.1 below.

Table 3.1: Number of publications identified by topic

Topic	Number of publications
Biodiversity Gain - Flora	4
Biodiversity Gain - Fauna	10
Ecological Connectivity / Dispersal	14
Habitat Fragmentation	13
Invasive Species	3
Ecosystem Services	5
Biomass	3
Air Quality	7
Climate Regulation	6
Surface Water and Flood Risk	5
Water Quality / Water Regulation	2
Hazard Regulation – Soil Retention / Slope Stability	4
Noise	11
Pollination	4
Cultural Services	7
Landscape and Visual Amenity	4
Driver Stress	3
Climate Resilience	12
Storm and Wind Damage	5
Temperature Effects on Road, Rail, Infrastructure	5
Subsidence / Land Slides	2
Flood Risk / Sea Level Change	2
Leaf / Branch Fall	2
Green Infrastructure	9
Bridge Design	1
SuDS	6
Green Bridge / Wildlife Crossing	1
Other	19
Total[1]	**161**

[1] The total number of studies does not equal the sum of the number by topic because some studies cover more than one topic.

3.2. Definition of terms and concepts

3.2.1. Transport soft estate

Transport soft estate is defined as the vegetated areas within road verges and on rail line-sides between the carriageway or rail track and the ownership boundary (Defra, 2007).

The Highways Agency and Network Rail manage a significant area of land, which has the potential to deliver ecosystem services and transport infrastructure resilience to climate change. Approximately 30,000 ha of land falls under the remit of the Highways Agency, supporting a wide range of habitats, including 40 million trees (Highways Agency, n.d., website). Network Rail manages over 32,000 km of track and has an interest in over 200 SSSIs (in England) covering over 650 ha (Network Rail SSSI register; Network Rail, 2014).

3.2.2. Green infrastructure

Green infrastructure (GI) is defined generally within the National Planning Policy Framework (NPPF) as: *'…a network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities*.' (DCLG, 2012, p.52).

Natural England provide a more qualitative definition for GI which stresses the importance of quality, management, and design, as well as giving some specific examples of land use which qualifies as GI:

'Green Infrastructure (GI) is a network of high quality green and blue spaces and other environmental features. It needs to be planned and delivered at all spatial scales from national to neighbourhood levels. The greatest benefits will be gained when it is designed and managed as a multifunctional resource capable of delivering a wide range of environmental and quality of life benefits (ecosystem services) for local communities. Green infrastructure includes parks, open spaces, playing fields, woodlands, wetlands, grasslands, river and canal corridors, allotments, and private gardens.'

3.2.3. Ecosystem services

The Millennium Ecosystem Assessment defined ecosystem services as '*the benefits people obtain from ecosystems*' (MA, 2005, p53). This generalised definition has been expanded on in recent years. For example, Fisher and Turner (2008) propose that '*ecosystem services are the aspects of ecosystems utilized (actively and passively) to produce human well-being',* whilst the UK National Ecosystem Assessment (UK NEA) considers them to be '*the outputs of ecosystems from which people derive benefits.'* (UK NEA, 2011 p16).

Classification of ecosystem services in the literature generally follows the four category system developed in the Millennium Ecosystem Assessment, which includes provisioning, regulating, supporting, and cultural services. Defra (2007) provides examples of each service including: food, fibre, and fuel (provisioning); climate regulation, air and water purification (regulating), recreation and aesthetic appreciation (cultural), and habitat provision (supporting).

The UK NEA further classifies ecosystem services into final ecosystem services and intermediate ecosystem services. Final ecosystem services '*directly contribute to the good(s) that are valued by people....'* whilst intermediate ecosystem services *'….underpin the final ecosystem services but are not directly linked to the good(s).'* (UK NEA, 2011, p16). Examples of final services include food, fibre, and fuel production as well as recreation, which are dependent on intermediate services such as soil formation, nutrient cycling, pollination and biomass production.

3.2.4. Biodiversity

The Convention on Biological Diversity (CBD) defines biological diversity as: '*the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.*' (CBD, 2006).

Biodiversity is integral to the ecosystem services approach. It is most usually recognised as a supporting service which underpins other services, such as the role which bacteria and fungi play in nutrient cycling. However, biodiversity can also be considered to be provisioning service, for example in bio-prospecting for new medicines and foods as well as a cultural service – ie the emotional and spiritual value derived from the continued existence of certain species (UK NEA, 2011).

3.2.5. Ecological connectivity

The Making Space For Nature Report describes an ecological network is a network of 'high quality core (wildlife) sites connected by buffer zones, wildlife corridors, and smaller but still wildlife-rich sites that are important in their own right and also act as 'stepping stones'' (Lawton *et al*, 2010). In terms of defining ecological connectivity, the report continues to clarify that although ecological networks differ in scale and management approach, there are a number of common elements, including *inter alia*, the '*emphasis on maintaining or strengthening ecological coherence, primarily by increasing connectivity with corridors and 'stepping stones''* (Lawton *et al*., 2010).

An alternative manner to consider ecological connectivity, often used in the modelling literature is through the Patch-matrix-corridor model as developed by Forman (1995). This describes landscapes as mosaics made up of three components: patches, corridors and the matrix. The patches are habitat areas that are homogeneous and differ from the surrounding landscape, the corridors are strips of habitat type that differ from their surroundings and the matrix is the dominant and most extensive habitat type. Both the matrix and the corridor facilitate connections between patches, but as fragmentation increases species and resources become increasingly reliant on corridors to maintain connectivity.

3.2.6. Habitat fragmentation

Habitat fragmentation is '*the process and spatial pattern resulting from the disruption of habitats into smaller, more isolated patches*' (EC, 2003). This process leads to conditions whereby individual animal and plant species, as well as their wider populations, are endangered by local, then more widespread extinction. Habitat fragmentation also reduces the availability and the suitability of adjacent areas for wildlife (EC, 2003).

Habitat fragmentation is a complex process which can operate differently on species diversity at different scales and is part of a wider issue which includes fragmentation of food and other resources (Ollf and Ritchie, 2002). Transport networks are one of the key causes of this disruption because they create divisions between natural habitats and ecosystems (Iuell *et al.*, 2003).

3.2.7. Climate change resilience and adaptation

Resilience describes the '*ability of a system to withstand a wide array of shocks and stresses*' (Leichenko, 2011), of which climate change would be a contributing environmental stressor. Increased numbers of hot days, increased heavy precipitation, more extreme seasonal changes, droughts, and sea level changes are some of the potential threats that climate change poses to the UK transport sector (Hooper and Chapman, 2012). Recommendations have already been made to improve the resilience of England's transport network to more extreme winters (DfT, 2010a) and a review has been started to assess the resilience of the whole UK network to extremes of weather (DfT, 2014).

Adaptation is a related concept, which the Intergovernmental Panel on Climate Change defines as the '*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*.' (IPCC, 2007). Natural England has identified six key principles for adaptation within a conservation context and published guidance on how capacity can be built to adapt to climate change (Natural England, 2007; 2008). The Department for Transport has also published climate change adaptation plans for the UK transport network (DfT, 2010b).

3.2.8. Vegetation management options

Vegetation in this context means all flora present in the soft estate of transport corridors, including trees, shrubs, grasses, and flowers. An overarching definition of vegetation management for transport infrastructure could not be found in the literature. However, in principle the objective of vegetation management should be to satisfy the operational requirements of the road or railway, whilst protecting and enhancing its environmental and amenity value (London Assembly, 2012). In the US, 'Integrated Vegetation Management' which combines a variety of operational management tools and ecological principles has been used to manage vegetation on rights-of-way and infrastructure corridors (NDOR, 2012).

Vegetation management techniques currently employed by Network Rail and the Highways Agency include: inspection, surveying, risk assessment, clearance (especially the removal of injurious and invasive weeds), mowing, removal of leaf and other litter, pruning, coppicing, selective felling, tree surgery, stump killing, planting, and seeding. Certain vegetation management techniques are mandatory in some instances to maintain operational safety and satisfy legal requirements. Others have some room for flexibility, and some are simply guidance (Network Rail, 2012; Highways Agency, 2001a).

3.3. Objective 1: Transport soft estate delivering biodiversity gain, ecological connectivity, and ecosystem services.

3.3.1. Introduction

Objective 1 of the literature review covers the very broad topic area of how transport soft estate can deliver ecosystem services, as defined above in Section 3.2.3. This section of the review investigates the evidence for how land within or adjacent to the transport corridor has been used/enhanced for green infrastructure that delivers biodiversity gain, ecological connectivity and ecosystem services.

3.3.2. Biodiversity gain

The importance of the natural world, including its biodiversity and constituent ecosystems toward human well-being and economic prosperity is frequently stressed in the literature (MA, 2005; CBD, 2006; UK NEA, 2011). The UK NEA in particular states that '*Ecosystem functions are more stable through time in experimental ecosystems with relatively high levels of biodiversity; and there are comparable effects in natural ecosystems. Taken together, this evidence shows that, in general terms, the level and stability of ecosystem services tend to improve with increasing biodiversity,'* (UK NEA, 2011).

Biodiversity 2020 is a strategic plan for the protection and enhancement of biodiversity in England over the next decade (Defra, 2011a). It leads on from the Natural Environment White Paper which resulted from the historic meeting in Nagoya to develop an action plan to stop global declines in biodiversity. The paper outlined the Government's vision for an integrated landscape scale approach to protect the natural environment and reported how the environment should be given greater value in decision making. Biodiversity 2020 aims to establish ecological networks and halt current trends of biodiversity loss. These targets will be achieved through an integrated and large scale approach to conservation, effort to reduce environmental pressures, improved knowledge of biodiversity and incorporating people into biodiversity polices.

The following sections look at the underpinning biodiversity value of the transport soft estate in the literature considering first the flora and then the fauna.

Flora

A review of the literature has shown that roadside verges provide a valuable habitat for many flora species and act as biodiversity hot spots in urban areas. The effectiveness of the roadside verges can depend on habitat type and management regime and research has been undertaken to find out the most effective management regimes for these important habitats.

Nordbakken *et al*. (2010) showed from a study in Norway that different methods for the restoration of roadside verges into biodiversity rich habitats produce different species compositions, even when identical seed material has been planted. Seed sowing and soil seed bank methods were used to create a grassland environment on an unestablished road verge. Some species which were successful in the above ground plots failed to establish from the seed bank whereas no species were found solely in the seed bank plots. Species abundance varied between restoration methods and after three years species composition was found to differ widely. In terms of species, *Avenula pubescens* and *Knautia arvensis*, found in more than 25% of the aboveground grassland plots, did not germinate from any of the seed bank samples. *Festuca rubra*, *Galium verum*, *Pimpinella saxifraga* and *Silene vulgaris* were more frequent in the aboveground plots than in the seed bank samples. *Pimpinella saxifraga*, *Galium verum* and *Lychnis viscaria* emerged quite well both from sown seeds and from the seed bank. *Avenula pubescens* was frequent in the aboveground vegetation, but did not germinate from sown seeds. The study concludes that different substrates and a combination of establishment methods, such as sowing and hay transfer, are needed as supplements to seed banks in order to re-establish species rich grassland.

A study by Auestad *et al*. (2010) examining the effect of management regimes on a vulnerable grassland species in roadside verges (highly managed/modified grassland) and pastures (semi-natural, traditional grassland) found that slightly higher population growth rates were found in the pastures. The pasture had lower survival rates but higher reproduction rates as a result of the differing management practices. Management practices, including early (June) and late (August) or just late summer cuts both with and without hay removal, were used along the road verge and the research revealed that such management enabled meta-populations to complement each other’s life history. In the study roadside verges were able to support the vulnerable grassland species and support species of different life history.

Suárez-Esteban *et al*. (2013) researched soft linear developments (SLD) in the Mediterranean. SLDs were found to contain a greater density of fleshy-fruited shrubs (dispersed by fruigivorous mammals) and bird-dispersed shrubs than adjacent shrubland. The authors’ conclusion was that because foxes and rabbits are highly mobile and often select SLD for faecal marking, these features can play an important role in plant conservation and land management. The SLD’s in this study consisted mainly of man-made trails and firebreaks through shrubland, it may not be possible to apply this finding to road and rail soft estate where greater disturbance may deter fauna. However, foxes are known to use transport corridors and their mortality rate is not materially affected (EC, 2003), so it may be possible to generalise this finding.

Hambrey (2013) identifies that in Scotland the most common form of management – one or more cuts each year – partially mimics that of hay meadows and certain forms of pasture. As such they may be regarded as relics or refugia of a declining habitat, and if appropriately managed can be relatively herb rich and associated with a diverse invertebrate fauna. Trees, hedgerows, scrub and ditches may also contribute to a mosaic or gradient of habitats. The report recommends continuing to encourage and where possible support locally appropriate and flexible verge conservation initiatives on the part of Local Biodiversity Action Plans (LBAPS) and local wildlife groups. It also identifies the constraints on operators in terms of delivering 2 cuts at the optimal times of the year (ie late April/early May and late August/early September) across the network and proposes that the verges that would most benefit from being cut at a particular time could be identified via a mapping approach. It also proposes simple guidance for verge management operators/contractors, supported by a resource pack for briefing and training purposes.

Fauna

Research has shown that roadside verges and urban habitats can act as refuges for many varieties of fauna. However there are also significant mortality, fragmentation, and barrier risks associated with fauna that inhabit transport corridors. The mortality risk depends on factors such as species, infrastructure characteristics, traffic density and speed, time of day, and is in general higher for motorways than for other highways. Data on railway casualties is less readily available than for roads, but is assumed to be much lower than for roads, with higher mortality seen on high speed lines than traditional lines (EC, 2003). In general species that occur in small isolated populations, and those which require extensive areas for their home ranges, or exert long migratory movements, are particularly sensitive to road mortality.

<u>Birds</u>

Meunier *et al*. (1999) investigated the use of road verges by bird communities in three land use types in France: intensive farmland, pine plantations and a matoral (a shrubland/*Quercus ilex* successional habitat found in the Mediterranean region). In general there was little difference between measures of species abundance and diversity for roadside and adjacent habitats, but for certain species types in certain landscapes there were clear distinctions. For bird species which disposed of large habitats in forested or matoral landscapes, the verges appeared to be adverse habitats. Similar findings were true of the farmland habitat, but only in the winter. By contrast, for bird species that typically inhabit small areas of woodland or hedges within farmland, the roadside verges proved to be favourable habitats relative to the adjacent farmland. As such, management of roadside verges for birds needs to take into consideration the particular habitat preferences of the species present, the landscape context, as well as seasonality.

Bird mortality on roads across Europe has been reviewed by Erritzoe *et al.* (2003). Their key findings are that the birds most frequently killed on western European roads were the house sparrow (*Passer domestica*) and blackbird *(Turdus merula*) and the most casualties occur between April and September, during hot and humid weather conditions. Road characteristics and the surrounding habitat also have an effect. In general the more vegetation surrounding a road, the greater the mortality especially in areas where there are breaks in the cover. Casualties are also higher where the road is at the same level or elevated relative to the surroundings. The authors propose some design considerations to minimise bird strikes, including: planting dense thorny bushes, continuous hedges and closely spaced trees to discourage low level flight across roads; and avoiding close proximity of vegetation cover where roads are elevated relative to surroundings.

Within the UK the barn owl has been noted as one of the species most severely affected by vehicle collision mortality. A report by the Barn Owl Trust (Ramsden, 2003) found that road networks are having a detrimental effect on the barn owl population, with road traffic related deaths increasing from 6% (1910-54) to 50% (1991-96). A finding of particular concerns was that the deaths recorded including healthy individuals and not just the weak or underweight. Major roads are the greatest areas for concern. The report found that barn owls are three times more likely to be dead than alive when seen on a major road, and 72% of those who encounter one are killed. Conversely on minor roads they are 57 times more likely to be seen alive. As such there has been a prolonged absence of resident barn owls within 0.5km of major roads and it is only 25km from a road that no effect on barn owl population is seen.

This report also made recommendations on how the impact of roads on barn owl populations may be reduced. These include creating vegetation barriers alongside transport corridors, increasing the area of barn owl habitat in agricultural areas, the attractiveness of land adjacent to roads should be reduced through introduction of dense brambles and limiting the development of roads in rural areas. The report also includes the recommendation of reducing grassland on road verges, as these attract mammals which in turn attracts barn owls to hunt here. Improvements could also be made in research through looking at the effectiveness of mitigation measures and the recording of roadside casualties.

Mammals

The Mammal Society's national survey of small mammals on grassland road verges undertaken from 1999 to 2000 and cited in the COST 341 report *Habitat fragmentation due to transport infrastructure* (EC, 2003) found that the wood mouse was the most commonly recorded species. Common shrews, bank voles and field voles were also frequently recorded in the survey. Less common species included water shrews, harvest mice and yellow necked mice.

Roadside verges were also found to be an extremely valuable refuge for small mammals in a heavily managed Mediterranean landscape (Ruiz-Capillas *et al*., 2013). Results showed that in small mammal species captured, populations were all significantly more abundant by the motorway studied than the surrounding areas. A population crash during study period revealed that small mammal populations near to the motorway were less affected than in the neighbouring areas, demonstrating the value of roadside verges for population abundance and stability.

The COST 341 report also identifies that corridors are important for foxes, roe deer, squirrels, badgers and bats which have all been shown to move along verges, particularly where there are well developed shrubs and wooded areas (EC, 2003). However it also identifies the fragmentation and barrier effects of transport infrastructure on fauna and the risks in relation to mortality. For common species such as rabbits and foxes, traffic mortality is generally considered insignificant and even for red and roe deer traffic mortality accounts for less that 5% of the annual spring populations in Europe. By contrast, for sensitive species such as badger, otter, and hedgehog, traffic strikes can account for up to 60% of overall mortality. More research is needed to determine how significant road casualties are in terms of overall population dynamics.

Amphibians

Amphibians are especially sensitive to road mortality as they exert seasonal migrations. Where routes cross trafficked roads, there may be considerable losses (EC, 2003). In comparison with other animals, research into the number and reasons for amphibian road casualties is relatively scarce. One of the few studies carried out investigated amphibian mortality on roads in lowland Central Europe discovered higher incidence of common toad (*Bufo bufo*) mortality in suburban areas whilst the common frog (*Rana temporaria*) and *Triturus spp.* newts were more often killed in rural contexts (Elzanowksi *et al*., 2009). There has been some effort to develop methods to reduce amphibian road kill in specific locations by using under-road tunnels and culverts, however there is scant evidence that such measures can protect populations in the long-term (Beebee, 2013).

Invertebrates

The restoration of roadside verges is strongly associated with insect conservation efforts, especially bees (Hopwood, 2008).

The size of roadside verges, as well as the grassland species they contain, has an effect on Lepidoptera (butterflies and moths). Saarinen *et al.* (2005) studied variations in abundance and diversity of Lepidoptera on three road types: highways, urban roads and rural roads. The study found that the abundance of both butterflies and diurnal moths increased with increasing size of roadside verge, whilst the diversity of butterflies was also greater. However, neither effect was shown to be statistically significant. The only significant differences were the lower numbers of butterflies along urban roads and the lower numbers of moths along rural roads. The butterfly effect was significantly related to nectar abundance – urban roads are under a more intensive mowing regime and thus have shorter vegetation and less nectar. The moth effect was significantly related to shelter – the verge along rural roads is narrower and thus provides less cover. In terms of surrounding landscape, the study found that verges surrounded by cultivated fields were generally related to low numbers of moths. The total number of Lepidoptera species increased if the surrounding landscape was forested.

Spider and ladybird assemblages were sampled on 28 Hungarian road rest stops by Szita *et al*. (n.d.) and it was found that 26.6% of Hungarian spider species and 18% of Hungarian ladybird species were found to reside within them. Conversely, research by Le Viol *et al*. (2008) showed that although planted hedgerows on roadside verges resulted in significantly higher plant species biodiversity, it had little effect on spider species.

Skórka *et al*. (2013) conducted a detailed study investigating the relationship between butterfly mortality on Polish roads and the characteristics of the adjacent verges. The overall numbers killed were 6.8% of the verge population, though the relative proportion was higher on busier and wider roads, as well as those which are more frequently mown. The mowing effect was suggested to be related to the fact that butterflies are forced to forage further afield, thus leading them to cross the road more frequently. An interesting finding was that increased traffic volume did not reduce butterfly species richness or abundance on roadside verges, which suggests that any road could have potential for successful conservation activities. Another intriguing finding from this study was that not only did plant species richness and abundance on road verges increase the butterfly species richness and abundance, it also reduced the number of roadkills, the proportion of roadkilled species and the proportion of roadkilled individuals. No explanation is given for this negative correlation, though it may be related to the explanation suggested above for the mowing effect, namely that in areas of poorer plant species richness and abundance, the butterflies need to cross the road more frequently to forage. The authors recommended management of road verges to increase plant species by sowing flowering and host plants on road verges, as well as minimising disturbances so that local plant species and strains from surrounding grasslands can spread naturally to road verges.

Management practices, such as different mowing treatments, play a key role in the biodiversity of roadside verges. A paper by Noordijk *et al*. (2009) investigated the effects of management practices (mowing once or twice per year with and without the removal of hay, versus no management) on flower visiting insects in the Netherlands. The results found that cutting verges twice a year with hay removal was the most beneficial for insects and flowers in terms of abundance, diversity and number of flower visits. The early summer cut was particularly important for insects as it resulted in feeding opportunities from re-flowering of plants later in the growing season. The study also indicated that a rotational scheme might further promote insect diversity and abundance, as verges will be flower-less immediately after mowing.

These findings, and in particular the management practices suggested could be used to enhance the role that transport soft estate plays in pollination services. This is discussed in Section 3.3.4 below.

<u>Priority species</u>

Analysis of the requirements of England’s priority species by Natural England NERR024 (Webb *et al*., 2010) showed that the conservation needs of almost three quarters of them could be met by managing their habitats to create the conditions they require. The “Mosaic Approach” aims to address this by helping land managers manage habitats in a way that supports multiple species by developing “mosaics” of different environmental features at a landscape scale, within a range of habitat types (Natural England, 2013). This approach includes improving the structural diversity of habitats so they support a wider range of species and are more resilient to climate change. For example, most species require a range of environmental features within a site or a wider landscape to complete their lifecycle. Many of these elements, such as small patches of bare ground, tall flower-rich vegetation, or scattered trees and scrub, are often absent from the English landscape, and even from the most important wildlife sites. However, they can be incorporated into management practice to provide the variety of features and niches such species need to complete their lifecycle.

The literature review did not find specific references to the application of the Mosaic Approach for addressing the needs of priority species in the transport sector, but given that the approach can be applied to any habitat/corridor, there is potential for this approach to be trialled within the transport sector e.g. by including scrub/shrub layers, creating woodland rides and glades etc, with the aim of creating more resilient ecological networks within the landscape.

3.3.3. Ecological connectivity/dispersal

Functions of ecological corridors

The role of ecological corridors in maintaining connectivity between habitat patches has been discussed above. However, ecological corridors have a broader functional array. Hess and Fischer (2001) identify six key functions of ecological corridors in the transmission of organisms and materials. These are as follows:

- Conduit: organisms pass from one place to another, but do not reside within the corridor.
- Habitat: organisms can survive and reproduce in the corridor.
- Filter: some organisms or material can pass through the corridor; other cannot.
- Barrier: organisms or material cannot cross the corridor.
- Source: organisms or material emanate from the corridor.
- Sink: organisms or material enter the corridor and are destroyed.

Hess and Fischer (2001) conclude that the functions of ecological corridors should be better defined to reduce ambiguity in this area and assist in more effective design.

Ecological corridors and transport soft estate

Although transport infrastructure has often been associated with habitat fragmentation, the soft estate alongside linear features such as roads and railways may also function as an ecological corridor to varying degrees. The following section will investigate to what extent road and railway verges (including hedgerows and woodland) could provide some of the ecological functions mentioned above, including resilience to other forms of disturbance.

<u>Roadside Verges</u>

Roadside verges can be the only remaining semi-natural habitat in many urban areas and contain a diverse range of species that are remnants from woodlands and ancients meadows that used to be much more widespread (Foy, 1980). Hampshire County Council commissioned this Road Verges of Ecological Importance (RVEI) report to recognize the value of roadside verges and assist in the identification of ecologically important verges. This aids decision making on how best to manage the verges, in particular the cutting regime, and to prioritise the verges of most importance. There is other similar work being undertaken across highway authorities in England, Scotland and Wales.

Hambrey Consulting (2013) highlights that in Scotland linear verge features may be regarded as important as corridors for the dispersal and movement of wildlife, and may contribute to a national ecological network (NEN). However their value is limited by their: relatively small area compared with similar habitats in the wider countryside; often limited width and frequent obstructions; proximity to a major hazard for wildlife; and significant practical and cost constraints on management. The study notes little account seems to have been taken of the opportunity to include roadside verges in integrated habitat and green infrastructure initiatives to date. This probably relates to a woodland and focal species dominated approach to habitat network analysis and enhancement, and perhaps relates also to the generally narrow width of roadside verges, which can significantly reduce their value in terms of connectivity. The report emphasises however that connectivity value is highly context dependent, and some stretches of verge may have exceptional qualities – or potential qualities in this regard. It identifies opportunities for more account to be taken of roadside verge grassland *and* adjacent farmland, which might benefit from agri-environment grants to enhance connectivity.

The COST 341 report identifies that the corridor effect is less clear cut, with verges providing valuable habitat, but primarily for less demanding, generalist species that are tolerant of disturbance and pollution and are resilient to increased mortality risk associated with traffic (EC, 2003). The report also identifies a number of examples where verges serve as conduits for species movement. These include a study in the Netherlands which showed that bank voles have used wooded verges of railways and motorways to aid colonisation of a new area, as well as several studies which showed that vehicle movement may serve as a vector for plants and seeds. The report goes on to identify the potential for transport corridors to become traps for certain species, with high bird-of-prey mortality noted where road corridors form part of hunting territory. The report concludes that it is not possible to identify which species are most sensitive to fragmentation, but that large, wide ranging species suffer more from fragmentation at the landscape scale, whilst sedentary species are more sensitive to loss and disturbance of their local habitat. It identifies several counties including the Netherlands, Belgium, Switzerland and Spain, which have defragmentation policies for new and existing infrastructure that aim to locate and address existing bottlenecks. The Netherlands and Sweden have carried out botanical inventories of their roadsides, identifying the potential to increase biodiversity and the positive use of the corridor effect.

Broad roadside verges (24m wide in this study) were found to be effective habitat corridor for Carabid Beetles when tested in a simulation programme by Vermeulen and Opdam (1995). Fewer individuals were found to be lost to adjacent areas in comparison to narrow verges (12m wide) and dispersal distances were simulated to be over a few hundred metres. Dispersal distance often increased when verges were within reach of the next local population. This study concluded that a higher reproduction rate leads to a higher number of long dispersal events. Higher reproduction rates can be achieved by introducing broader sites with suitable habitat to a corridor to reduce the effect of population decline on dispersal distances. For the Carabid Beetle, verges should be at least 20-30m wide and contain suitable habitat in the central strip. The consequence of the conclusion of this study is that corridors that are thought to connect fragments of habitat must be much broader than the average corridor size. Adverse effects of activities on adjacent land (for example fertilisation) will lower the habitat quality of the border zone more than is the case for highway verges bordered by woodland.

A survey of roadside verges in selected counties of northern England showed 54% to be of low and 40% to be of medium conservation value (Akbar *et al*., 2010). Only 6% of those verges surveyed were found to be of a high conservation status. Despite the results roadside verges were found to be useful sites for a variety of plant and animal species which could be improved through better management techniques. Improvements could lead to them fulfilling their potential to preserve natural plant assemblages and manage species diversity. Disturbance was found to affect the majority of sites with nearly 54% being moderately to heavily disturbed and an additional 46% being slightly disturbed, which included disruption by off road vehicles, parking, mowing and presence of utility services such as pipes and cables. In addition to disturbance, the authors identify other possible causal factors for the low conservation status of the verges as fertilizer input, damage to hedges and de-icing salts. In addition, the study also found that the majority of roadside verges perform poorly in terms value for fauna. This was attributed to the lack of vegetation density and diversity (including vertical diversity and structure) with the dominance of a small number of grasses and weeds.

In their literature review, Akbar *et al*. (2010) also found that careful selection of species for re-vegetation, increase in native plant species, weed control, management of roadside soils for salinity and fertility control, and the protection of roadside hedges were the key factors in improving the conservation status of roadside verges. Additionally uniform policy needs to be implemented in order to encourage a holistic approach to the management of roadside verges across the many bodies who are responsible for their management. In the discussion the author highlights the following in relation to the conservation status of roadside verges: Wider road verges tend to have higher species diversity and are less affected by neighbouring land use and disturbance; Neighbouring areas of natural and semi-natural vegetation provide a source of genetic material which supports increased diversity and can protect from invasive species. By contrast verges surrounded by intensively farmed land or urban areas are less stable and less diverse; The presence of utility services on road verges can have an adverse effect on vegetation due to disturbance from maintenance works; Diversity of hedge structure is considered to increase the habitat value of roads side verges.

A study by Zwaenepoel *et al.* (2006) in Belgium showed that vehicles can also be important species dispersal vectors. The research demonstrated that car mud retention was a crucial factor in seed dispersal, affecting the number of seeds attached as well as their size and composition and that car-borne seed dispersal is consequently highly seasonal. The nature of vehicle-borne flora showed greater resemblance to flora in the zone immediately adjacent to the carriage way than to the road side verges.

Railway Edges

Penone *et al*. (2012) found that railway edges can act as effective transport corridors for mobile plant species, where 'mobile' primarily refers to wind-pollinated species. They were not effective for moderately mobile species that are pollinated by insects or have their seeds dispersed by birds or mammals, and were also ineffective for self-pollinating species which have poor mobility. Functional connectivity was largely maintained across spatial breaks resulting from railway stations (except for self-pollinating species), however, those resulting from overpasses were shown to cause habitat fragmentation and disrupt seed dispersal. This is because the slipstream of trains which contributes to seed dispersal, can be interrupted by air turbulence or crosswind when the train traverses overpasses. In addition, insects and terrestrial mammals are also thought to be disturbed by overpasses, though birds are not. The location of invasive species was not influenced by habitat fragmentation along railway edges and was instead strongly related to the degree of urbanization.

Reconnecting Networks

The COST 341 report recommends that corridors should be: as continuous as possible; as wide as possible to maximise habitat areas and minimise risk; be predominantly semi-natural; be as diverse in vegetation composition and age structure as possible; and act as a conduit for colonisation or re-colonisation of sites linking areas which are reservoirs of species (EC, 2003). To achieve this requires both a project level and a strategic level approach to reconnecting ecological networks.

At the project level this involves putting in place infrastructure solutions such tunnels, wildlife underpasses, culverts, bat bridges, green bridges and hop-overs. For example, green bridges or wildlife overpasses are vegetated bridges that can be used as landscape connectors for a variety of species of wildlife. They are often used to preserve the migratory paths for large mammal species and have been used successfully in a number of countries in Europe and North America, although they are a relatively unused mitigation tool in the UK (EC, 2003). There are, however, a few examples of green bridges in the UK, one being on the M40 in Oxfordshire. The installation was to mitigate habitat fragmentation affects as a result of the M40 crossing Bernwood Forest, which is an area of high conservation value with populations of muntjac and fallow deer.

Bridges are often features which create fragmentation (Penone *et al.*, 2012); but their design can be modified to improve connectivity and habitat quality. For example, the positioning of the abutments can be set back far enough to allow natural riverbank and riverbed to be retained. Where engineering considerations allow, the bank can be 'softened' using techniques such as log piling, willow hurdles or hazel faggots. If hard protection is necessary, it can still be softened with gabions and boulders in preference to concrete and softer treatment above the waterline. This would allow for easy access for otters in and out of the river (EC, 2003).

However, there was a lack of studies which discuss and evaluate specific management regimes and design features of these installations. As such this review was not able to investigate this topic in any more detail and this is an area where more research is recommended.

At the strategic level, this requires solutions to identify where and how networks should be re-established at a landscape level, and also institutional and political commitment and resources to develop and carry out restoration programmes. The literature review was able to identify several examples of this across the EU and beyond, as follows:

Work has been done in Bulgaria to develop a long term programme to restore the ecological networks across transport corridors. This involved encouraging inter-institutional collaboration, improving environmental impact assessments (EIAs) for new transport developments, producing a defragmentation strategy (i.e. looking into areas where fauna passages such as tunnels and bridges may be most successful), running pilot programmes and monitoring schemes, and raising public and political awareness of habitat fragmentation (van der Grift *et al*. 2008).

Gurrutxaga *et al*. (2010) used an objective and repeatable GIS-based approach to identify connection zones to complete the Natura 2000 network in the Basque Country, Spain using spatial modelling. A set of friction surfaces (these are land cover types such as forest, meadows, water bodies and urban areas/highways that have been given a value based on how significantly they impede the movement of species) were used for the dominant species in the region and then the least-cost paths were identified as potential linking areas. The final connected ecological network should consist of key areas, linking areas, linking corridors and buffer zones. The method was designed to aid decision making and to create the most effective ecological connectivity networks. It could be used at multiple scales – subra-regional, sub-regional and local.

Gurrutxaga *et al*. (2011) later developed a methodology for quantitatively evaluating the connectivity between protected areas to allow more effective targeting of ecological conservation. The software is able to inform decision making in territorial planning through assessing which protected areas and linking areas play the greatest role in functional connectivity and identify transport networks that are causing habitat fragmentation. Their methodology was applied to the Basque Country and considered the dispersal distance of species and impact of highways to identify those areas which are most likely to benefit from functional connectivity within an ecological network. The results identified areas that should be prioritised for conservation to prevent fragmentation, and since 2005 the results of these analyses have been used to inform environmental assessments of plans and projects in the Basque Country (Gurrutxaga *et al.,* 2011).

Another GIS-based methodology was used, carried out in the Longgang District of Shenzhen in China, as a decision support tool for green infrastructure planning in suburban areas in a study by Chang *et al.* (2012). The tool integrates GIS ecological connectivity assessment with a patch-corridor-matrix model (in this case a few large patches of natural vegetation, major stream or river corridors, connectivity with corridors and stepping stones between large patches, and heterogeneous bits of nature across the matrix) to identify valuable habitats and ecological corridors that should be protected or restored from development (Chang *et al.* 2012).

Von Haaren and Reich (2006) analyse the use of German greenways and how they are being used increasingly as valuable habitats. Initially the greenways were developed by landscape planners to protect areas from urban sprawl, to improve air quality in industrialised areas and to offer recreational opportunities. The linear habitats are now being used to move from the traditional approach of conserving nature in small and isolated protected areas to creating an ecological network for species to disperse across. It is hoped that the greenways will compensate for the habitat fragmentation that has resulted from its high density transportation network. These areas enable the provision of multifunctional habitats, however, progress has been limited by conflicts with landowners.

Invasive species

Hansen and Clevenger (2005) explored the role of transportation corridors in the spread of invasive species by sampling the frequency of alien species along railway and road transects. The research showed that invasive species were more abundant along transport corridors than in control sites and that grasslands had a higher abundance of non-natives than forested areas. Transportation corridors had a significant effect on the abundance of invasive species in the forested areas, where the abundance decreased with distance from corridor, but did not for grasslands. The results highlighted that grassland and roadside verges are more prone to invasion compared to forested habitats and demonstrates the need for measures to minimize disturbance to communities adjacent to transport corridors during construction or maintenance works.

However, linear transport corridors were found to have little effect on the dispersal of invasive species in a study by Sullivan *et al*. (2009) in New Zealand. The number of residences within 250m was highlighted as an important factor in the abundance of invasive species on roadside verges as well as the presence of woody debris. The species that were most abundant included those spread by invertebrates, naturalized species and agricultural species and weeds. The study results found that the control of invasive species should not be focused on transportation corridors and instead as part of wider landscape.

Garnier *et al.* (2006) simulated the escape of oilseed rape crops into natural habitats through modelling roadside verge management, seed dispersal, seed bank and density-dependence. The model showed the crop to last at least 5 years despite the large extinction probabilities and that a combination of anthropogenic and intrinsic factors determine the population persistence. Such modelled methodologies are useful in understanding gene transfer into the natural population to be used to increase understanding and mitigate the spread of invasive species.

In a study by Penone *et al*. (2012) it was found that the location of invasive species was not influenced by habitat fragmentation along railway edges and was instead strongly related to the degree of urbanization.

Biodiversity: Summary

Transport soft estate has been shown as having the potential for increased biodiversity value in the literature. Establishment of species rich grassland especially along road verges is an identified opportunity for biodiversity enhancement.

Roadsides with a higher species diversity have a significantly greater abundance and diversity of bees and butterflies. It was found that the breadth of the verge and volume of traffic did not affect bee abundance, with the plant species present being the most controlling factor (see pollination section). Verge width did affect moth abundance, narrower verges having less shelter, whilst wider verges were beneficial for carabid beetles and their dispersal.

The research showed road verges to be valuable refuge for some fauna such as small mammals including wood mouse, common shrew, bank voles and field voles, but the transport network can also lead to fragmentation, barrier and mortality impacts on fauna. For sensitive species such as badger, otter, hedgehog road mortality can account for up to 60% of overall mortality. More research is needed to determine how significant road casualties are in terms of overall population dynamics.

Verges can provide shelter for some bird species, when they are a complementary habitat to the dominant habitat in the surroundings. For example if the surrounding habitat is highly fragmented by intensive cropping, a contrasting verge habitat would be most favourable, though there are seasonality factors to take into account. Woody debris can enhance bird species diversity and abundance on verges. However, some sensitive species such as the barn owl are adversely affected by road networks, with major roads having the most significant effect.

Butterfly and moth diversity has been shown to increase with the size of roadside verges and increasing plant species by sowing flowering plants on road verges is also thought to be beneficial for butterflies.

Differences in width, the surrounding land use, and management techniques for transport soft estate can all affect the associated biodiversity. The surrounding landscape influences ecological quality of transport soft estate. Activities such as fertilization associated with agricultural land can lower the habitat quality of the border zone, whereas organic practices have been shown to be beneficial for plant species and for bees (see pollination).

The management of road verges has been found to play a key role in the biodiversity of roadside verges. Cutting verges twice a year with hay removal was the most beneficial for insects in terms of abundance, diversity and number of flower visits. The early summer cut was particularly important for insects as it resulted in feeding opportunities from re-flowering of plants later in the growing season.

The Mosaic Approach, although untested in the transport sector, could offer a potential approaches to managing the soft estate in a way that is beneficial for a range of species.

Ecological Connectivity: Summary

The literature identifies that the connectivity value is highly context dependent. In some circumstances, transport corridors can act as ecological corridors to connect otherwise isolated habitat patches. Often the benefits of verges as corridors for species movement are primarily for less demanding, generalist species that are tolerant of disturbance and pollution and are resilient to increased mortality risk associated with traffic. For other species such as those present in small isolated populations, requiring extensive areas for their home ranges, or exerting long migratory movements, the barrier/fragmentation and mortality risks associated with such corridors can be significant.

Using transport soft estate to reconnect ecological networks requires both a project level and a strategic level approach. At the project level, there is potential to use animal tunnels and bridges to address habitat fragmentation as a result of transport networks. Although not addressed in detail in this review, the literature suggests that there is a paucity of robust information to verify the effectiveness of these measures. At the strategic level, GIS methodologies have been reported in the literature as effective methods to identify the best places to locate ecological networks as well as prioritise the location of connecting areas for conservation. Studies have also suggested that networks of recreational greenways could be an effective means of compensating for habitat fragmentation resulting from new transport networks. This is an area that would benefit from further investigation but is beyond the scope of this review.

Ecological connectivity can also promote the spread of invasive species and management practises need to be designed to limit the growth of such species. The literature suggests that control should focus on the wider landscape, not just the transport corridor.

3.3.4. Ecosystem services

Management from an ecosystem services perspective is normally concentrated on delivering final ecosystem services as these are the ones which directly benefit human well-being (UK NEA, 2011). The final ecosystem services deemed to be relevant to transport soft estate are listed in Table 3.2 using the categorisation specified by the UK NEA. Pollination is not a final ecosystem service as per the UK NEA definition, however it has been included within this section because its relationship with provisioning services is well understood.

Table 3.2. Ecosystem services classification set out in UKNEA

Ecosystem Service Category	Ecosystem Service
Provisioning services	Biomass: Trees (woodfuel), standing vegetatation
Regulating services	Air quality regulation Climate regulation (local temperature/precipitation, GHG sequestration, etc) Soil quality regulation Water quality regulation Hazard regulation (ie storm/flood protection, bank stability) Noise regulation
Supporting Services	Pollination
Cultural services	Landscape and visual amenity Health Goods[2]

Modified and adapted from UK NEA (2011).

Provisioning services of Crops, Livestock/aquaculture, Fish, and Water supply have been removed as they are considered to be services that are not widely applicable the transport soft estate. Although wild species diversity can be regarded as a final ecosystem service (many humans derive a benefit from the existence value of certain flora and fauna, and some of these species may have yet-to-be-discovered potential as food or medicine), management for this benefit has been considered within the biodiversity section above.

Provisioning services

Biomass

In the management of roadside verges, cuttings are frequently removed to allow the regrowth of plant species. The use of these cuttings in anaerobic digestion to produce energy was investigated by Salter *et al*. (2007). The results showed that the process of roadside cuttings could be self-sustaining, as the energy gained is greater than that used in the cutting, removal and processing of the grass. Additionally the biogas produced by anaerobic digestion can be used to power the vehicles used for cutting.

An article by ClickGreen (2013) describes a research project undertaken at a National Trust farm in Wales to trial a new technology, developed in Germany, which could turn soft rush, gorse and bracken crops found along roadsides into viable biomass fuel. The COMBINE project is being coordinated by non-profit company Severn Wye Energy Agency in partnership with the National Trust and the sustainable waste management organisation, Cwm Harry Land Trust. The project is

[2] The term “Health Goods” as set out in the UK NEA is included in the context of how a greener soft estate may positively affect driver mood and reduce stress.

funded by the European Union and the Welsh Government Trunk Road Agency. The technology known as IFBB (Integrated Generation of Solid Fuel and Biogas from Biomass), is also being trialled in Germany, Belgium and France where roadside verges are being tested for their potential to be turned into pellets or briquettes – a research area of keen interest to the Welsh Government's Trunk Road Agency. This technology could help resolve the conflict between bio-energy and food production by utilising raw materials which have previously not been suitable for biomass, such as roadside verges.

Experiments were carried out to examine the feasibility of separating K and Na components out of grass from road verges to make the grass a more productive biofuel. Verge grass is commonly used as biofuel in the Netherlands, however the high ash, K, Cl and N contents limit the amount of thermal conversion. The study showed that was possible to create an effective solid biofuel from low quality grass through using this process to separate out wet fractions to produce fibre fraction of good quality grass (Elbersen *et al*. n.d.).

A Masters thesis by Qin (2011) has investigated the potential for willow cultivation on roadside verges in the Netherlands. The study includes an analysis of the estimated area of road verge available for willow cultivation, taking into account constraints such as land use conflicts, road safety and ecological concerns. Six different management options were developed. These were composting of verge grass; gasification of verge grass; and four willow cultivation options defined by different available areas, fertiliser and herbicide input and rotation lengths. Road verge without any application of fertiliser or herbicide had the best energy performance. The current management regime is mowing and transporting verge grass twice a year and compared with this baseline, the cultivation of willow would result in a saving of energy and cost. The change from composting of verge grass to biogas production would according to this study result in a cost saving of about 34,500 Euro for Rijkswaterstaat and municipal authorities annually. The study found that the mowing of grass twice a year required more energy than harvesting willow sticks every two years, and transporting freshly cut grass costs more energy than collecting dry willow sticks with a lower water content.

The Forestry Commission has produced a number of publications and technical notes on woodfuel, including 'Small-scale Systems of Harvesting Woodfuel Products' (2005). This technical note provides guidance on the selection of appropriate systems for small scale harvesting operations and includes woodfuel production costs.

A report produced for the Highways Agency has recently identified the opportunity to utilise its soft estate for its timber, with potential products ranging from biomass for power generation through to traditional woodland products (Ground Control, 2013). Biomass for power offers a good potential return for investment and responds to the need to meet the UK target for 2020 to have 15% of energy generated from renewables. It also delivers against the nation's carbon reduction targets with the need to reach an 80% reduction (against 1990 levels) by 2050. The HA is about to start its Biomass project in the north of England. It is envisaged that the pilot should provide an objective basis for maximising the value of a sustainable approach to the management of the HA soft estate.

Regulating services

Air quality regulation

Cooter *et al*. (2013) highlight the importance of the atmosphere in the provision of ecosystem services and how its value is often overlooked. The atmospheric and biological systems are tightly coupled, where changes in land use can affect local temperatures and weather patterns. Air-ecosystem services are involved with two-way feedback between the atmosphere, biosphere, weather and pollution. Ecosystems provide clean air through the removal and dilution of harmful chemicals in the environment. Changes in land use, weather and pollution emissions can affect air quality. Roads in particular have a profound effect on air quality (Kim *et al.*, 2004); though diesel exhaust from train engines can also have localised effects around freight yards (Hricko *et al.,* 2014).

Roadside vegetation can play an important role in reducing local pollution levels and improving air quality. A study by Sæbø *et al*. (2012) looked at how effective different tree and scrub species were for air pollution removal. They found that the amount of particulate matter (PM) accumulated on the leaves varied with the leaf properties such as the amount of hair and wax cover. Out of the forty species studied dwarf mountain pine (*Pinus mugo*), Scots pine (*Pinus sylvestris*), yew (*Taxus media, Taxus baccata*) Stephandra (*Stephanandra incise*) and silver birch (*Betula pendula*) were found to capture PM most effectively. The results found in the test sites in Norway and Poland found leaf particulate matter in the different size fractions to vary by up to 15 fold. The results can be used for selecting the best plant species to be used in urban areas or on transport networks for clean air provision.

The United States Department of Agriculture (USDA) Forest Service has developed a software suite called ‘i-Tree’ which provides quantitative analysis of the ecosystem services supplied by urban forests. One of the components (i-Tree Streets) focuses on the benefits provided by street trees within an urban context. The outputs of this model have informed a number of reports in the US, Australia, Canada, Spain, and the UK (USDA Forest Service, 2014). One such report for Edinburgh’s urban tree cover estimated that the city’s trees removed 100 metric tonnes (MT) of a suite a pollutants from the local atmosphere in 2011 (Forest Research, 2012). Air quality related recommendations from this report include: sustaining existing tree cover especially large healthy trees, planting more trees especially in areas of poor air quality, and selection of tree species to maximise air quality amelioration effects. A similar study in the Torbay conurbation found that pollution removal by trees and shrubs was of the order of 50 MT per annum and was particular effective in the summer when the trees were in full leaf (Rogers *et al.,* 2011). Both studies found that trees were most effective at removing ozone, followed by PM_{10} and nitrogen dioxide. Larger tree species in particular appear to provide more air quality benefits (USDA Forest Service, 2013). Although the i-Tree findings relate to an urban context, they could be applicable to Highways Agency soft estate, especially where it passes through major settlements and conurbations.

A number of studies have researched the effectiveness of vegetative barriers along roadsides, to see if they could provide a sustainable to minimising pollution levels along transportation corridors.

The Comprehensive Turbulent Aerosol Dynamics and Gas Chemistry (CTAG) model was modified to be used to explore the impacts of vegetation barriers on road verges on local particulate matter (PM) concentrations (Steffens *et al*. 2012);. The roadside barriers work through effecting turbulent mixing and the dry deposition of atmospheric particles. The model showed that an increase in leaf area index, used to characterise plant canopies, increased the effectiveness of vegetation barriers, although the response was not linear. A greater simulated wind speed was found to increase the number of particles larger that 50nm that were trapped by the vegetation barrier but have minimal effect on smaller particles, as more impaction occurred but particle diffusion was unaffected. When validated against measured PM concentrations, the model was found to perform well overall but needs to improve simulated movements on small PM.

Conversely, modelling simulations by Vos *et al*. (2013) found that roadside urban vegetation can actually lead to increased local air pollution levels due to decreased air flow and consequent reduction in pollution dilution. The effect of the barrier to aerodynamic flows was found to outweigh the removal of pollutants by the vegetation.

Brantley *et al*. (2014) investigated the effect of roadside noise barriers on air quality. Through sampling ultrafine particles at 3 near-road locations, they found that solid barriers may mitigate near-road impact. Evergreen, deciduous and a brick wall barrier were studied and results showed that ultrafine particle concentration was reduced by up to 50% by the wall. However, trends at vegetative barrier sites were found to vary and the barrier effect was shown to be uncertain. The vegetative barriers were relatively thin tree stands and further research regarding the mitigation potential of vegetative barriers of other configurations (e.g., greater density, wider buffer) is encouraged.

A river restoration scheme in the centre of Seoul, South Korea (the Cheonggyecheon Stream restoration works) improved local air quality and resulted in a reduction in air small particle concentration by 35% (Hwang, n.d.). There were additional benefits for water quality, climate regulation and biodiversity. To what extent the air quality impacts are attributable to the significantly reduced traffic (a 12-lane highway was replaced by a much smaller thoroughfare) or the green infrastructure aspect is not clear, but clearly the scheme had a significant positive outcome.

A Natural England report (Bignal *et al.*, 2004) suggests that roadside shelterbelts of trees and shrubs can capture road dust efficiently and can also be effective in reducing transport of metals from a motorway. The report recognises that the effectiveness of vegetation in trapping particulates is species dependent, with conifer species found to be most effective due to their finer, more complex foliage structure.

Deciduous broadleaves and small-needle conifers were found to be the most efficient species in preventing the dispersal of lead and cadmium. However, in terms of gaseous pollutants, the report revealed that levels of NO2 along the M6 were found to be lower only on the immediate tree side of the shelterbelt; 50 m from the road the NO2 levels were not affected by the presence of the shelterbelt. Furthermore, the same study reported that whilst many tree species can act to improve air quality, other species can have adverse effects through emitting volatile organic compounds (VOCs), which together with NOx, can contribute to the formation of pollutants such as ozone and secondary particles. Species with the greatest capacity to improve air quality include ash, larch, Scots pine and silver birch whereas species such as oak, willow and poplar have the potential to worsen air quality. Vegetative buffer zones may therefore be best seen as providing a physical distance between the road and the protected site, rather than an area of vegetation that is able to remove pollutants from the atmosphere.

Climate regulation

Carbon sequestration

Green infrastructure in urban areas and along transport corridors can help regulate climate through carbon sequestration, particularly in the context of sustainable urban development, climate change and reducing greenhouse gas emissions.

Bouchard *et al*. (2013) investigated the capacity of roadside vegetation filter strips in North Carolina to sequester carbon. Monitoring was done in two environments of differing soil type, the Piedmont and Coastal Plain, for the total soil carbon and carbon density. Wetland and dry swales were also compared. The carbon densities of vegetation strips were similar to those found in research in grassland environments indicating that grassland data could be used as a surrogate in calculating carbon sequestration along roadsides. The data showed that carbon sequestration rates used in the Federal High Administration report were overestimated. Percentage of carbon was significantly greater in wetland swales than dry swales, however, carbon density did not differ between them. The research work demonstrated that in terms of carbon sequestration wetland sales appear to be preferable to dry swales for roadside carbon stores. The research can be used to predict the maximum carbon content of grassed roadside soils in order to calculate the net carbon source and sinks on roadside vegetation strips.

However, Chisholm (2010) describes the conflict between the ecosystem services of water and carbon and how schemes to promote carbon sequestration are not always advantageous, particularly in areas of high biodiversity. For example afforestation of timber in South Africa may be beneficial for carbon sequestration but can result in habitat loss, declines in biodiversity and adverse effects on water supply. The author created a model to simulate this scenario in a South African shrubland catchment, to see if economic gains from afforestation would outweigh the costs. Although the model runs showed timber plantations to be economically viable for the region, they would not be if the industry were to pay the true cost of the water used by the plantations. The conclusions of research are that legislation should define the environmental conditions where afforestation is a viable strategy for carbon sequestration. Afforestation along transport corridors may be useful in providing a visual screen or sequestering roadside carbon but may not be the best solution if a valuable linear habitat is already present.

Davies *et al*. (2011) quantified and mapped above-ground biological carbon storage in Leicester through conducting vegetation surveys across the city. The research calculated that 97% of the 231,521 tonnes of carbon stored in the above ground vegetation was in trees rather than herbaceous plants. Levels of stored carbon in domestic gardens was of a similar magnitude to that of herbaceous plants. The authors go on to suggest this research can be used to inform local authorities in realistic carbon emission targets on city-wide scales.

Greening of urban car parks is a method being used to enhance urban carbon sequestration, biodiversity and aesthetics. O'Donoghue and Shackleton (2013) sampled 28 urban car parks in South Africa to record tree species composition and density in order to calculate the annual carbon sequestration potential. The average tree density was 27.2 trees per hectare and average annual carbon sequestration potential was 1390 kg per hectare. Car park greening is recommended in urban areas to sequester carbon as well as provide the associated ecosystem services and visual benefits.

Radford and James (2013) also looked at how the value of carbon sequestration services change along the rural to urban gradient, which occurs along many transport corridors. The results found carbon sequestration to be highest in peri-urban sites, due to the presence of gardens with a diverse range of native and non-native plant species.

The i-Trees reports also assess the carbon sequestration potential of urban forests. Edinburgh's urban trees were estimated to store 145,611 MT of carbon in 2011, and were also estimated to sequester 4,721 MT of carbon (Forest Research, 2012). Meanwhile Torbay's urban trees store and annually sequester 98,000 MT and 3,320 MT of carbon respectively (Rogers *et al.,* 2011). As well as tree size, the two i-Trees reports also link carbon sequestration potential and other benefits to leaf area size. The three most important tree species identified in the Edinburgh study were *Acer pseudoplantus* (sycamore), *Ilex aquifolium* (holly), and *Prunus* spp (e.g. cherry trees). The three most important tree species identified in the Torbay study were *Fraxinius excelsior* (European ash), *Acer pseudoplantus* (sycamore), and *Cupressus leylandii* (Leyland cypress).

Temperature regulation

There is extensive literature related to the role of vegetation in reducing temperature in urban areas and mitigating the urban heat island effect, through shading and evapotranspiration (c.f. Hwang, n.d.; Gill *et al.*, 2007), but no studies could be found that provide evidence for the role of vegetation in reducing temperature of non-urban road surfaces and rail track (see section 3.3 below for more detail).

Managing surface water and regulating flood risk

As the climate changes, extreme rainfall events will likely be more prominent and flood risk is a significant issue that is gaining awareness across large parts of Europe and the UK. Mitigating future flood risk is high on the agenda of many governments as the health and economic risks from extreme flood events can be severe and long-lived (Defra, 2014).

The development and implementation of green infrastructure within transport corridors can have a significant impact on mitigating flood risk and enhancing climate resilience. A key step towards reducing flood risk is associated with changing the land use type so that it is less susceptible to flooding events during periods of extreme rainfall. The literature identifies several approaches towards achieving this objective, such as the implementation of floodplain woodland restoration, sustainable drainage systems and urban stormwater management and (Nisbet and Broadmeadow, 2003; Dickie *et al.*, 2010).

Through the identification and mapping of areas within a catchment where woodland could best aid flood control, the subsequent restoration of floodplain woodland and upstream woodland can provide many benefits. Nisbet and Broadmeadow (2003) identified four main ways that woodland could assist in flood control - through delayed floodplain flows, delayed channel flows, delayed soil runoff and increased water use. Their study on the River Parrett catchment in southwest England found that the greatest scope for suitable floodplain restoration sites were in the middle and upper reaches of the catchment, equating to 21% of the entire fluvial floodplain. Furthermore, opportunities were identified in the wider catchment for new woodland planting where parts of the catchment are classified as having imperfectly or poorly drained soils that are liable to generate rapid surface runoff, and comprises soils at risk of severe structural degradation or have a high vulnerability to soil erosion. Woodland planting could be expected to largely remove the risk of soil compaction, and by improving soil structure and soil infiltration rates, help to reduce and retard soil runoff and thus flood flows (Nisbet and Broadmeadow 2003).

There is an extensive body of research on sustainable drainage systems (SuDS), although mainly associated with urban areas rather than transport corridors through rural areas. However, many of the same principles could still apply. SuDS schemes mimic natural drainage processes and can reduce flood risk because they slow down flow rates into watercourses, provide areas for temporary water storage, and allow more time for water to move directly to the air through straight evaporation or evapotranspiration (Jones and Macdonald, 2007; Dickie *et al.*, 2010). A number of SuDS systems can be used along roads such as filter strips, swales, rain gardens, filter drains and rills (Wilson *et al*. n.d.). A common example of this is a soakaway, which can slow the rate at which water runs off road surfaces and into watercourses.

When planned properly, SuDS create habitats that encourage biodiversity, reduce flood risk, improve water quality management and increase a systems adaptive capacity (Mcbain *et al*. 2010). The Flood and Water Management Act 2010 promotes the use of SuDS and makes local councils responsible for their implementation on new developments through the creation of SuDS Approving Bodies (SABs). They are already recommended features to be used alongside the grey aspects of road and rail infrastructure (Highways Agency *et al*, 2001).

Despite their potential, a number of factors need to be considered prior to implementing a SuDS scheme including the underlying groundwater condition, the hydraulic performance, environmental performance, project feasibility, and cost implications. Ellis *et al* (2004) have developed a multi-criteria framework to select suitable SuDS to control run-off from roads. This includes socio-economic factors as well as environmental considerations, and also takes into account the extent to which water release can be controlled at source as well as stakeholder feedback. Their framework has been used in the assessment of potential schemes in France.

There are additional issues affecting SuDS uptake in England and Wales. Some of the issues of scheme ownership have now been addressed, but there remain a number of barriers to wider implementation such as how to regulate across a scheme's lifetime and how to conduct robustness checks (Anglian Water, 2009; Wheater and Evans, 2009).

Water quality

Water quality is an environmental area currently receiving much attention due to the implementation of the European Union Water Framework Directive (WFD) and its outlined requirement for all water bodies to meet good ecological status by 2027. The management of land and water are intrinsically linked and changes in land use can alter flood risk, available water resources and water quality. Poor urban water quality, polluted from sources including road runoff, industrial pollution and spillages, presents a future challenge for river management (Wheater and Evans 2009). This is particularly sensitive in ground water dominated catchments where pollution can lead to a long term legacy of poor water quality.

Transport corridors, in particular, can act as channels collecting and transporting pollutants that can enter watercourses. For example, a study of Fishkill Creek in New York found that road grit that is intensively applied to roads in the catchment was entering the watercourse and threatening future fresh water availability (Jin *et al*. 2011).

In addition to their surface water regulation properties, SuDS can also improve water quality by filtering out harmful pollutants before they can reach water bodies. SuDS such as vegetation and soil-based filter strips along roads could therefore be a solution to transport-related water pollution issues. Piguet *et al*. (2008) conducted research on behalf of the Swiss Federal Road office into a new road runoff management concept which encourages diffuse infiltration of runoff from roads into infiltration slopes. The infiltration slope was a 20m long structure consisting of a shoulder made from crushed stone seeded with grass, with a road base and a bentonite geotextile. The study found that soils are able to retain particles and contaminants, which lowers the impact of roads on the environment and improves the recharge of aquifers. Monitoring found that contaminant retention was at its lowest during thunderstorm events as pollutants are remobilised and able to infiltrate into the soil. It was found that the on-road concentrations of low mobility (Pb, Mn, Ti) pollutants was substantially reduced after thunderstorm events whereas high mobility pollutant (Br, Ba, Mo) concentrations remained similar. Concentrations of the high mobility pollutants were, however, lower in the aquifer due to dilution effects. Trials undertaken found that the management concept would be useful in areas where aquifers are slightly vulnerable but are out of groundwater protection zones and lowers the pollution impact of roads without compromising road safety.

Another example of a SuDS approach to control runoff from motorways is the addition of roadside retention ponds (Le Viol *et al.*, 2009). This study in France found the biotic characteristics of these ponds to differ to those in the surrounding area due the retention of pollutants within them. Interestingly, they still provided important refuges for a variety of flora and fauna. Macroinvertebrate assemblages contained a greater number of short lived species compared to nearby ponds but the population was found to be just as diverse. The study found roadside ponds to be important in water management as well as acting with roadside verges to promote ecological connectivity and provide important species refuges.

However, there was a dearth of other studies on the applicability of green infrastructure to water quality problems alongside transport corridors specifically. Nevertheless, it may be possible to extrapolate findings from studies of vegetated riparian buffer strips to filter pollutants and protect river water quality. The Soil and Water Assessment Tool (SWAT) was used to model the flow of water from crop land into rivers through contour and riparian buffer strips (Sahu and Gu 2009). It was used to test how effective linear buffer strips are at reducing the NO3-N and sediment concentrations of surface flows. Simulations showed that the effectiveness of buffer strips varied with size and location. Those that were 10-50% of the sub-basin area have the potential to reduce NO3-N concentrations by 55-90%. The study illustrates the potential of vegetation filter strips along features such as rivers, roads and rail lines to trap pollutants and protect water quality.

There may be significant potential to utilise vegetated SuDS techniques, such as creating swales, infiltration strips, detention ponds along transport corridors for flood attenuation and water quality management. Transport operators are already adopting vegetative sustainable drainage systems such as balancing ponds into the design of new road schemes to aid both flood attenuation and improve water quality. For example:

- The A34 was designed to incorporate a surface flow wetland and balancing pond;
- The A417 has a dry balancing pond (Highways Agency, 2006);
- The M40 at J8a (Wheatley services) was designed to include a swale, a wet balancing pond, and a series of lagoons and reedbeds to deal with run off and waste water (Highways Agency, 2006; Susdrain, 2014);
- Hopwood motorway service area at M42, junction 2 has a range of solutions including grass filter strips, stone collector trenches, spillage basins, grass swales and balancing ponds to treat run-off from the HGV lorry park (Susdrain, 2014), and;

- The Bath Road near Heathrow Airport, London has a system of infiltration trenches and soakaways to allow water from a contaminated land site to drain whilst simultaneously trapping heavy metals (Susdrain, 2014).

Hazard regulation: Soil retention and slope stability

The Department of Natural Resources, Environment and Arts of the Northern Territory Government produced guidelines on erosion and sediment control for transport corridors (Northern Territory Government n.d.). The guidelines were produced to assist land developers, owners and managers to protect the landscape from anthropogenic soil erosion. If precautionary measures are not taken transport corridors could lead to excessive soil erosion and the removal of soil particles from one area to another. Erosion control measures can be used to strengthen soils and prevent erosion and sediment control measures to capture the eroded sediment. The site topography, drainage, soil type and vegetation cover should be assessed to identify the soil erosion risk. Commonly used control measures can be temporary or permanent and include diverting waterways, adding culverts, drains and crowning.

However, green infrastructure has a role in promoting soil retention and slope stability. Trees are known to promote these services through mechanical root reinforcement and by the establishment of soil suctions (Briggs *et al*. 2013). This is discussed in greater depth in Section 3.3.

Noise regulation

In general the literature concentrates on road noise over rail noise. A recent Defra study identifies road traffic as the main source of anthropogenic noise studied globally (accounting for 60% of all studies), with rail traffic accounting for less than 5% of studies (Defra, 2013b). However, a report by Directorate General for Internal Policies (2012) reports that 1.7% of the population are affected by rail noise in the UK, which is fairly low compared to the other EU countries featured (with Austria being the worst affected with 9.3%).

Noise from urban areas and transport corridors has been found to affect animal communication and behaviour (Warren *et al*. 2006). These environments are characterised by the presence of reflective surfaces and spatial and diurnal noise level variations – all of which have analogues in the natural world.

A recent UK Government review found that the most robust research had been undertaken in relation to the impacts of traffic noise on birds and bats (Defra, 2013b). For example, song frequency shifts amongst some bird species is associated with road traffic noise (Patricelli and Blickley, 2006). Moreover, elevated noise levels in cities is leading to reductions in reproductive success in bird species, although the causal mechanisms behind this remain unclear (Warren *et al*. 2006). Other studies on UK protected species and species of principal importance have focused on abundance and breeding bird density at noisy roadsides compared to control sites (Reijnen *et al*, 1996; Rheindt, 2003; Peris and Pescador 2004). While these studies implicate noise as a factor in their reported results, it is difficult to draw firm conclusions because there is no control for confounding factors such as overall disturbance levels, lighting and air pollution. Moreover, fitness implications are difficult to extract from such data.

Assessments of the impact of road traffic noise on a species of gleaning bat (the greater mouse-eared bat *Myotis myotis*) represent some of the best work on the influence of anthropogenic noise in mammals (Schaub *et al*., 2008; Siemers and Schaub, 2011), and show reduced foraging efficiency when exposed to traffic noise. Since greater mouse-eared bats use the same foraging strategy as the brown long-eared bat (Swift and Racey 2002; Siemers and Swift 2006), it can be inferred that foraging efficiency in this species is likely to be influenced by the presence of road traffic noise.

Green infrastructure can be used to minimise the effects of noise pollution from transport systems on human and ecological receptors.. Typical solutions include vegetation belts and soft earth berms which can be used as an alternative to hard-engineered acoustic barriers. These are likely to be particularly effective in rural, suburban and peri-urban areas, but less effective in urban locations (Radford and James (2013).

Some research has been conducted to compare the relative merits of green acoustic barriers such as vegetation strips and soft earth berms with their grey-engineered equivalents. For example, a study comparing the noise reduction impacts of vertical walls and earth berms, raised soil banks, found that in the long term, including periods of strong winds, acoustically soft berms to be more effective (van Renterghem and Botteldooren 2012). A full-wave numerical model used found that noise walls can have little effect in windy conditions compared to an unobstructed area. Berms with a slope gradient greater than 1:3 and a flat top had an average wind effect that was smaller than 1dBA due to their streamlined shape.

The effect of a vegetation belt of a maximum depth of 15m was tested using 3D finite-difference time-domain calculations by van Renterghem *et al*. (2012). The calculations showed that a forest floor alone can lead to sound reductions compared to grassland. Presence of a forest floor and tree stem configuration were found to be equally important in reducing road traffic noise. Increasing the stem diameter lead to greater noise reductions, with distance between the road and tree stand being the most effective factors in predicting sound reduction effects. A shrub zone that is 15m long and has an above ground biomass of 4g/m2 was predicted to give a noise reduction loss of 4.7dBA (for light vehicles travelling at 70km/h) compared to grassland. The study found that 15m deep tree stands could have similar noise reducing effects to a 1-1.5m noise barrier as well as offering other services such as carbon dioxide sequestration, improve quality and improve the visuals of an area.

Vegetation belts were found to be effective noise barriers along roadsides in a study in India by Tyagi *et al*. (2006). Noise attenuation by vegetation belts were measured across different sound frequencies to find that attenuation increases with frequency. An attenuation of 10 to 16 dB was found at a low frequency of 314 to 400 Hz compared to an attenuation of over 20 dB at 10 to 12.5 kHz. Vegetated sound barriers were found to be effective for noise mitigation as high attenuation was found in middle range frequencies, which are most commonly heard by humans.

Despite their effectiveness at reducing noise disturbance, acoustic screens create other problems for human receptors. A pilot study showed that residents who benefit from noise screens also complain about loss of light, restriction of view, poor maintenance of the barrier, and restricted access (Arenas, 2008). The study also found that residents tended to prefer to vegetated barriers. However, the study did note that the noise reductions were minimal unless the vegetation is very dense and wide. In practice, vegetation is often used to soften and enhance the appearance of a grey barrier, and guidance exists as to how best to incorporate it in the design (Kotzen and English, 2009).

Whether noise barriers provide biodiversity benefits is uncertain. Clearly, if noise reduction were the only consideration then they ought to be effective and indeed some researchers advocate their use (Reijnen and Foppen, 1996). However, the same authors also point out that screens and wall barriers may be a form of disturbance in their own right as, in open areas, many birds will avoid such structures. As a physical construct their presence has mixed impacts. Arenas (2008) speculates that as a physical barrier they reduce the ability of ground-based wildlife to cross roads. This would reduce the frequency of vehicle collisions but would exacerbate fragmentation. Moreover, some species of birds frequently collide into transparent sound barriers (Reijnen *et al*., 1997). Purpose built wildlife crossings would mitigate the problems for ground based animals, whilst treatment of transparent screens with tinted or opaque material would reduce bird collisions (Arenas, 2008). However, no studies were identified which go on to test these theories.

Supporting services

<u>Pollination</u>

Ecological corridors are important conduits for species dispersal. A study by Townsend and Levey (2005) explored whether the assumption that these corridors facilitate the dispersal of species, more specifically those which rely on insect pollination. They monitored the dispersal of two plant species, one pollinated by bees and wasps (*Rudbeckia hirta*) the other by butterflies (*Lantana camara*), down a habitat corridor into a new habitat patch. The use of fluorescent powder showed that pollen transfer by butterflies, bees and wasps was significantly higher in connected patches than unconnected patches suggesting that ecological corridors enabled pollen transfer in fragmented landscapes.

Other studies have gone on to specifically investigate the potential for transport corridors to promote ecological connectivity. For example, Henriksen and Langer (2013) found that roadside verges next to organic wheat fields had a higher density of valuable bee plants than their inorganic counter parts. A 10 fold higher mean density of flowering plants was found in organic fields compared to conventional fields. This effect was also seen to a lesser extend in neighbouring roadside verges, which saw a 1.9 fold increase. Organic farming practices were found to have a beneficial effect on high value bee plant species both in the fields and adjacent road verges.

The relationship between restored roadside verges and native bee populations was explored in a study by Hopwood (2008). These roadside verges were found to support a number of species and provide valuable sources of pollen and nectar sources, due to the fact that they are uncultivated unlike agricultural areas. Restored roadsides that had been planted with a number of native species were found to have a significantly greater abundance of bees and species richness. It was found that the breadth of the verge and volume of traffic did not affect bee abundance, with the plant species present being the most controlling factor. Hopwood (2008) concluded that the restoration of roadside verges could have an important impact for bee conservation efforts.

Noordijk *et al*. (2009) recognised the importance of roadside verges in Norway for pollinators and investigated the best management techniques for these. Through a three year experiment it was found that mowing twice a year with the removal of hay showed the higher abundance of flower and insect species. The cut in the early summer was found to be the most important for insect feeding opportunities as it encouraged the re-flowering of plants later in the growing season. The results found the rotational management scheme on roadside verges to be the most valuable for pollinators and flowering plant species.

Cultural Services

<u>Landscape/sense of place and visual amenity</u>

Roads have a dual role in the visual landscape as described by Garré *et al*. (2009). They act both as dominant features that can often affect the aesthetics of a landscape and features that give access to the countryside and to visually stimulating scenery. Garré *et al*. (2009) found, however, that roads do not entirely open up the landscape and that scenery can be blocked by features such as roads and houses. Road networks were perceived to impact the landscape negatively in a participant survey. Participants were given photos of landscapes and asked to score them and those with road networks featured came out with the lowest scores. Results also showed that the type of road plays a large role in the score it was given where unpaved roads were given positive scores but roads with manmade materials were scored poorly. The surveyed results showed that trees, shrubs and water had a positive impact people's visual landscape preferences.

Ambiguity surrounds the attribution of economic value to landscape resources, which has led to them being undervalued in UK planning policy (Mell *et al*. 2013). The UK Natural Ecosystem Assessment was the first national scale economic assessment of our natural resources, which was supported by the Valuing Attractive Landscapes in the Urban Economy (VALUE) project to develop methodologies to economically evaluate the green investments in north west Europe. Mell *et al*. (2013) analysed VALUE street tree investments in Manchester through a willingness to pay (WTP) index created using results from a green infrastructure valuation survey. The survey results showed that 75% of participants were willing to pay for green infrastructure, with the amount they are willing to pay increasing with the size and greenness of the structure. The survey participants reported benefits of GI to include clean streets, reduced crime, climate control and less pollution.

Efforts have been made to aesthetically enhance the design of road and transport networks, although transportation networks still remain a contentious issue with many local residents. A literature review by Blumentrath and Tveit (2014) identified twelve visual characteristics of roads and objectives in road design: coherence referring the uniform design of roads; ‘imageability’ so that roads create a ‘sense of place’; simplicity regarding clarity of design and reduction of road furniture e.g. road signs; visibility reflecting the perceived scale of road environments and preference towards open spaces; maintenance of roads which can affect aesthetics; naturalness as a preference for natural materials and vegetated areas; integration of roads with the surrounding environment; contrast should be achieved where integration cannot be achieved through the addition of something new and positive to the landscape; variety of infrastructure to enhance visual characteristic; aesthetics of flow as an objective means that the road should be visually pleasing at all speeds of movement; legibility refers to the road network being understandable for the user and orientation so that road users gain an understanding of their environment as they travel. The authors conclude that an objective methodology and terminology on the aesthetics of roads should be integrated for assessing the visual quality of roads in order to incorporate this into planning policy.

<u>Visual Screening and Driver/Resident Stress</u>

Transport soft estate plays a dual and sometimes contrarian role in visual screening. On the one hand, vegetation can provide a visual screening service to local residents and landscape users, which reduces the impact on visual amenity that a road or railway might have. (See for example: Oxfordshire County Council, 2005; ERM, 2009). In addition there is also evidence that the visual qualities of vegetated screens reduce the noise and annoyance of railways better than the visual qualities of other types of barrier. Maffei *et al* (2013) used an Immersive Virtual Reality System (IVRS) to simulate several types of barrier next to a railway line. Residents were then asked to assess the noise reduction properties of the barrier. The barriers included: industrial aspect (concrete), bright aspect (flaming colours) and green aspect (plant type) along with opaque barrier (non-visible noise source) and transparent barrier (visible noise source). The green barrier performed the best in terms of relative noise perception and annoyance, offering a justification for the role of roadside vegetation in acoustic screening.

However, this study also revealed a secondary effect where, for all barrier types, noise perception and noise annoyance were lower for visually transparent barriers rather than opaque barriers. No explanation was offered as to why this phenomena occurred, and this would certainly warrant further investigation.

Belts of vegetation also screen the surrounding land use from drivers and other road users. Where the surrounding land use is built up, this effect is beneficial, with evidence from another driving simulation study suggesting that driver frustration is lower when road edges are vegetated as compared to ones which are urban (Cackowski and Nasar, 2003). Survey data also corroborate this finding with drivers preferring landscape settings where trees screen adjacent commercial land use (Wolf, 2003). However, in a rural setting, the result is the opposite with open views being perceived as more calming and positive than densely forested ones (Antonson *et al.,* 2009). This latter study also considers other driver behaviour characteristics such as speed and steering wheel grasp under three different landscape scenarios: open, forested, and varying. Average speed was significantly different between the three scenarios with the varying landscape producing the lowest speed and the forested landscape the highest speed. The forested landscape also resulted in a significantly less frequent steering wheel grasp than the open landscape. These results suggest that densely forested roads may be less safe than roads with open or varying landscapes.

Access

The value of integrating the needs of non-motorised users into the design and management of transport networks is widely recognised in transport planning and policy (DfT 2013). Networks of greenways and quiet lanes have been shown to provide a valuable part of the transport network. In a review of greenway planning in Britain, Turner (2006) found that the greenway concept was used by 33% of authorities over the past decade but that 75% expected it to become significant during the next decade. There is potential for the soft estate to be designed and managed to make non-motorised routes associated with the transport network greener. Sustrans is undertaking a large scale project to survey, protect and enhance biodiversity along some of the traffic-free sections of the National Cycle Network (Sustrans website n.d.). There is evidence to support the links between access to greenspaces and benefits for mental and physical health (Natural England 2014).

In addition, railways and roads can provide access to visitor destinations and can be used to promote sustainable travel, green growth and ecotourism, with potential for the soft estate to be designed and managed to enhance the attractiveness of transport networks when serving as gateways to visitor destinations. Two case studies in the Netherlands (Beunen et al, 2007) show that attractive gateways can tempt many visitors to park their car at the gateway, which results in reduced traffic flow within an area. One of factors in determining the attractiveness of a gateway to visitors was the beauty of the location. By implication there is potential for vegetation on the soft estate to be used to enhance the attractiveness of transport networks when serving as gateways for visitor destinations.

Ecosystem services: Summary

There were a number of studies which demonstrated the potential for the use of soft estate vegetation to produce biomass for renewable energy generation. Proposals have already been made to make use of the Highways Agency's tree assets for this purpose at certain locations on the road network. No studies were identified which investigated the potential for comparable projects on the rail network.

The effectiveness of vegetative barriers along roadsides for removing pollutants has been found to be variable. Vegetation is generally regarded as effective at removing particulate matter although has been found to depend on the particulate size as well as the vegetation species and characteristics, such as crown density, leaf area density, and tree size. Studies found there to be significant variation due to the amount of hair and wax cover on the leaves. However, in some cases vegetation can reduce air flow which can reduce the air pollution dilution effect. It may therefore be better to view vegetative buffer zones as providing a physical distance between the road and air quality sensitive ecological receptors, rather than an area of vegetation that is able to remove pollutants from the atmosphere.

Certain green infrastructure projects can also bring carbon sequestration benefits. Research suggests that wetland swales are preferable to dry swales as roadside carbon stores. Afforestation to provide visual screens for transport infrastructure will also have a carbon sequestration gain. However, when considering green infrastructure for climate mitigation, decision-makers will also need to assess the trade-off with the ecological value of the existing habitat which may be higher.

Although there is little literature that is specific to the transport sector, it is our view that surface water management techniques applied in urban areas could be applied in the transport sector. SuDS such as filter strips, swales and balancing ponds can act as multifunctional structures which have the potential to manage water quality, mitigate flood risk, enhance transport infrastructure resilience and also sequester carbon (Defra, 2013). The literature has shown the potential of vegetation filter strips to reduce the salt content in road runoff. Transport operators can also engage with land managers and other partners to identify land that could be used to reduce the flood risk to transport estate. Payment for ecosystems services could be one way to develop such a relationship. Transport operators such as Highways Agency are already adopting vegetative sustainable drainage systems such as balancing ponds into the design of new road schemes to aid flood attenuation and improve water quality. Several examples of SuDS are already in place on soft estate owned by the Highway Agency including the A34, A417, M40 and M42 (Highways Agency, 2006; Susdrain, 2014).

Noise disturbance has significant human and ecological impacts. The review has found that vegetation can be effective as a noise barrier, though the effectiveness depends on its size, shape, and composition. It performs better in rural and peri-urban areas than in an urban context. Vegetation also needs to be of a reasonable density to be effective. Attenuation increases with frequency and is effective in the human audible range. Vegetated noise barriers can also help avoid some of the adverse visual side effects of their grey equivalents. Some possible ecological advantages have also been proposed but no studies have yet been concluded which corroborate these hypotheses.

The literature highlights the potential for transport corridors to provide habitat for pollinators and that management on adjacent habitats can have a significant effect on density of flowering plants in the corridors, and hence on pollinators. Breadth of verge and volume of traffic did not affect bee abundance, although wider verges can benefit other pollinators (e.g. butterflies and moths). The best management techniques involve mowing twice a year with the removal of hay. Rotational mowing of road/rail sides verges (i.e. mowing at slightly different times on different areas) could also be very valuable for flowering plant species and pollinators.

Green infrastructure can also play an important role in enhancing the aesthetics of transportation corridors. The research suggests people attach a greater economic values to locations where areas of street trees are larger and greener. Studies also show that integration with the surrounding environment, creating a sense of place and the use of natural materials and vegetated areas are all important to aesthetically enhance the design of road and transport networks. The aesthetics of these linear habitats can affect how much residents value the visual amenity of an area as well as their perception of noise levels from local transport routes.

The presence of vegetation along the sides of roads plays a role in driver stress and behaviour. In urban contexts, vegetation helps screen adjacent built-up and commercial land use which improves driver experience and lowers stress level. However, in a rural context, when the surrounding landscape is densely vegetated with no open space, drivers experience less calm and drive less safely than when there are fully or partially open landscapes.

There is potential for designing and managing the transport soft estate to provide enhanced facilities for non-motorised users. The literature, though not specific to the transport soft estate, identifies the importance of gateways being visually attractive. By implication there is potential for vegetation on the soft estate to be used to enhance the attractiveness of transport networks when serving as gateways for visitor destinations.

3.4. Objective 2: Transport soft estate delivering infrastructure resilience to climate change

How green infrastructure has been used or enhanced to deliver ecosystem services both within and adjacent to the transport corridors to increase transport infrastructure resilience to climate change (i.e. green solutions to network resilience)

Transport networks are critical components of a nation's economic success. For example, the UK road network was valued as the government's single most expensive asset in 2005 with major trunk roads and motorways having an approximate value of £62 billion (DfT, 2005). However, they are also particularly vulnerable to the impacts of a changing climatic factors, which include: more intense storms and wind, greater extremes of temperature (especially summer heat), subsidence and landslides, flooding and sea level rise, and leaf and branch fall (Hooper and Chapman, 2012).

These can have material economic, social, and environmental consequences. Moreover, many existing and planned infrastructures will still be in use by 2030 or 2050 when climate change might have far more substantial impacts than today. This means that the potential impacts of a changing climate need to be routinely factored into investment decisions, policy development, guidance, design, construction, maintenance and operations (Highways Agency 2011; DfT 2010). Adapting the transport system to the projected impacts of climate change is an essential part of building, maintaining and operating a transport system which continues to support national economic competitiveness and growth (Giordano 2012). Effectively managing these risks at an early stage should result in reduced costs over the lifetime of decisions with benefits for the UK economy and transport users.

However, there is considerable uncertainty and complexity involved in climate change adaptation planning. Variability arises in climate prediction models at a global and local level, as well as in long term socio-economic models. As such, decision-makers need to make choices today based on incomplete and imperfect information (Climate Adapt, 2013). Resilience planning is one way to handle these uncertainties. A UK infrastructure network which is resilient to today's natural hazards and prepared for the future changing climate is a fundamental factor in the transition to a green economy (Defra 2011b). For new infrastructure this means location, design, construction, and operation should be able to cope with a wide range of potential climatic variation. Meanwhile, existing infrastructure can be made climate resilient by ensuring that maintenance regimes incorporate the potential range of climatic variation over the asset's lifetime (Highways Agency 2011; DfT 2010).

Measures to adapt the current transport infrastructure include ensuring infrastructure is resilient to potential increases in extreme weather (e.g. FUTURENET, 2009-2013); ensuring investment decisions take account of changing patterns of consumer demand as a result of climate change; building in flexibility so infrastructure assets can be modified in the future without incurring excessive cost; and ensuring that infrastructure organisations and professionals have the right skills and capacity to implement adaptation measures (Defra 2011b). Furthermore, to create a transport network that is more resilient to the effects of climate, we need to understand the socio-economic scenarios as well as the probabilistic climate changes in order to effectively mitigate against future disruption (Jaroszweski *et al.* 2010). Therefore the planning and designing of infrastructure to account for climate uncertainties is fundamental and the impact of these extremes on transport systems and adaptation measures must be flexible (Love *et al.* 2010). Consequently, the shape of the transport system in the 2080s will have an impact on the best approaches to adopt, i.e. will there be more high speed trains, or more or less electric rails etc. (Jaroszweski *et al*. 2010; Network Rail, 2011).

To achieve climate resilient transport infrastructures, it is essential that the impacts on the natural environment are considered and ways to use the natural environment in a sustainable manner are harnessed. Where new technologies are used to increase infrastructure resilience to climate change such as road surfaces made from materials that are able to cope with hotter temperatures and intense rainfall (Defra 2011b), these could have effects on the natural environment. For example the UK government introduced new road surface specifications, similar to those applied in the south of France, and introduced improved drainage standards for new works and renewals (Defra, 2009). This will improve drainage, allowing for increases in rainfall intensity of 20% – 30%, and will ensure that excess water is removed more quickly. However, there could be knock effects on the quantity and speed of water entering local watercourses, which could result in in localised flooding. Green Infrastructure could represent a solution to this kind of problem. For example, the use of SuDS in this situation could enhance water use and slow down water flow at appropriate locations by enabling infiltration into the ground, evaporation, and evapotranspiration (Gill *et al.*, 2007).

Ecosystem-based Adaptation (EbA) is a similar approach that has worked on both a national and international level at various sites. The aim of EbA is to use biodiversity and ecosystems to help people adapt to the adverse effects of climate change (EbA Flagship, 2004). The method uses an integrated approach to the management of land, water and living resources that promotes conservation and sustainability, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities towards climate resilience. The approach has been successfully applied in several countries, such as Kenya where the local conditions are suitable to use biodiversity to assist in climate resilience.

The concept of EbA could also be applied to transport corridors in the UK at a local level. For example, Dunnett *et al*. (1998) found that the relations between weather and vegetation dynamics in road verges near Bibury, Gloucestershire showed that even within what may be thought of as relatively stable vegetation there can be marked interannual fluctuations in species' abundance, partially explained by a response to climatic variability. Therefore the appropriate use of vegetation that can withstand climate variability, assist in landscape stability and reduce flooding can be used as a tool for climate adaptation (Defra 2010).

Together, Green Infrastructure and EbA could be seen as an integral part of adapting to climate change and to achieving a future resilient transport network. These may add costs now but there is potentially synergistic overlap with low-carbon attributes which will save considerably in the long-term (Quinn n.d.; Kennedy and Corfee-Morlot 2013).The following sections will consider how these approaches are being developed to tackle specific challenges posed by climate change to transport infrastructure.

Storm and wind damage

Wind is an aspect of the weather which has considerable uncertainty under future climate change scenarios. UKCP09 climate projections indicate that there may be an increased number of winter storm systems to the UK, which in turn may bring stormier and windier weather, albeit with some uncertainty in their distribution (Murphy *et al*. 2010) . In the event of an increased number of windstorms, there will be implications for the UK's transport network. High-sided vehicles will be more at risk of blowing over, as will trees and power lines located close to road or rail networks. The knock-on effects of such incidents include damage to road infrastructure such as bridges and barriers as well as road closures causing delays in the transport network (Hooper and Chapman 2012). For example, the 'Windy Thursday' storm of 18 Jan 2007 overturned 50 goods vehicles and caused £50 million in delay costs across the UK (Highways Agency, 2007).

Increased wind and storm events damage can have direct implications on rail power lines through an increase in the frequency and strength of high winds which may increase the incidence of dewirements and damage generated from the snagging of overhead lines with the pantograph of trains (Eddowes *et al*. 2003). Furthermore, storms may indirectly increase the incidence of damage to overhead lines by fallen trees and by wind-blown debris, in turn weakening the supporting brackets and fixings to power cables. In some conditions, railway lines can act as wind corridors because of the lack of intervening barriers. This can further exacerbate the impact of wind on overhead power lines as well as other nearby electricity infrastructure (Penone *et al*. 2012b).

Hooper and Chapman (2012) suggest that storm response procedures should be put in place to minimise the disruption when a storm event occurs. Such mitigation procedures have already been implemented by the transport sector to reduce the impacts from extreme weather events. For example, following the 'Windy Thursday' event, a new Alert system was put in place by the Highways Agency to mitigate windblown effects, with a r*ed alert stating "goods vehicles drivers should leave the road network and find a safe place to park up, and wait until the status is reduced to Amber", and an amber alert stating "you should make sure you and your vehicle are prepared for severe weather. Keep up to date with local weather conditions. If possible, use a different route to avoid the area of severe weather"* (Highways Agency, 2007).

Such mitigation procedures can be effective in the short-term, but if an extreme wind or storm event prevails for a sustained period, this is likely to have significant economic implications. As a result, the use of alternative measures to improve climate resilience should be considered. Network Rail (2011) have suggested the possibility of using ‘green landscaping’ as an adaptation strategy to reduce heat and flood risks. However there has been little research to date on how such measures could provide protection from the wind. If anything, from a wind perspective tree cover is still seen as a potential liability to transport networks and management manuals rely on a strict inspection, risk assessment, and felling regime (Network Rail, 2012).

However, in agriculture and conservation projects relatively dense rows of tree cover are often installed and managed for their effect in reducing wind speed (Zhou *et al*, 2005). Because they are semi-porous, these ‘shelterbelts’ are more effective than impermeable man-made barriers at protecting agricultural land or habitats on the leeward side. When wind strikes an impermeable barrier it is forced up and over, but very quickly regains its speed on the other side creating turbulence that is often more damaging than a straight wind. However, when it strikes more porous structures, such as rows of trees wind speeds reduce by 30% to 50% across areas up to 10 times their height without the turbulence effect (Caborn, 1965). Recommendations in use in sustainable land management projects in New Zealand are for these belts to be continuous, at least 24 times as long as there are high, and to be carefully managed to ensure that cover remains constant. Cover need not be entirely coniferous: although deciduous trees provide less cover in winter, they are less prone to being blown over by gales (Taranaki Regional Council, n.d.). Further research is required to assess the potential for applying this approach to transportation networks and would need to consider the appropriateness of shelterbelts within the wider landscape character, as well as optimum distance and locations to avoid the hazards related to trees close to rail tracks and roads.

Summary

Climate change is expected to result in a higher frequency of storms with greater intensity. Damage from these events will affect vehicles, trees, power lines, bridges and other infrastructure causing safety issues and delays. Current adaptation suggestions revolve around warning systems which advise where and when to avoid travelling. Green infrastructure in the form of shelterbelts (relatively dense patches of trees) has been employed in other contexts to reduce wind effects. However, in a transport context, large vegetation is still managed more as a wind liability due to safety risk of tree or branch fall. Some of this risk may be avoidable by appropriate shelterbelt design and species composition, but this is an area where more research is required to ensure that safety requirements can be met.

Temperature effects on road and rail track

The UKCP09 central estimate at the 50% probability level, shows that there is likely to be a temperature increase of between 3°C and 6°C by 2080 (Murphy *et al*., 2009). This would have significant direct and indirect effects on both road and rail infrastructure.

Direct effects

Higher summer temperatures will have a number of direct impacts on the transport network including road rutting, rail buckling, decreased thermal comfort, increased thermal loading on road pavement resulting in melting tarmac, roadway buckling, expansion/buckling of bridges, and an increased numbers of tyre blow-outs (Network Rail, 2011; Hooper and Chapman 2012). These impacts are already being felt in the UK. For example, the railway network has experienced an increased number of track buckling instances during heatwaves, observed in the hot summers of 2002, 2003, 2006 and 2008 (Standley *et al.,* 2009).

In addition, higher temperatures will also cause overhead power lines to sag in locations where there are no balancing weights to take up the thermal expansion. This will reduce the clearance between adjacent cables as well as between cables and other structures; it may also reduce the overall capacity of the overhead power lines (Eddowes *et al*., 2003). Current specifications suggest overhead cables that supply electrical power to trains have a design temperature tolerance range of between -18°C to +38°C (Network Rail, 2011). However, sag occurrences have been far more common than the number of days breaching this threshold, which have led Network Rail to re-examine these thresholds. In fact, a recent temperature threshold exceedence analysis found that average occurrence of overhead line equipment sag is projected to increase by the 2040s (Network Rail 2011).

However, reduced frequency of cold winters could be a positive outcome for UK transport infrastructure. For example, in the case of winter maintenance, all transport networks stand to benefit as a decreased number of cold days will reduce icing problems for electric rail systems and reduce the frequency that road gritting is required. Moreover, reduced frost and ice occurrence will increase safety across the transport network. (Hooper and Chapman 2012; Eddowes *et al.,* 2003).

Indirect effects

The changes to the type and seasonality of damage caused by temperature effects will have positive and negative consequences for health and safety of transport infrastructure staff and the costs of maintenance. Milder winters will reduce the risks associated with cold weather but warmer summers will expose staff to the dangers of working in extreme heat. Meanwhile, the costs of maintenance will shift from the winter season to the summer season (Hooper and Chapman, 2012).

A report by the Infrastructure Transitions Research Consortium on infrastructure hazards predicts an increase in the number of incidents of roads being affected by fires, caused by smoke from wildfires drifting across the motorway network (Dunn and Robson, 2013). The scale to which this might occur was not given in the report.

Damage to transport infrastructure has knock-on impact for journey time, due to repair work and reduced speeds in compromised locations (Network Rail, 2011). These are already being noticed in the UK. For example, a study has estimated that in the summer of 2003 alone, there were 165,000 delay minutes on the UK's railways which could be attributed to hot weather, compared to only 30,000 delay minutes for the same period in 2004 (Hunt *et al.,* 2006).

On the road networks, higher temperatures may increase congestion in certain areas such as the south east as greater tourism and people looking to make the most of warmer climates will put increased pressure on the transport network. Standley *et al*. (2009) found that during the high temperatures of 2002, 2003, 2006, 2008 traffic jams occurred on many of the roads and motorways around London as people left the city to make the most of the good weather on the coast. This has an indirect effect on road safety as an increased number of road users adds to the problems of melting tarmac and reduced skid resistance on road surfaces following prolonged periods of higher temperatures (Hooper and Chapman, 2012).

<u>Adaptation</u>

Present adaptation strategies are generally grey engineered solutions to reducing track and road buckling, as well as management approaches to reduce speeds in higher temperatures, and ensure that staff, passenger, and drivers are less exposed to heat effects (Dobney *et al.*, 2010; Network Rail, 2011).

An alternative to rebuilding the transport network to withstand higher temperatures under new design specifications is to use green infrastructure as an adaptation measure. Trees and vegetation can significantly reduce the surrounding air temperature and provide shade for road and rail surfaces. Gill *et al*., (2007) suggest in a modelling study that a 10% increase in green vegetation in an urban area can effectively reduce temperatures by several degrees. The studies on the effect of vegetation on temperature in urban areas can to a certain degree be applied to transport corridors. However, the particular species and distance at which trees are planted from roads and rail track are important considerations. Species with high water demand such as oak, poplar, willow, and hawthorn have a greater tendency to cause seasonal track instability and so should be located further from the track (Briggs *et al*. 2013). There are also significant safety issues related to trees close to rail tracks and roads.

Other assets such as bridges and pylons may also require adaptation strategies to be incorporated into upgrade and future development works to prevent more extensive costs in a few decades' time (Hooper and Chapman 2012; Eddowes *et al*., 2003).

Summary

Information on the heat effects on road and rail track were well documented, but solutions offered for rail buckling and melting of tarmac were engineered ones and no evidence of the mitigating effect of vegetation was found. However a study by Gill *et al*., (2007) claimed that trees and vegetation can significantly reduce the surrounding air temperature and provide shade for road and rail surfaces. However, increased vegetation close to transport networks may pose more risk from fires if summer temperatures increase (Dunn and Robson, 2013) as well as issues of leaf and branch fall during storms.

Subsidence and land slides

UKCP09 projections suggest drier summers but with heavier precipitation events all year round (Murphy *et al*., 2009). In addition there may be vegetation changes along the verges of transport networks in response to changing climatic factors (Dunnett *et al*., 1998). These conditions will be problematic for transport operators because they increase the vulnerability and susceptibility of subsidence and landslips along major transport routes in the UK, inevitably leading to speed restrictions, associated delays for rail and road users and a substantial cost for infrastructure owners (Briggs *et al*., 2013).

Drier summer periods may lead to drought which in turn could lead to increased failure of earthworks due to changes in the water table (Hooper and Chapman, 2012). Meanwhile, dry summer periods also cause embankment material to become desiccated, so when intense precipitation events occur, the earth is less stable and is more prone to landslips and track buckling (Eddowes *et al*., 2003). Furthermore, seasonal shrink–swell movement in earthworks can affect the level and alignment of the track due to the natural variability of temperatures and rainfall in the seasons (Briggs *et al*., 2013). Increased rainfall intensities may increase the instability of slopes and embankments leading to landslides, undercutting and bridge scour across all modes of transport (Clarke *et al*. 2002; DfT, 2005).

Landslips are a serious problem for the railway as they could cause derailments. The problem is particularly serious in areas where the underlying geology is clay, such as the south of England (Network Rail, 2011). Research by Manning *et al*. (2008) investigated the response of earth embankments along the railway line to current and future climate scenarios, including the effects of rainfall and evapotranspiration on slope hydrology and stability. The findings show that for the system of clay embankments, the moisture profile through the embankment at the end of the summer months has a critical effect on system stability, both in terms of expected failure timing and probability of failure.

Given that the moisture content of an embankment is strongly influenced by vegetation type and cover, the possibility that changes in climate may also lead to changes in vegetation presence along railway networks is of particular concern.

Hence, if vegetation cannot adapt to future climate change and dies back , then the absence of vegetation may lead to increased embankment instability, contributing to the possibility of landslips occurring where the embankment is also exposed to other elements of climate change (Eddowes *et al*. 2003). In order to maintain the important functions of vegetation along transport corridors, the response of existing vegetation to increases in temperature, drought and changes in precipitation should be monitored (Hooper and Chapman, 2012).

An additional concern for the UK is that much of the rail network is on or in earthworks (embankments and cuttings) constructed more than 100 years ago (Briggs *et al*. 2013), whilst many of the major motorways and trunk roads were designed and built under specifications which pre-exist modern climate predictions (Highways Agency, 2008). As such, improving the resilience of the transport network to subsidence and landslips is a major priority for operators. However, predicting when and where landslips will occur is a challenge and operators are not yet certain how the number of these events will change over the coming few decades (Network Rail, 2011).

The implementation of green infrastructure along transport corridors is one approach which can use the natural environment to help protect the road and rail networks from subsidence and landslip risk, without having to completely redesign and implement new road and rail specifications. From an engineering perspective, trees aid slope stability through mechanical root reinforcement and by the establishment of soil suctions (Briggs *et al*. 2013). Trees covering many of the UK's railway earthwork slopes also provide a natural habitat for wildlife and biodiversity while creating a visual and acoustic screen for residential areas. However, vegetation can similarly cause seasonal shrinking and swelling of the soil in some circumstances.

Briggs *et al*. (2013) suggest that in order to implement effective land management of lineside vegetation, guidance is required in the location and planting of new trees and to identify and manage the removal of problematic trees, while avoiding full tree clearance on earthworks slopes. In the study of sixteen sites across the London Underground Limited Network and from an instrumented railway embankment the National House Building Council guidance 'Building near trees' was used to determine whether a tree of a particular species, tree height and distance from the track is likely to influence track movement. Through adopting this approach, it is possible to use green infrastructure to mitigate against slope and embankment instability, whilst also minimising the effect of seasonal shrink-swell movement on tracks. The same authors showed that high water demand species (e.g. Oak, Poplar, Willow), located within the threshold ratio of the track, as defined in the NHBC guidance, were shown to cause seasonal track movement greater than 10 mm and correlated with incidences of poor track quality. Moderate and low water demand tree species (e.g. Ash, Sycamore, and Birch) were not associated with seasonal track movements greater than 10 mm, even when a large number of lineside trees were located on an embankment slope.

Summary

Much of the UK's rail network is on or in earthworks (embankments and cuttings) and therefore slope stability is a key concern. The problem of landslides is particularly serious in areas where the underlying geology is clay, such as in the south of England Bank moisture content is an important factor in bank stability, which is strongly influenced by heavy precipitation events, dry summer periods and vegetation type and cover. The possibility that changes in climate may also lead to changes in vegetation presence along railway networks is also of concern and the response of this vegetation to climatic changes needs monitoring.

It is evident that effective land management and the use of green infrastructure can assist in mitigating the impacts of slope instability associated with a climate change. In particular, trees can be used along transport corridors to improve soil stability, prevent embankments being swept away during heavy precipitation events and intercept and infiltrate runoff. Moderate and low water demanding plant species can also be used to increase bank stability, particularly in clay soils.

Flood risk and sea level change

The UKCP09 climate projections for the UK suggest that it is likely by the 2080s that there will be an increased frequency in the number of heavy/extreme precipitation events and an increase in the amount of precipitation that falls on these events, which will increase flood risk to some parts (Murphy *et al*. 2009). This will have a significant effect on Europe's and in particular the UK's transport network as more intense winter precipitation will cause increased fluvial and surface water flooding, whilst storms will increase the chance of coastal flooding (Defra, 2012). This was witnessed in the storms of early 2014 and with the collapse of the rail line at Dawlish as a result of rapid erosion of the supporting infrastructure from sea surge damage.

Flooding and associated landslides have a number of direct and indirect impacts on this sector (Penning-Rowsell *et al*., 2005). Direct impacts include: the damage to hard assets such as track, tarmac, bridges, and buildings; safety risk to transport users and staff; and also damage to soft estate including the inherent ecology. Indirect impacts include business continuity issues and economic costs associated with additional journey time for commuting and goods transport. In the long term flooding can cause significant spatial changes in business and tourism patterns (DfT 2010).

On the road networks, increased heavy precipitation will have a number of impacts including an increase in road submersion and underpass flooding; road scouring and road washout due to flooding, and more occasions for poor driving visibility (Hooper and Chapman 2012). Indirect effects caused by flooding and indeed other elements of climate are also of great importance and it is here that the true costs of a changing climate and its effects on transport become apparent as climate change related shifts in weather patterns might cause infrastructure disruptions (Hooper and Chapman, 2012; Koetse and Rietveld 2009). Increased instances of flooding as a result of more heavy precipitation events will increase highway maintenance costs, increase delays to journeys on all modes of transport with some even being cancelled, especially during peak hours (Hooper and Chapman 2012). In addition, literature show that precipitation affects road safety by increasing accident frequency, but decreasing severity as people generally drive around 10% slower in wet conditions (Koetse and Rietveld 2009).

On the railway networks, increased heavy precipitation will lead to increased river and localised flooding leading to scour and flooding of bridges, embankment scour, culvert washout, depot flooding and track, lineside equipment failure and an increase in rail submersion and underpass flooding (Network Rail, 2011; Hooper and Chapman 2012). Flooding can also cause infrastructure damage to tracks, the ground beneath and also the lineside equipment, and causes extra debris on the tracks (Standley *et al*. 2009). In extreme cases, flooding may even lead to ballast stones being washed away (Hooper and Chapman 2012). Between 2004 and 2010, the approximate number of delay minutes attributable to fluvial flooding was 156,000 amounting to a cost of nearly £11.5 million (Network Rail, 2011). Sea level rises and storm surges may also increase flood risk and cause localised problems to coastal transport routes, as witnessed in Dawlish in early 2014. Existing research into the vulnerability of the rail network found that the Welsh coastline is likely to experience flooding as a result of sea level rise due to the flat terrain on which most of the railway lines are built (Eddowes *et al*. 2003), whilst other coastal routes such as the Dawlish Railway in south Devon will require improved railway flood defences associated with sea level rises and storm surge increases because of increase coastal erosion (Network Rail, 2011).

There are a number of ways in which the UK’s road and rail infrastructure can be improved to increase its resilience to climate change. The creative use of green infrastructure is one of the most promising opportunities for adaptation and this needs to be recognized in the planning process at all scales (Gill *et al*. 2007). Network Rail (2011) is looking at emerging/alternative technologies to reduce flood risks such as ‘green landscaping’, a technique particularly effective in urban environments. Green infrastructure can intercept and infiltrate precipitation, reducing and/or delaying the amount of water that reaches rivers during peak discharges, whilst flood storage is especially important in corridors, but also has some importance as Sustainable Drainage Systems (SuDS), which can delay the time storm water and surface runoff meet rivers, mitigating the occurrence of flooding (Gill *et al*. 2007). A review has also found SuDS to be cost-effective flood control mechanisms although it is not specific to transport (Duffy *et al*., 2008). There is significant potential to utilise vegetated SuDS techniques, such as creating swales, infiltration strips, detention ponds along transport corridors for flood attenuation and water quality management. Transport operators such as Highways Agency are already adopting vegetative sustainable drainage systems such as balancing ponds into the design of new road schemes to aid flood attenuation and improve water quality. These have already been discussed in some depth in Section 3.2.2 above.

In terms of coastal flooding, the focus is often on short term solutions and a reliance on hard defences. However these often provide only a temporary solution and can cause knock on effects such as accelerating the process of coastal erosion elsewhere. There is a need to take a more long-term view on adaptation in coastal areas. The Shoreline Management Plans (SMPs) process looks at how the coast will change over the next 100 years and how it will be managed. Looking at how to encourage natural defences to develop may be part of the solution in some locations. Managed realignment of the coast as a flood defence strategy may be possible in some areas. Soft ‘defences’ such as coastal marshes, sand dunes and beaches can take out the power of storm surges and prevent flooding inland, but they require sediment from eroded material elsewhere to replenish them (National Trust, 2014). In some locations infrastructure may need to be relocated because it is not feasible to retain it where it is in the longer term. Following the recent storms, transport bodies with infrastructure assets at the coast need to assess how their assets were affected by the recent severe winter, and how they could be affected if such events occur in the future. One approach adopted by the National Trust is to map coastal hotspots at risk of erosion and flooding. This could lead to the development of adaptation plans for hotspots in consultation with partners involved in SMPs.

Summary

The literature highlights green infrastructure as a method of flood risk mitigation that has a high potential. Gill *et al*. (2007) point out that green infrastructure is one of the most promising ways opportunities for adaptation and that this needs to be recognised in the planning process at all scales. In particular the use of Sustainable Drainage Systems (SuDS) delay the lag time of storm water reaching rivers to mitigate the occurrence of flooding. No literature was found which monitored the success of SuDS schemes undertaken by rail and highways authorities, although SuDS are identified in the Highways Agency’s Design Manual for Roads and Bridges (Volume 11) as a pollution control measure that can be used to mitigate the impact of road-runoff pollution. There are also examples of new highways road schemes that have incorporated SuDS into scheme design. A longer term approach is needed in relation to coastal flooding. The Shoreline Management Plans (SMPs) process looks at how the coast will change over the next 100 years and how it will be managed. Looking at how to encourage natural defences to develop may be part of the solution in some locations. Managed realignment of the coast as a flood defence strategy may be possible in some areas. Soft ‘defences’ such as coastal marshes, sand dunes and beaches can take out the power of storm surges and prevent flooding inland, but they require sediment from eroded material elsewhere to replenish them (National Trust 2014). In some locations infrastructure may need to be relocated because it is not feasible to retain it where it is in the longer term.

Leaf and branch fall

Leaf and branch fall is a seasonal problem that effects the UK's transport system and in particular the railway network. Hooper and Chapman (2012) identify a number of reasons why climate change could exacerbate the situation. Firstly, seasonal changes associated with climate change will favour longer summers and shorter winters, which will mean changes in the growing season and timing of leaf-fall for railways. Additionally, although uncertain at this stage, there is also the potential for more windstorms as a result of climate change. These consequences of climate change will have an effect on the transport infrastructure as the amount of debris and vegetation blown onto roads, motorways and railway tracks may become more severe. 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, whilst drizzly conditions can exacerbate the problem. In 2009 alone there were 400 incidents of foliage falling on to lines resulting in 240,000 lost minutes and a cost of £6 million (Network Rail, 2011).

A reduction in the number of frost days occurring in a year is one change to the growing season which may impact on leaf production, and hence leaf fall on railway lines, as longer growing seasons provide more favourable conditions for greater leaf production and potentially cause increased visual obstructions on transport routes *(*Eddowes *et al.* 2003). The impact of seasonal changes may be an increase in vegetation growth periods and therefore the possibility of more leaves on railway lines. This has to be considered as this will significantly affect leaf fall timetables, especially the dates they are enforced and the length of time they are enforced for (DfT, 2005). Leaf fall timetables are an important adaptation measure and have to be enforced due to leaves falling on rail tracks and then being compacted into mulch on the rails (Hooper and Chapman, 2012). This may become an increased problem of climate change as there is a possibility that the amount of mulch created on rail tracks will increase (Clarke *et al*. 2002). Furthermore, if there is an increase in autumn winds, this may cause further problems in the form of concentrated leaf fall and result in ineffective braking for trains, causing problems with safety associated with, low adhesion and ineffective braking from skid, loss of traction and wheel spin (Eddowes *et al*., 2003). Evidently, changes in the timing, duration and intensity of the leaf fall in autumn have important implications for road and rail operators. The most likely consequence of climate change in the UK is a later, longer season and an increase in the weight of the leaf mulch, which might exacerbate the problems of rail adhesion.

Adaptation strategies suggested to mitigate against leaf and branch fall problems in the future centre on planting and maintenance regimes, as well as leaf fall timetables. (Eddowes *et al,.* 2003). Existing guidelines already exclude certain tree species from planting on Network Rail land due to leaf fall problems. These include Sycamore, Horse Chestnut, Ash, Poplar, and Lime varieties amongst others (Network Rail, 2012b).

Summary

Leaf and branch fall is a recognised issue especially along rail corridors. Climate change may result in stronger autumn winds which has the potential to cause more concentrated leaf fall as well as a longer season with leaf fall extending into December. Measures to adapt to changes in leaf fall could be more frequent cutting back of vegetation and planting of different species. Network Rail already have guidance on which tree species are suitable in proximity to rail tracks.

4. Conclusions

4.1. Objective 1: Transport soft estate delivering biodiversity gain, ecological connectivity, and ecosystem services

4.1.1. Biodiversity

The literature review identified two main conclusions. Firstly, the transport soft estate has the potential to support high levels of biodiversity interest, though this varies by species and depends on the surrounding landscape context. Secondly, the management of transport verges plays a key role in the maintenance and enhancement of biodiversity value.

There are opportunities to create species rich grassland and shrubland within transport corridors. Techniques to enhance the species richness of grassland verges include seed sowing, hay transfer and the use of existing seed banks (Nordbakken *et al*, 2010). Management practices such as early and late cuts with or without hay removal were also effective in establishing vulnerable grassland species (Auestad *et al*, 2010; Hambrey, 2013). There is also potential to make use of seed dispersing fauna common to transport soft estate to increase dispersal of certain types of shrub (Suarez-Estaban *et al*, 2013).

Road verges can also provide a shelter for certain bird species, though this most commonly occurs when they are a complementary habitat to the dominant surrounding habitats. For example, if the surrounding habitat is highly fragmented by intensive cropping, a contrasting verge habitat would be most favourable (Meunier *et al*, 1999). However, roads also represent a considerable bird mortality risk especially during certain seasons and weather conditions. In the UK, barn owls are most severely affected by road traffic strikes (Ramsden, 2003). General design considerations for roads to reduce bird mortality include the planting of dense and continuous bush, hedge or tree cover, as well as avoiding the close proximity of vegetation to elevated roads (Erritzoe *et al*, 2003).

Road verges can be a valuable refuge for some fauna such as small mammals including wood mouse, common shrew, bank voles and field vole (Ruiz-Capillas *et al.*, 2013). They also provide ecological corridors for many mammals though this increases road strike risk, which can represent up to 60% of overall mortality of sensitive species such as badger, otter, and hedgehog (EC, 2013). Amphibian road mortality is also a potential concern though this is an under-researched area and current mitigation measures (under-road tunnels, culverts) may not be entirely effective (Elzanowski *et al.*, 2009; Beebee, 2013).

Insects can benefit from well managed verges, especially where the habitat created is large and species rich (Vermuelen and Opdam, 1995; Saarinen *et al.*, 2005; Le Viol *et al*, 2008; Skórka *et al*, 2013). Careful scheduling of mowing is important. Twice-yearly cuts result in greater plant species richness which benefits pollinators especially later in the summer, but too much disturbance can encourage wider foraging which increases the road kill risk (Noordijk *et al*, 2009; Skórka *et al*, 2013).

The Mosaic Approach, although untested in the transport sector**, could** offer a potential approach to managing the soft estate in a way that is beneficial for a range of species.

4.1.2. Ecological connectivity

Transport corridors play a dual role in ecological connectivity. In some circumstances, they can act as ecological corridors to connect otherwise isolated habitat patches, with both animals and vehicles acting as dispersal vectors (Zwanepoel *et al*, 2006; Penone *et al*, 2012; Hambrey Consulting, 2013). However, for certain species in other circumstances they create a barrier and are associated with increased mortality and fragmentation (EC, 2003). Spatial breaks caused by road overpasses are particularly significant connectivity barriers (Penone *et al*, 2012). Moreover, there is evidence that transport corridors also promote the spread of invasive species though the wider landscape context is also an important factor (Hansen and Clevenger, 2005; Garnier *et al*, 2006; Sullivan *et al*, 2009; Penone *et al*, 2012).

Both project level and strategic level solutions are important in improving the ecological quality of transport soft estate and thus enhance its connectivity role. At the project level this involves putting in place infrastructure solutions such tunnels, wildlife underpasses, culverts, bat gantries, green bridges and hop-overs. However, the use of these has not been addressed in detail in this review. This is an area that would benefit from further investigation. At a strategic level this requires institutional and political commitment and resources to develop and carry out restoration programmes. The literature review was able to identify examples of this across the EU and beyond (van der Grift *et al*. 2008).

In addition, GIS methodologies can be effective methods to identify the best places to locate ecological networks as well as prioritise connecting areas for conservation (Gurrutxaga *et al*, 2011; Chang *et al*, 2012). A GIS site selection tool which estimates connectivity of habitat patches by measuring distance between source and local species populations shows great potential to enhance the ecological value of transport corridors (Nikolakaki, 2004).

4.1.3. Ecosystem services

<u>Biomass</u>

There could be potential in some locations on the road and rail network to utilise verge vegetation for biomass for energy generation (Ground Control, 2013). Experience form the Netherlands shows that there are opportunities to use verge grass as biofuel (Elbersen *et al*, n.d.). A trial is also currently being undertaken in Wales to test a new German technology to process biomass before transport to biomass plants (ClickGreen, 2013). Opportunities to cultivate willow for biofuel on road verges have been explored in a Dutch study and found to be theoretically viable (Qin, 2011).

Air quality

The effectiveness of vegetative barriers along roadsides for removing pollutants has been found to be variable. Vegetation is generally regarded as effective at removing ozone, particulate matter, and some gaseous pollutants although has been found to depend on the particulate size as well as the vegetation species and characteristics, such as crown density, leaf area density and tree size (Steffens *et al*, 2012; Vos *et al*, 2013; Brantley *et al*, 2014; Rogers *et al.*, 2011; Forest Research, 2012). More specifically, there is significant variation in pollutant removal due to the amount of hair and wax cover on the leaves (Sæbø *et al*., 2012). A Natural England report (Bignal *et al*., 2004) revealed that wooded shelterbelts effectively capture particulates, including their metal component, thereby reducing transport to sites further away from the road. However, their role in preventing the spread of gaseous pollutants such as NO_2 is less clear. There is some evidence to suggest that they act as a physical barrier to NO_2 transport, changing dispersal patterns rather than taking up the pollutant. The report suggests that it may be better to view vegetative buffer zones as providing a physical distance between the road and air quality sensitive ecological receptors, rather than an area of vegetation that is able to remove pollutants from the atmosphere (Bignal *et al*., 2004).

Carbon sequestration

The promotion of green infrastructure and especially tree cover brings beneficial carbon sequestration properties (Rogers *et al.,* 2011; Forest Research, 2012). In the absence of trees, the literature suggesting that wetland swales are preferable to dry swales as roadside carbon stores (Bouchard *et al*, 2013). Afforestation along transport corridors may be useful in providing a visual screen and/or sequestering roadside carbon, however, consideration should be given to the value of the existing habitat which may be of greater ecological value (Chisholm, 2010).

Water management

Although there is little literature that is specific to the transport sector, surface water management techniques used in urban areas could be applied in this context. SuDS such as filter strips, swales and balancing ponds can act as multifunctional structures which have the potential to provide an opportunity to manage water quality, mitigate flood risk, enhance transport infrastructure resilience and also sequester carbon (Dickie *et al*, 2010; Defra, 2013). The literature has shown opportunity to use vegetation filter strips to reduce the pollutant content in road runoff (Piguet *et al*, 2008; Jin *et al*, 2011). SuDS solutions are already in place at certain locations on Highways Agency land in the UK (Highways Agency, 2006; Susdrain, 2014). There is great potential for transport operators to engage with land managers and other partners to identify land that could be used to reduce the flood risk to transport estate. Payment for ecosystems services could be one way to develop such a relationship.

Noise

Vegetation is often used to mitigate the visual impact of grey engineered acoustic barriers, and has also been used as a barrier in its own right. Some studies show vegetated barriers to be as effective as their grey equivalents under certain circumstances of size, shape, layout and density (van Renterghem and Botteldooren, 2012; van Renterghem *et al*, 2012). In addition they are often viewed as preferable by residents (Arenas, 2008). Although transport noise has adverse effects on animal communication and reproductive success, it is not known if the implementation of acoustic barriers (vegetated or otherwise) has net positive or negative effects on biodiversity due to other factors.

Pollination

The potential and management regimes necessary for transport soft estate to provide good quality habitat for insects has been discussed above. Some of the findings such as plant species richness and twice-yearly rotational mowing with hay removal can also be applied to pollinating insects such as bees (Noordijk *et al*, 2009). Breadth of verge and volume of traffic did not affect bee abundance (Hopwood, 2008), although we know from other literature that wider and more strategically managed verges can benefit other pollinators e.g. butterflies and moths (Saarinen *et al.* 2005). In addition, the management of adjacent habitats can have a significant effect on density of flowering plants in the corridors, and hence on pollinators (Henriksen and Langer, 2013).

Landscape/sense of place and visual amenity

There is evidence that green infrastructure can play an important role in enhancing the aesthetics of transportation corridors. People are willing to pay for green street infrastructure, where the amount they are willing to pay increases with the size and greenness of the structure (Mell *et al*, 2013). Studies show that integration with the surrounding environment, creating a sense of place and the use of natural materials and vegetated areas are all important to aesthetically enhance the design of road and transport networks (Blumentraht and Tveit, 2014). Residents also show a preference for green barriers in reducing visual and acoustic impacts of neighbouring transport networks (Arenas, 2008; Maffei *et al*, 2013).

Visual screening and driver/resident stress

The presence of vegetation along the sides of roads plays a role in driver stress and behaviour. In urban contexts, vegetation helps screen adjacent built-up and commercial land use which improves driver experience and lowers stress level (Cackowski and Nasar, 2003; Wolf, 2003). However, in a rural context, when the surrounding landscape is densely vegetated with no open space, drivers experience less calm and drive less safely than when there are fully or partially open landscapes (Antonson *et al*, 2009).

Access

There is potential for designing and managing the transport soft estate to provide enhanced facilities for non-motorised users. The literature, though not specific to the transport soft estate, identifies the importance of gateways being visually attractive (Beunen et al, 2007).

4.2. Objective 2: Transport soft estate delivering infrastructure resilience to climate change

Climate change presents a complex management challenge where the resilience of transport infrastructure will be an important factor in adapting to future uncertainty (Jarozsweski *et al*, 2010; Defra, 2011b). Green infrastructure and 'Ecosystem-based Adaptation' offer a range of potential solutions to specific problems which will be created by climate change (EbA Flagship, 2004; Gill *et al*, 2007; Defra, 2010).

Storm water and wind damage

There is little literature to suggest how green infrastructure could be used to mitigate wind damage resulting from extreme weather events. There are studies showing the extent to which vegetated buffer strips can slow wind speeds in urban and rural contexts, but these have not been studied in a transport context (Zhou *et al*, 2005; Penone *et al*, 2012b; Taranaki Regional Council, n.d.).

It is clear that the active management of woodland to remove weak or diseased trees that may be vulnerable to high winds is required for safety reasons (Network Rail, 2011; 2012). Further research is needed into the potential to use shelterbelts in the wider landscape to provide shelter for exposed sections of the transport network.

Temperature effects on road and rail track

Information on the direct and indirect heat effects on road and rail track were well documented (Eddowes *et al*, 2003; Hunt *et al*, 2006; Standley *et al*, 2009; Network Rail, 2011; Hooper and Chapman, 2012). However, solutions offered for rail buckling and melting of tarmac were engineered ones and no evidence of the mitigating effect of vegetation was found. One study did find that that trees and vegetation can significantly reduce the surrounding air temperature and provide shade for road and rail surfaces (Gill *et al*. 2007). It will be important to balance benefits with potential risks such as fire risk if summer temperatures increase (Dunn and Robson, 2013), and issues of leaf and branch fall during storms.

Subsidence and landslides

Much of the UK's rail network is on or in earthworks (embankments and cuttings) and therefore slope stability is a key concern. The problem of landslides is particularly serious in areas where the underlying geology is clay, such as in the south of England (Network Rail, 2011).

Effective land management and the use of green infrastructure can assist in mitigating the impacts of slope instability associated with a climate change. In particular, trees can be used along transport corridors to improve soil stability, prevent embankments being swept away during heavy precipitation events and intercept and infiltrate runoff.

Bank moisture content is an important factor in bank stability, which is strongly influenced by heavy precipitation events, dry summer periods and vegetation type and cover. The possibility that changes in climate may also lead to adverse change in vegetation presence along railway networks is of concern (Dunnett *et al*, 1998; Manning *et al*, 2008). In order to maintain the important functions of vegetation along transport corridors, the response of existing vegetation to increases in temperature, drought and changes in precipitation should be monitored (Hooper and Chapman, 2012).

Briggs *et al*. (2013) showed that high water demand species (e.g. Oak, Poplar, Willow) located within the threshold ratio of the track, were shown to cause track movement greater than 10mm. Moderate and low water demand tree species (e.g. Ash, Sycamore, Birch) were not associated with track movements. Adapting planting and woodland management by moving towards lower water demand species such as ash, sycamore and birch could help with this, although it should be noted that ash and sycamore are actively discouraged on the lineside as their large leaves cause leaf litter problems on the track (Network Rail, 2012).

Flood risk and sea levels

The literature highlights green infrastructure as a method of flood risk mitigation that has a high potential. Gill *et al*. (2007) see green infrastructure as one of the most promising ways opportunities for adaptation and that it needs to be recognised in the planning process at all scales. The use of Sustainable Drainage Systems (SuDS) to increase the lag time of storm water reaching rivers will be an important factor to reduce the occurrence of flooding. There were no examples in the literature review of studies that monitored the success of SuDS schemes undertaken by rail and highways authorities, although SuDS are identified in the Highways Agency's Design Manual for Roads and Bridges (Volume 11) as a pollution control measure that can be used to mitigate the impact of road-runoff pollution. SuDS solutions are already in place at certain locations on Highways Agency land in the UK (Highways Agency, 2006; Susdrain, 2014).

Coastal defences currently rely on hard engineered, short term solutions. But there is potential for soft defences to be employed to reduce the power of storm surges such as coastal marshes, sand dunes, and beaches (National Trust, 2014). This area needs more consideration, potentially through the Shoreline Management Plan process.

Leaf and branch fall

Leaf and branch fall is a recognised issue especially along rail corridors (Network Rail, 2011). Climate change may result in stronger autumn winds which has the potential to cause more concentrated leaf fall as well as a longer season with leaf fall extending into December (Hooper and Chapman, 2014). Adaptation measures to changes in leaf fall impacts include cutting back of vegetation and planting of different species (Eddowes *et al*, 2013). These can work in tandem with existing Network Rail health and safety guidance on which tree species are suitable in proximity to rail tracks (Network Rail, 2012).

4.3. Summary of findings

The review identified a number of studies which related to role of transport soft estate in delivering biodiversity gain, ecological connectivity, ecosystem services, resilience to climate change, and as a serious alternative to grey-engineered solutions. The distribution of research and guidance was not evenly distributed. A far greater proportion of the papers identified covered road as opposed to rail networks. In addition there was a considerable bias towards studies discussing the impacts of transport on biodiversity, ecological connectivity, ecosystem services and the impacts of climate change on transport. There were relatively few studies of existing or proposed green infrastructure solutions in a transport soft estate context, so many of the suggestions have been transposed from comparable situations.

Overall, the review has found that transport soft estate has the potential to provide biodiversity gain for a variety of flora and fauna though this is highly species and context dependent. This could occur through well managed and maintained grassland i.e with two cuts per year, or woodland that is coppiced and has open glades or rides. The main beneficiaries would be vulnerable grassland species restored to roadside verges as well as the insects which rely on them. Its impact on other fauna is more mixed with some birds and mammals benefiting from the soft estate whilst posing a significant risk to others such as barn owl. The management of verges and design of vegetation cover are important factors in enhancing species richness as well as minimising safely and operational risk such as risk of vehicle collisions and leaf and branch fall. Recommendations have been made to take into account these factors.

Similarly, transport soft estate can both enhance and reduce ecological connectivity depending on the species and context. At the same time they can also be a factor in the spread of certain invasive species. Project level solutions to these problems include green bridges and other wildlife crossings. In addition, bridges and overpasses are often a major barrier feature and ecological considerations should be factored into their design. GIS methods offer a means for transport planners to take a strategic approach, taking landscape-level factors into consideration when designing and modifying infrastructure networks.

There is considerable evidence that transport soft estate can provide a range of ecosystem services which would benefit communities. Provisioning services include the use of road or trackside biomass for fuel. Regulating services include the use of vegetation strips to improve local air quality, reduce local heat effects, provide a wind and noise shield and sequester carbon. The use of SuDS along transport corridors could also improve water quality and mitigate flood risk. In addition, the restoration of transport soft estate can provide important habitat for pollinators. Well managed vegetation strips can improve the visual amenity of the road for local residents, and in some instances reduce driver stress.

Transport networks will be severely affected by climate change, though the extent, location and frequency of its impacts will be hard to predict at this juncture. The evidence suggests that green infrastructure can provide a resilient adaptation to some of these effects, such as increased storm and wind damage, summer heat effects, subsidence and landslides, flood risk and sea level rise, as well as increased leaf and branch fall. Vegetation strips and SuDS would appear to offer the best potential. However, many of the studies of green infrastructure application were carried out in a non-transport context and there is a need for further work to investigate their applicability to road and rail networks. Management of vegetation will also be important, especially as transport operators will also need to consider health and safety factors.

A summary of the benefits and challenges of green infrastructure associated with transport corridors is presented in Table 4.1 below.

Table 4.1: The importance of transport soft estate (green infrastructure) for final ecosystem services

The quantity of research was rated as follows: 1-5 studies (Low), 5-10 studies (Moderate), 10-15 studies (High), 15+ studies (Very High). The extent to which research was supportive was rated as follows: 85%+ supportive (Very Supportive), 75-85% supportive (Supportive), 65-75% (Moderately Supportive), 35-65% (Inconclusive), 25-35% (Moderately Unsupportive), 15-25% (Unsupportive), <15% (Very Unsupportive)

Benefits to ecosystem services	**Benefits to transport infrastructure**	**Challenges**	**Addressing challenges**	**Literature supporting or refuting benefits**
Wild species diversity and habitat provision	**Extent of Research: Very High (23 studies)**		**Supportivity: Very Supportive (91%)**	
Soft estate can act as linear ecological corridors, connecting habitats and increasing ecological coherence (but transport infrastructure can also be a significant barrier to movement of some species). Increase species diversity and adaptation to climate change. Soft estate can also provide habitat in its own right, including shelter and food.	See benefits listed under individual ecosystem services: - Biomass harvesting - Air quality regulation - Carbon sequestration - Water management - Water quality - Bank stability and erosion control - Wind shelter - Pollination - Noise abatement - Sense of place/Visual amenity	Leaf and tree fall and other fallen down vegetation can cause disturbance to transport infrastructure. Risk of spread of invasive species. Risk to wildlife from road and rail traffic e.g. fragmentation, barrier and mortality effects	Active management of track and roadside verges may be required including application of Mosaics Approach Planting of native species must be encouraged along with management of existing invasive species. Monitoring sensitive species e.g. barn owl to observe population trends. Trial new management approaches in priority locations.	✓ Akbar *et al*. (2010) ✓ Auestad *et al*. (2010) ✓ Chang *et al*. (2012) ✓ EC (2003) ✗ Erritzoe *et al.* (2003) ✓ Foy (1980) ✓ van der Grift *et al*. (2008) ✓ Gurrutzaga *et al*. (2011) ✓ Gurrutxaga *et al*. (2010) ✓ von Haaren and Reich (2006) ✓ Hambrey Consulting (2013) ✓ Meunier *et al*. (1999) ✓ Nordbakken *et al*. (2010) ✓ Penone *et al*. (2012) ✗ Ramsden (2003)

Benefits to ecosystem services	**Benefits to transport infrastructure**	**Challenges**	**Addressing challenges**	**Literature supporting or refuting benefits**
				✓ Ruiz-Capillas *et al*. (2013) ✓ Saarinen *et al*. (2005) ✓ Skórka *et al*. (2013) ✓ Suárez-Esteban *et al*. (2013) ✓ Szita *et al*. (n.d) ✓ Vermeulen and Opdam, (1995) ✓ Le Viol *et al*. (2009) ✓ Zwaenpoel *et al*. (2006)
Fuel provision	**Extent of Research: Moderate (6 studies)**		**Supportivity: Very Supportive (100%)**	
Trees and scrub can be managed as a source of biomass. Highways Agency land harvest 861,000 tonnes per year.	Income for transport estate owners from sale of biomass (e.g. wood fuel) and potential energy security.	Production of large enough quantities for biomass production from road and rail sides may be a challenge in terms of access and safety.	Consider planting on neighbouring land or in areas where the transport corridors are wide so as to keep trees and access points away from the road/rail. Consider accessing soft estate via adjacent landowners rather than road/rail side.	✓ ClickGreen (2013) ✓ Elbersen *et al*. (n.d.) ✓ Forestry Commission (2005) ✓ Ground Control (2013) ✓ Qin (2011) ✓ Salter *et al*. (2007)
Air quality maintenance	**Extent of Research: Moderate (9 studies)**		**Supportivity: Supportive (78%)**	
Vegetation, particularly trees, can intercept air pollutants and play an important buffering role	Through buffering and intercepting air pollutants, trees can reduce the number of complaints	Performance of vegetation in intercepting air pollutants is variable depending on factors such	Consider choice of species.	✓ Bignal *et al*. (2004) ✗ Brantley *et al*. (2014) ✓ Cooter *et al*. (2013) ✓ Hwang (n.d.)

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
where habitats sensitive to air pollution (e.g. NOx) lie close to transport networks. Vegetation can provide a buffer distance between air pollution source and receptor with benefits for public health.	made about transport networks.	as species, time of day and time of year.		✓ Sæbø *et al*. (2012) ✓ Steffens *et al*. (2012) ✓ Rogers *et al.* (2011) ✓ Forest Research (2012) ✗ Vos *et al*. (2013)
Climate regulation, resilience and adaptation		**Extent of Research: High (11 studies)**		**Supportivity: Very Supportive (100%)**
Trees provide carbon sequestration leading to mitigation of climate change. Soft estate can act as linear ecological corridors connecting habitat patches and providing opportunities for species migration to adapt to climate change, particularly for low mobility species. Climate resilient species of flora must be used, however.	Trees can provide shading and can have a cooling effect on infrastructure, particularly as summer temperatures increase due to climate change.	Branch debris/tree fall on road/track from high winds. Leaf fall in autumn depending on species (rail). Risk to highly mobile migrating wildlife e.g. fragmentation, barrier and mortality effects	Management of lineside trees in order to prevent risk to transport operations through frequent cutting back of vegetation, removing dead and diseased trees and producing leaf fall timetables. Monitoring sensitive species to observe population trends. Trial new management approaches in priority	Carbon sequestration: ✓ Bouchard *et al*. (2013) ✓ Davies *et al*. (2011) ✓ O'Donoghue and Shackleton (2013) ✓ Radford and James (2013) ✓ Rogers *et al.* (2011) ✓ Forest Research (2012) Found no evidence of a cooling effect on transport infrastructure caused by green infrastructure, but there is more general

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
			locations.	evidence on resilience and adaptation: ✓ Defra (2010) ✓ Dunnett *et al*. (1998) ✓ EbA Flagship (2004) ✓ Gill *et al*. (2007) ✓ Hwang (n.d.)
Water purification and flood regulation	**Extent of Research: Moderate (9 studies)**		**Supportivity: Very Supportive (100%)**	
Use of vegetated SUDs can and improve water quality by removing pollutants and sediments. Biodiversity improvements to wetland habitats such as reduced amount of sediment entering watercourses.	Use of vegetated SUDs for drainage from roads/rail can improve drainage, reduce flooding and improve water quality by removing pollutants and sediments. Runoff mitigation – interception of rainfall by trees and other vegetation can slow down flooding. This can reduced occurrence of flooding events that affect road/rail infrastructure	Invasive vegetation can enter watercourses and grow rapidly. This can lead to eutrophication as a result of reduced oxygen levels. Vegetation can fall into drainage channels causing blockages and flooding.	Planting of native species is encouraged. Management and maintenance to remove dead, diseased or storm damaged vegetation to prevent it causing damage to infrastructure or ecosystems.	✓ Dickie *et al*. (2010) ✓ Graham *et al*. (n.d.) ✓ Highways Agency *et al*. (2006) ✓ Nisbet and Broadmeadow (2003) ✓ Piguet *et al*. (2008) ✓ Sahu and Gu (2009) ✓ Susdrain (2014) ✓ Le Viol *et al*. (2009) – high pollutant concentrations in water storage ponds ✓ Wilson *et al*. (n.d.)
Natural hazard protection	**Extent of Research: High (12 studies)**		**Supportivity: Supportive (83%)**	
Trees and other vegetation can help to prevent	Trees and other vegetation can help to stabilise banks	Branch debris/tree fall on	Scrub vegetation can help to catch leaf fall and	✓ Briggs *et al*. (2013) ✓ Clarke *et al*. (2002)

Benefits to ecosystem services	**Benefits to transport infrastructure**	**Challenges**	**Addressing challenges**	**Literature supporting or refuting benefits**
landslides which can be damaging to both plant and animal species e.g. the silting of aquatic ecosystems. Vegetation has the potential to provide wind shelter to other habitats, including cropland.	through mechanical root reinforcement and prevent landslides in severe weather. Shelterbelts in wider landscape have the potential to provide wind shelter. Runoff mitigation – interception of rainfall by trees and other vegetation can slow down flooding. This can reduced occurrence of flooding events that affect road/rail infrastructure	road/track from high winds. Leaf fall in autumn depending on species (rail). Tree roots can cause damage to infrastructure such as roads, rails and pedestrian pavements. Shrink and swell caused by vegetation, particularly in clay soils causing movement of track in some circumstances (rail). Vegetation can fall into drainage channels causing blockages and flooding.	reduce the establishment of undesirable tree species. Trees should be planted in appropriate locations and managed accordingly. Moving towards lower water demand species to reduce shrink and swell in clay soils (rail)	✓ Eddowes *et al*. (2003) ✓ Gill *et al*. (2007) ✗ Hooper and Chapman (2012) – leaf fall ✗ Department for Transport (2005) – leaf fall ✓ Highways Agency (2006) – SuDS ✓ Network Rail (2011) ✓ Northern Territory Government (n.d.) ✓ Susdrain (2014) ✓ Le Viol *et al*. (2009) ✓ Wilson *et al*. (n.d.) – SuDS
Erosion control		**Extent of Research: Low (1 study)**		**Supportivity: Very Supportive (100%)**
Vegetative cover plays an important role in soil retention. Erosion control by vegetation reduces the amount of sediment and pollutants that enter	Trees can help to stabilise cuttings and embankments to prevent erosion.	Branch debris/tree fall on road/track from high winds. Leaf fall in autumn depending on species (rail).	Management of lineside trees in order to prevent risk to transport operations through frequent cutting back of vegetation, removing dead and diseased trees and producing leaf fall	✓ Northern Territory Government (n.d.)

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
watercourses which preserves water quality.			timetables.	
Noise abatement		**Extent of Research: Moderate (studies)**	**Supportivity: Supportive (80%)**	
Public health and quality of life benefits. Benefits for species diversity and wildlife if appropriate species mix and well managed.	Trees can provide a useful barrier to noise pollution (and perception of noise through visual screening) from transport networks, reducing complaints.	Branch debris/tree fall on road/track from high winds. Leaf fall in autumn depending on species (rail). No evidence that green barriers have biodiversity benefits.	Management of lineside trees in order to prevent risk to transport operations through frequent cutting back of vegetation, removing dead and diseased trees and producing leaf fall timetables. Research into effects of green barriers on biodiversity	✓ Arenas (2008) ✓ Maffei *et al*. (2013) ✓ Radford and James (2013) ✓ van Renterghem *et al*. (2013) ✓ van Renterghem *et al*. (2012) ✓ van Renterghem and Botteldooren (2012) ✓ Tyagi *et al*. (2009) ✓ Reijnen and Foppen (2006) × Reijnen and Foppen (2006) × Reijnen *et al* (1997)
Regulation of pests, diseases and invasive species		**Extent of Research: Low (4 studies)**	**Supportivity: Inconclusive (50%)**	
Green infrastructure can improve the health of the landscape. Pests and		Care needed to ensure linear corridors don't aid dispersion of invasive	Avoiding the planting of species prone to disease or the facilitating of	× Garnier *et al*. (2006) – escape of oilseed rape crops to natural

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
diseases tend to occur more in stressed ecosystems than healthy ones. Trees and other vegetation planted in the vicinity of cropland can increase the prevalence of pest predators.		species or diseases which could potentially cause a decline in native species, damage to tracks/roads or blocked sightlines.	conditions which encourage pests, diseases and invasive species to spread. Avoid disturbance where possible. Healthy, diverse and well managed estate and adjacent land can reduce the risk of spread of invasives.	habitats via roadside verges × Hansen and Clevenger (2005) – invasives more abundant along transport corridors than control sites × Penone *et al*. (2012) – invasives more prevalent in urban areas than railway edges × Sullivan *et al*. (2009) – verges had little effect on spread of invasives
Pollination		**Extent of Research: Moderate (6 studies)**		**Supportivity: Very Supportive (100%)**
Can provide species-rich grassland to aid pollination. Mowing verges up to twice a year and removing arisings will allow them to flower and thereby provide pollen and valuable nectar sources for bumble bees, butterflies and other	Possible financial benefits to transport operators if cutting/mowing of soft estate is carried out once or twice per year and scrub encroachment reduced.	Road and trackside verges may need to be actively managed to ensure new species are able to establish and invasive plants and weeds do not dominate.	Establishment of best management guidelines for trackside and road verges.	✓ Henriksen and Langer (2013) ✓ Hopwood (2008) ✓ Noordijk *et al*. (2009) ✓ Townsend and Levey (2005) ✓ Saarinen *et al*. (2005). ✓ Skórka *et al*. (2013)

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
invertebrates. Increased yield for pollination-dependent agricultural crops.				
Cultural Services – Access	**Extent of Research: Low (4 studies)**		**Supportivity: Very Supportive (100%)**	
Potential to provide pedestrian/ cycle access with associated benefits for human health. Railways and roads provide access to visitor destinations, promoting green growth/ ecotourism.	Network accessible to a wider range of users	Pedestrian/ cycle access may result in safety risks or increased expenditure on security	Hedges on boundary can prevent trespassers on the transport network.	✓ Garré *et al*. (2009) ✓ von Haaren and Reich (2006) ✓ Natural Economy North West (n.d. ✓ Beunen *et al*. (2007)
Cultural Services – Landscape and sense of place	**Extent of Research: Low (4 studies)**		**Supportivity: Very Supportive (100%)**	
Soft estate can be designed to reflect the local landscape character e.g. open landscape and can provide the setting for access gateways, benefitting the wider landscape and people's enjoyment of it.	Soft estate can provide visual screening of the transport corridor in both urban and rural areas, reducing complaints.	Trees, though providing screening, can also block the view of more open landscapes.	Neighbouring landscapes must be taken into account.	✓ Blumentrath and Tveit (2014) ✓ Garré *et al*. (2009) ✓ Maffei *et al*. (2013) ✓ Mell *et al*. (2013)

Benefits to ecosystem services	Benefits to transport infrastructure	Challenges	Addressing challenges	Literature supporting or refuting benefits
Cultural Services – Visual Screening / Stress	**Extent of Research: Low (5 studies)**		**Supportivity: Supportive (83%)**	
Soft estate can provide a visual screen which is more favourable to residents. Roadside vegetation reduces stress and frustration of drivers.	Fewer complaints from residents about transport infrastructure. Greater road safety and fewer "road rage" incidents	Vegetated screens may be more visually appealing, but it may not be possible to make them dense enough to provide other services due to space limitations. The stress/behaviour/safety effect is only found in an urban context. In a rural context open or varying landscape is better.	Appropriate site selection, but even a moderate amount of vegetation may improve experience for drivers at least. Importance of varying landscape in rural context – avoiding long stretches of dense forest/shrub.	✓ Arenas (2008) ✓ Maffei *et al*. (2013) ✓ Cacowski and Nasar (2003) ✓ Wolf (2003) ✓ Antonson *et al*. (2009) × Antonson *et al*. (2009)

4.4. Recommendations

4.4.1. Biodiversity gain, ecological connectivity, and ecosystem services

The literature review has identified some specific recommendations for biodiversity gain, ecological connectivity, and ecosystem services within transport soft estate:

- Greater use could be made of the transport soft estate for pollinators, with reintroduction of appropriate grassland management for species-rich grass verges to promote plant and pollinator species diversity.

- There is potential for a mosaic approach to be applied to the management of the soft estate to increase biodiversity, with greater levels of thinning, coppicing and removal of trees (but retaining any trees that are veteran/ancient or support locally important ecosystem services) to create glades and to increase the variety of habitats on the soft estate. Where width allows using ecotones (ie gradual blending between two habitats) to transition from one habitat to another.

- Take greater account of the land use immediately adjacent to the transport corridor in management decisions for the soft estate and maximise the potential for linkages with the surrounding landscape.

- Consider the design of roadside vegetation strips to reduce the mortality of individual species. Balancing conflicting needs of different species may present challenges in relation to the soft estate management and will need to be addressed at the local level.

- Consider solutions which deliver multiple ecosystem services, such as wetland swales and balancing ponds which can act as carbon stores and wildlife habitat as well as water flow and quality regulators.

- New approaches to the management of the soft estate could bring multifunctional benefits for the natural environment and people, as well as the operation and resilience of the network. For example managing woody vegetation through coppicing and restoring areas of grassland could benefit pollinators and reduce the hazards associated with tree and leaf fall, as well as potentially providing a sustainable source of woodfuel for local communities.

4.4.2. Transport resilience and green infrastructure

The literature review has identified some specific recommendations for using green infrastructure to build a more resilient transport infrastructure:

- Greater recognition should be given to the relationship between transport and the natural environment and consideration of the impacts of transport resilience solutions on the natural environment, which in turn could affect the long term operation of transport systems.

- There should be more consideration of soft as well as hard solutions and further investigation into the role of green infrastructure in developing climate resilient transport infrastructure.

- The collaboration between academic institutions, road and rail operators and other bodies such as Natural England on the Natural Environment White Paper (NEWP) 32 commitment is a positive development and should be encouraged and expanded for future work.

- Long term adaptation/resilience strategies need to be developed that look at the potential synergies between transport infrastructure climate change resilience goals and other environmental goals where there is potential for multiple benefits.

4.4.3. Further research

The literature review uncovered considerable evidence regarding the role that transport soft estate plays in biodiversity, ecological connectivity, ecosystem services, climate change resilience and green infrastructure solutions. However, there were also some significant gaps in certain key areas where knowledge would greatly inform and improve the delivery of these features.

As discussed above, there were considerably more studies related to road as opposed to rail networks. Whilst there are similarities in the environmental impacts of both types of transportation, there are material differences in terms of vehicle type and frequency, as well as the accessibility of the verges. Management regimes proposed for roadside verges may not be applicable to track because of these differences. In particular, studying the animal mortality data for rail would be informative as has proved with the roadside verge studies.

Another general area of relative information scarcity regards the applicability of green infrastructure and climate change resilience solutions to transport soft estate. The majority of applications discussed in the review derive their legitimacy from other contexts, such as urban or rural projects. Further work should investigate the success of SuDS in relation to the transport soft estate in general. Vegetation strips are better understood, but there are still gaps in the literature. More work is needed to investigate the design features of vegetation strips alongside roads and rail that would be necessary to provide wind shelters, reduce localised temperatures and reduce subsidence (on tracksides), whilst at the same time not compromising public safety from treefall.

As mentioned earlier, this review did originally have a third objective, which was to investigate the opportunities and challenges facing transport operators in transitioning from grey engineered to green ecosystems-based solutions. However, the review found a scarcity of literature concerning this topic. For example, further research is needed to explore the role of shelter belts as part of the wider landscape; whilst there is little evidence to demonstrate the effectiveness of SuDS being applied to transport soft-estate. Given the potential of transport soft estate to provide ecosystem services and climate change adaptation solutions, the lack of information in guiding the transition process presents an opportunity for continued research and investigation. Green bridges were also considered with respect to the greening of grey infrastructure; these are more common overseas than in the UK where small scale solutions to connectivity have been prioritised. More work is required to better understand the contexts in which these features are most effective and to look for opportunities to include them within the network in the future.

Otherwise, the literature review did identify some more specific areas for future research. For example, the role of transport corridors in ecological connectivity appears to be very complex and context dependent and would benefit from further elucidation to understand the risks and maximise the benefits for biodiversity. Particular attention should be focussed on the nature of the relationship between the positive and negative corridor effects and how these can be balanced to benefit wildlife. In addition, a better of understanding is required for how transport infrastructure should be integrated into ecological networks to maximise biodiversity benefits without increasing the risk of animal-vehicle collisions. In this regard, identifying pinch points for wildlife mortality is important, as is understanding the role of crossing points and how best to manage vegetation to deter animals from riskier zones. A greater knowledge of the species that benefit from transport corridors and those than are challenged by it would also be useful, and where there are known risks for species such as barn owls, further work is needed to find solutions that will benefit the species whilst also reducing safety and operational risk to the network, for example from tree or leaf fall.

Further work could also explore the potential for commercial benefits from the harvesting of wood or other biomass products from the transport soft estate in ways that could also benefit biodiversity such as the thinning or coppicing of trees to create glades and rides. There are also neighbourhood considerations here, for instance how to enter into agreements with adjacent landholders to use their land to access the vegetation to be harvested for biomass. However, this could also lead to further opportunities to work with neighbours to improve and enhance land management practices at a landscape scale and not just immediately on the soft estate itself. There could be mutual benefits, in particular to provide flood attenuation and pollination services which could be potentially funded through payment for ecosystem services schemes.

Bibliography

Akbar, K. F., Hale, W.H.G., Headley, A.D. and Ashraf, I. 2010. Evaluation of conservation status of roadside verges and their vegetation in north England. Polish Journal of Ecology 58, 459-467.

Anglian Water. 2009. Guidance on the use of sustainable drainage systems (SUDS) and an overview of the adoption policy introduced by Anglian Water.

Arenas, J.P. 2008. Potential problems with environmental sound barriers when used in mitigating surface transportation noise. The Science of the total environment, 405(1-3), pp.173–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18678395 [Accessed January 31, 2014].

Antonson, H., Mardh, S., Wiklund, W., and Blomqvist, G. 2009. Effect of surrounding landscape on driving behaviour: A driving simulator study. Journal of Environmental Psychology 29, 493-502.

Auestad, I. *et al*. 2010. Pimpinella saxifraga is maintained in road verges by mosaic management. Biological Conservation, 143(4), pp.899–907. Available at: http://linkinghub.elsevier.com/retrieve/pii/S000632070900545X [Accessed December 19, 2013].

Beebee, T.J.C. 2013. Effects of Road Mortality and Mitigation Measures on Amphibian Populations. Conservation Biology, 27 (4), 657-668.

Bennett, V., Smith, W., and Betts, M. 2011. Toward Understanding the Ecological Impact of Transportation Corridors. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station: General Technical Report PNW-GTR-846.

Beunen, R., Hielke, D., Regnerus, C., and Jaarsma, F. 2008. Gateways as a means of visitor management in national parks and protected areas. Tourism Management 29 (1), 138–145.

Bignal, K., Ashmore, M. and Power, S. 2004. The ecological effects of diffuse air pollution from road transport. English Nature ENRR580. Available from: http://publications.naturalengland.org.uk/publication/133002 [Accessed January 16, 2014].

Blumentrath, C. and Tveit, M.S. 2014. Visual characteristics of roads: A literature review of people’s perception and Norwegian design practice. Transportation Research Part A: Policy and Practice, 59, pp.58–71. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0965856413002127 [Accessed January 31, 2014].

Bouchard, N.R. *et al*. 2013. The capacity of roadside vegetated filter strips and swales to sequester carbon. Ecological Engineering, 54, pp.227–232. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925857413000335 [Accessed January 31, 2014].

Brantley, H.L. *et al*. 2014. Field assessment of the effects of roadside vegetation on near-road black carbon and particulate matter. The Science of the total environment, 468-469, pp.120–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/24008075 [Accessed January 30, 2014].

Briggs, K.M. *et al*. 2013. Managing the extent of tree removal from railway earthwork slopes. Ecological Engineering, 61, pp.690–696. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925857412004314 [Accessed January 31, 2014].

Caborn, J.M. 1965. Shelterbelts and Windbreaks. Faber and Faber.

Cackowski, J.M. and Nabar J.L. 2003. The restorative effects of roadside vegetation: Implications for Automobile Driver Anger and Frustration. Environment and Behavior, 35 (6), 736-751.

Chang, Q. *et al*. 2012. A GIS-based Green Infrastructure Planning for Sustainable Urban Land Use and Spatial Development. Procedia Environmental Sciences, 12, pp.491–498. Available at: http://linkinghub.elsevier.com/retrieve/pii/S187802961200309X [Accessed December 12, 2013].

Chisholm, R.A. 2010. Trade-offs between ecosystem services: Water and carbon in a biodiversity hotspot. Ecological Economics, 69(10), pp.1973–1987. Available at: http://linkinghub.elsevier.com/retrieve/pii/S092180091000203X [Accessed January 31, 2014].

Clarke, S. *et al*. 2002. London's Warming: The Impacts of Climate Change on London Summary Report, London.

ClickGreen. 2013. National Trust looks to generate green energy from roadside verges. Available from: http://www.clickgreen.org.uk/news/national-news/124078-national-trust-looks-to-generate-green-energy-from-roadside-verges.html [Accessed April 16, 2014].

Climate Adapt. 2013. Uncertainty Guidance. Avaiable at http://climate-adapt.eea.europe.eu/uncertainty-guidance [Accessed 9 Jun, 2014].

CBD (Secretariat of the Convention on Biological Diversity). 2006. Global Biodiversity Outlook 2. Montreal, 81 + vii pages.

Cooter, E.J. *et al*. 2013. The role of the atmosphere in the provision of ecosystem services. The Science of the total environment, 448, pp.197–208. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22921509 [Accessed January 31, 2014].

Davies, Z.G. *et al*. 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. Journal of Applied Ecology, 48(5), pp.1125–1134. Available at: http://doi.wiley.com/10.1111/j.1365-2664.2011.02021.x [Accessed January 21, 2014].

DCLG. (Department for Communities and Local Government). 2012. National Planning Policy Framework.

Defra (Departmentment for Environment Food and Rural Affairs). 2005. The UK Government Sustainable Development Strategy - Securing the Future.

Defra. 2007. An introductory guide to valuing ecosystem services. Available at: https://www.gov.uk/government/publications/an-introductory-guide-to-valuing-ecosystem-services [Accessed 4 June, 2014].

Defra. 2010. Climate Change Plan 2010.

Defra. 2011a. Biodiversity 2020 : A strategy for Englands wildlife and ecosystem services.

Defra. 2011b. Climate Resilient Infrastructure: Preparing for a Changing Climate.

Defra. 2012. UK Climate Change Risk Assessment : Government Report.

Defra. 2013a. Payments for Ecosystem Services (PES): best practice guide. Available from: https://www.gov.uk/government/publications/payments-for-ecosystem-services-pes-best-practice-guide [Accessed January 16, 2014].

Defra. 2013b. The effects of noise on biodiversity NO0235.

Defra. 2014. Policy: Adapting to climate change. Available from: https://www.gov.uk/government/policies/adapting-to-climate-change [Accessed April 16, 2014].

DfT (Department for Transport). 2010a. The Resilience of England's Transport Systems in Winter: An Independent Review. Interim Report.

DfT. 2010b. Climate Change Adaptation Plan for Transport 2010-2012 Enhancing resilience to climate change.

DfT. 2014. Transport resilience review: call for evidence.

DfT. 2013. Action for Roads, A Network for the 21st Century

DfT. 2005. Climate Change Adaptation Plan for Transport 2010-2012. Enhancing resilience to climate change.

Dickie, S. *et al*. 2010. Planning for SuDS – making it happen, London.

Directorate-General for Internal Policies. 2012. Reducing railways noise pollution.

Dobney, K., Baker, C., Quinn, A.D., and Chapman, L. 2010. The future cost to the United Kingdom's railway network of heat related delays and buckles caused by the predicted increase in high summer temperatures due to climate change. Proc. Inst. Mech. Eng. (F): Journal of Rail and Rapid Transit, 224 (1), 25-34.

Dunn, S. and Robson, C. 2013. ITRC WS2 IUK infrastructure hazard and data report. Infrastructure Transitions Research Consortium, Engineering and Physical Sciences Research Council.

Dunnett, N.P. *et al*. 1998. A 38-year study of relations between weather and vegetation dynamics in road verges near Bibury, Gloucestershire. Journal of Ecology, 86(4), pp.610–623. Available at: ISI:000075695300006.

EbA Flagship. 2004. Making the Case of Ecosystem-based Adaptation - Building Resilience to Climate Change.

Eddowes, M.J. *et al*. 2003. Engineering: Safety Implications of Weather, Climate and Climate Change. Rail and Safety Standards Board.

Elbersen, H.W., Keijsers, E.R.P. and van Doorn, J. n.d. Biorefinery of verge grass too produce bio-fuel.

Ellis, J.B. *et al*. 2004. Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff. The Science of the total environment, 334-335, pp.251–60. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15504512 [Accessed January 31, 2014].

EC (European Commission) DG for Research. 2003. COST Action 341 Habitat Fragmentation due to Transportation Infrastrastructure, EUR 20721.

ERM (Environmental Resources Management). 2009. The Chiltern Railways (Bicester to Oxford Improvements) Order Environmental Statement: Volume 2, Assessment of Impacts, Section 7: Landscape and Visual Impacts.

Erritzoe, J., Mazgajski, T.D., and Rejt, L. 2003. Bird casualties on European roads - a review. Acta Ornithol. 38, 77-93.

Eycott, A. *et al*. 2010. Library CEE review 08-006 Do landscape matrix features affect species movement?.

Fisher, B. and Turner, R. 2008. Ecosystem Services: Classification for Valuation. Biological Conservation 141 (5), 1167-1169.

Forest Research. 2012. Estimating the Ecosystem Services Value of Edinburgh's Trees.

Forestry Commission. 2005. Small-scale Systems of Harvesting Woodfuel Products.

Forman, R. 1995. Some general principles of landscape and regional ecology. Landscape Ecology 10(30), 133-142.

Foy, A. 1980. Road Verges of Ecological Importance (RVEI) in Hampshire.

Garnier, a., Deville, a. and Lecomte, J. 2006. Stochastic modelling of feral plant populations with seed immigration and road verge management. Ecological Modelling, 197(3-4), pp.373–382. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0304380006001621 [Accessed December 19, 2013].

Garré, S., Meeus, S. and Gulinck, H. 2009. The dual role of roads in the visual landscape: A case-study in the area around Mechelen (Belgium). Landscape and Urban Planning, 92(2), pp.125–135. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204609000620 [Accessed February 6, 2014].

Gill, S.E. *et al*. 2007. Adapting Cities for Climate Change : The Role of the Green Infrastructure. Built environment, pp.115–133.

Giordano, T. 2012. Adaptive planning for climate resilient long-lived infrastructures. Utilities Policy, 23, pp.80–89. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0957178712000409 [Accessed December 19, 2013].

Graham, A. *et al*. n.d. Sustainable drainage systems: Maximising the potential for people and wildlife.

Van der Grift, E., Biserkov, V. and Simeonva, V. 2008. Restoring ecological networks across transport corridors in Bulgaria. (June).

Ground Control. 2013. Managing the Highway lanscape: Area 12 Biomass Pilot Study. A Report for the Highways Agency and AOne+.

Gurrutxaga, M., Lozano, P.J. and del Barrio, G. 2010. GIS-based approach for incorporating the connectivity of ecological networks into regional planning. Journal for Nature Conservation, 18(4), pp.318–326. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1617138110000075 [Accessed January 30, 2014].

Gurrutxaga, M., Rubio, L. and Saura, S. 2011. Key connectors in protected forest area networks and the impact of highways: A transnational case study from the Cantabrian Range to the Western Alps (SW Europe). Landscape and Urban Planning, 101(4), pp.310–320. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204611001022 [Accessed December 11, 2013].

Von Haaren, C. and Reich, M. 2006. The German way to greenways and habitat networks. Landscape and Urban Planning, 76(1-4), pp.7–22. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204604001318 [Accessed January 24, 2014].

Hambrey Consulting. 2013. The management of roadside verges for biodiversity. *Scottish Natural Heritage Commissioned Report No. 551.*

Hansen, M.J. and Clevenger, A.P. 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. Biological Conservation, 125(2), pp.249–259. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320705001680 [Accessed December 12, 2013].

Henriksen, C.I. and Langer, V. 2013. Road verges and winter wheat fields as resources for wild bees in agricultural landscapes. Agriculture, Ecosystems and Environment, 173, pp.66–71. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0167880913001187 [Accessed December 19, 2013].

Hess, G.R. and Fischer, R.A. 2001. Communicating clearly about conservation corridors. Landscape and Urban Planning, 55(3), pp.195–208. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204601001554 [Accessed December 11, 2014].

Highways Agency. 2001a. Design Manual for Roads and Bridges. Volume 10. Environmental Design and Objectives.

Highways Agency *et al*. 2001. DESIGN MANUAL FOR ROADS AND BRIDGES DESIGN AND MANAGEMENT OBJECTIVES THE SCOTTISH EXECUTIVE DEVELOPMENT.10.

Highways Agency. 2006. Vegetated Drainage Systems for Highways Runoff Design Manual for Roads and Bridges Volume 4, Section 2 HA 103/06

Highways Agency. 2007. Highways Agency - Severe Weather Alert for Goods Vehicles Severe Weather Alert for Goods Vehicles. pp.1–2.

Highways Agency. 2008. Design Manual for Roads and Bridges: Managing Geotechnical Risk.

Highways Agency. 2011. Highways Agency Climate Change Risk Assessment. (August).

Hooper, E. and Chapman, L. 2012. Transport and Climate Change_Chapter 5.pdf. In T. Ryley and L. Chapman, eds. Transport and Climate Change. Bingley: Emerald Group Publishing Ltd, pp. 105 – 136.

Hopwood, J.L. 2008. The contribution of roadside grassland restorations to native bee conservation. Biological Conservation, 141(10), pp.2632–2640. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320708002826 [Accessed February 4, 2014].

House of Commons 2014 House of Commons Transport Select Committee, Better Roads: Improving England's Strategic Road Network, HC 850 London: The Stationery Office Limited.

Hricko, H, Rowland,G., Eckel, S., Logan, A., Taher, M, and Wilson, J. 2014. Global Trade, Local Impacts: Lessons from California on Health Impacts and Environmental Justice Concerns for Residents Living near Freight Rail Yards. Int. J. Environ. Res. Public Health 11 (2), 1914-1941.

Hunt, A., Boyd, R., Taylor, T., Kovats, S, Lachowyx, L, Watkiss, P., and Horrocks, L. 2006. Report on the costs of the hot summer of 2003, DEFA - Climate change impacts and adapataion: Cross regional research programme. Metroeconomica Limited.

Hwang, K.Y. n.d. Restoring Cheonggyecheon Stream in the Downtown Seoul Sections of Cheonggyecheon to be Restored The restoration project covers the area from the Donga building in the CBD to the ending point of.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007 - Impacts, adaptation, and vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press.

Iuell, B., Bekker, G.J., *et al*. (eds). 2003. Wildlife and Traffic: A European Handbook for Identifying Conflicts and Managing Solutions.

Jaroszweski, D., Chapman, L. and Petts, J. 2010. Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach. Journal of Transport Geography, 18(2), pp.331–335. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0966692309001185 [Accessed January 31, 2014].

Jin, L. *et al*. 2011. Salting our landscape: an integrated catchment model using readily accessible data to assess emerging road salt contamination to streams. Environmental pollution (Barking, Essex : 1987), 159(5), pp.1257–65. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21316826 [Accessed January 31, 2014].

Jones, P. and Macdonald, N. 2007. Making space for unruly water: Sustainable drainage systems and the disciplining of surface runoff. Geoforum, 38(3), pp.534–544. Available at: http://linkinghub.elsevier.com/retrieve/pii/S001671850600145X [Accessed January 31, 2014].

Kennedy, C. and Corfee-Morlot, J. 2013. Past performance and future needs for low carbon climate resilient infrastructure– An investment perspective. Energy Policy, 59, pp.773–783. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421513002814 [Accessed December 19, 2013].

Kim, J.J, Smorodinksy, S., Lipsett, M, Singer, B.C., Hodgson, A.T., and Ostro, B. 2004. Traffic related Air Pollution near Busy Roads. Am. Jour. Respiratory and Critical Care Medicine 170 (5), 520-526.

Koetse, M.J. and Rietveld, P. 2009. The impact of climate change and weather on transport: An overview of empirical findings. Transportation Research Part D: Transport and Environment, 14(3), pp.205–221. Available at: http://linkinghub.elsevier.com/retrieve/pii/S136192090800165X [Accessed January 24, 2014].

Kotzen, B. and English, C. 2009. Environmental Noise Barriers: A Guide to Their Acoustic and Visual Design. Second Edition. Abingdon: Taylor and Francis.

Lawton, J.H., Brotherton, P.M. *et al*. 2010. Making Space for Nature: A reivew of England's Wildlife Sites and Ecological Network. Report to Defra.

Leichenko, R. 2011. Climate change and urban resilience. Current Opinion in Environmental Sustainability 3 (3), 164-168.

Love, G., Soares, A. and Püempel, H. 2010. Climate Change, Climate Variability and Transportation. Procedia Environmental Sciences, 1, pp.130–145. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1878029610000113 [Accessed January 31, 2014].

London Assembly. 2012. On the right lines? Vegetation Management on London's Railway Embankments.

MA (Millenium Ecosystem Assessment). 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington D.C.

Maffei, L. *et al*. 2013. The influence of visual characteristics of barriers on railway noise perception. The Science of the total environment, 445-446, pp.41–7. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23314121 [Accessed January 24, 2014].

Manning, L.J. *et al*. 2008. Spatial analysis of the reliability of transport networks subject to rainfall-induced landslides. Hydrological Processes, 22(17), pp.7–9.

Mcbain, W., Wilkes, D. and Retter, M. 2010. Flood resilience and resistance for critical infrastructure.Mell, I.C. *et al*. 2013. Promoting urban greening: Valuing the development of green infrastructure investments in the urban core of Manchester, UK. Urban Forestry and Urban Greening, 12(3), pp.296–306. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1618866713000526 [Accessed January 22, 2014].

Meunier, F.D., Verheyden, C. and Jouventin, P. 1999. Bird communities of highway verges: Influence of adjacent habitat and roadside management. Acta Oecologica, 20(1), pp.1–13.

Murphy, J.M. *et al*. 2010. UK Climate Projections: Climate change projections, Exeter.

Natural England. 2007. Conserving biodiversity in a changing climate: guidance on building capacity to adapt.

Natural England. 2008. England Biodiversity Strategy Climate Change Adaptation Principles: Conserving biodiversity in a changing climate.

Natural England. 2013. The Mosaic Approach: Managing Habitats for Species (B2020-009). Available at: http://publications.naturalengland.org.uk/publication/6415972705501184?category=5856835374415872 [Accessed 22 July, 2014].

Natural England. 2014b. Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2) (NERR057) http://publications.naturalengland.org.uk/publication/6692039286587392 [Accessed 11 December, 2014].

Natural Economy Northwest. 2009. “ Putting the green in the grey”. Creating sustainable grey infrastructure: A guide for developers, planners and project managers.

NDOR (Nebraska Department of Roads). 2012. NDOR Roadside Vegetation Establishment and Management.

Network Rail. 2011. Network Rail Climate Change Adaptation Report: In reponse to the UK Government’s Adaptation Reporting Power.

Network Rail. 2012a. Management of lineside vegetation.

Network Rail. 2012b. Recommended Planting - Species Matrix.

Network Rail. n.d. SSSI Register. Available at http://www.safety.networkrail.co.uk/On-site-Solutions/Environment/Network-Rail-Sites-of-Special-Scientific-Interest-Register [Accessed 6 June, 2014].

Network Rail. 2014. About us. Available at www.networkrail.co.uk/aspx/729.aspx [Accessed 6 June, 2014].

Nikolakaki, P. 2004. A GIS site-selection process for habitat creation: estimating connectivity of habitat patches. Landscape and Urban Planning, 68(1), pp.77–94. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204603001671 [Accessed December 18, 2013].

Nisbet, T.R. and Broadmeadow, S. 2003. Opportunity mapping for trees and floods. (December), pp.1–24.

Noordijk, J. *et al*. 2009. Optimizing grassland management for flower-visiting insects in roadside verges. Biological Conservation, 142(10), pp.2097–2103. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320709001761 [Accessed December 19, 2013].

Nordbakken, J.-F. *et al*. 2010. Successful creation of species-rich grassland on road verges depend on various methods for seed transfer. Urban Forestry and Urban Greening, 9(1), pp.43–47. Available at: http://linkinghub.elsevier.com/retrieve/pii/S161886670900082X [Accessed December 19, 2013].

Northern Territory Government. n.d. Erosion and Sediment Control Guidelines: Transport Corridors.

O'Donoghue, A. and Shackleton, C.M. 2013. Current and potential carbon stocks of trees in urban parking lots in towns of the Eastern Cape, South Africa. Urban Forestry and Urban Greening, 12(4), pp.443–449. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1618866713000782 [Accessed January 27, 2014].

Olff, H. and Ritchie M. 2002. Fragmented nature: consequences for biodiversity: Landscape and Urban Planning 58, 83-92.

Oxfordshire County Council. 2005. Policy: The Management of Highway Trees.

Patricelli, G.L, and Blickley, J.L. 2006. Overview. Avian communication and urban noise: the causes and consequencs of vocal adjustment. The Auk 123, 639-649.

Penone, C. *et al*. 2012a. Do railway edges provide functional connectivity for plant communities in an urban context? Biological Conservation, 148(1), pp.126–133. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320712000547 [Accessed December 12, 2013].

Penone, C. *et al*. 2012b. Do railway edges provide functional connectivity for plant communities in an urban context? Biological Conservation, 148(1), pp.126–133. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320712000547 [Accessed January 21, 2014].

Peris, S.J. and Pescador, M. 2004. Effects of traffic noise in passerine populations in Mediterranean wooded pastures. Applied Acoustics 65, 357-366.

Piguet, P., Parriaux, A. and Bensimon, M. 2008. The diffuse infiltration of road runoff: an environmental improvement. The Science of the total environment, 397(1-3), pp.13–23. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18417191 [Accessed January 31, 2014].

Quinn, A. n.d. What does the future look like?

Qin, L. 2011. Can we get more out of our roads? Master of Science (MSc) from consortium of University of Southampton, Lund University, University of Warsaw and University of Twente.

Radford, K.G. and James, P. 2013. Changes in the value of ecosystem services along a rural?urban gradient: A case study of Greater Manchester, UK. Landscape and Urban Planning, 109(1), pp.117–127. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204612002885 [Accessed January 29, 2014].

Ramsden, D. 2003. Barn Owls and Major Roads – The Barn Owl Trust.

Reijnen, R. and Foppen,R. 2006. Impact of road traffic on breeding bird populations. In Davenport J. and Davenport, J.L. (Eds), The Ecology of Transportation: Managing Mobility for the Environment. Chapter 12, pp 255-274.

Reijnen, R., Foppen, R., and Meeuwsen, H. 1996. The Effects of Traffic On the Density of Breeding Birds in Dutch Agricultural Grasslands. Biological Conservation 75, 255-260.

Reijnen, R., Foppen, R., and Veenbaas, G. 1997. Disturbance by traffice of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. Biodiversity Conservation 6, 567-81.

Van Renterghem, T. *et al*. 2013. The potential of building envelope greening to achieve quietness. Building and Environment, 61, pp.34–44. Available at: http://linkinghub.elsevier.com/retrieve/pii/S036013231200323X [Accessed January 23, 2014].

Van Renterghem, T. and Botteldooren, D. 2012. On the choice between walls and berms for road traffic noise shielding including wind effects. Landscape and Urban Planning, 105(3), pp.199–210. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204611003689 [Accessed January 31, 2014].

Van Renterghem, T., Botteldooren, D. and Verheyen, K. 2012. Road traffic noise shielding by vegetation belts of limited depth. Journal of Sound and Vibration, 331(10), pp.2404–2425. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0022460X12000260 [Accessed January 31, 2014].

Rheindt, F.E. 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? J. Ornith. 144, 295-306.

Rogers, K., Jarratt, T., and Hansford, D. 2011. Torbay's Urban Forest: Assessing Urban Forest Effects and Values. A report on the findings from the UK i-Tree Eco pilot project. Exeter: Treeconomics.

Ruiz-Capillas, P., Mata, C. and Malo, J.E. 2013. Road verges are refuges for small mammal populations in extensively managed Mediterranean landscapes. Biological Conservation, 158, pp.223–229. Available at: http://linkinghub.elsevier.com/retrieve/pii/S000632071200420X [Accessed December 19, 2013].

Saarinen, K. *et al*. 2005. Butterflies and diurnal moths along road verges: Does road type affect diversity and abundance? Biological Conservation, 123(3), pp.403–412. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320705000182 [Accessed December 19, 2013].

Sæbø, a *et al*. 2012. Plant species differences in particulate matter accumulation on leaf surfaces. The Science of the total environment, 427-428, pp.347–54. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22554531 [Accessed January 27, 2014].

Sahu, M. and Gu, R.R. 2009. Modeling the effects of riparian buffer zone and contour strips on stream water quality. Ecological Engineering, 35(8), pp.1167–1177. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925857409000834 [Accessed January 31, 2014].

Salter, A., Delafield, M., Heaven, S. and Gunton, Z. 2007. Anaerobic difestion of verge cuttings for transport fuel. Proceeding of the ICE - Wastge and Resource Management 160(3), 105-112.

Schaub, A., Oswald, J. and Siemers, B.J. 2008. Foraging bats avoid noise. Journal of Experimental Biology 211 (19), 3174-80.

Skórka, P. *et al*. 2013. Factors affecting road mortality and the suitability of road verges for butterflies. Biological Conservation, 159, pp.148–157. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320712005265 [Accessed December 12, 2013].

Siemers, B.M. and Schaub, A. 2010. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proc. R.Soc. B: Biological Sciences 278 (1712), 1646-52.

Siemers, B.M. and Swift, S.M. 2006. Differences in sensory ecology contribute to resource partitioning in the bats: *Myotis bechsteinii* and *Myotis nattereri* (Chiroptera: Vespertilionidae). Behavioral Ecology and Sociobiology 59, 373-380.

Standley, S. *et al*. 2009. Wild weather warning a London climate impacts profile, London.

Steffens, J.T., Wang, Y.J. and Zhang, K.M. 2012. Exploration of effects of a vegetation barrier on particle size distributions in a near-road environment. Atmospheric Environment, 50, pp.120–128. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1352231011013410 [Accessed January 31, 2014].

Swift, S., and Racey, P. 2002. Gleaning as a foraging strategy in Natterer's bat *Myotis nattereri.* Behavioural Ecology and Sociobiology 52 (5), 408-416.

Suárez-Esteban, A., Delibes, M. and Fedriani, J.M. 2013. Unpaved road verges as hotspots of fleshy-fruited shrub recruitment and establishment. Biological Conservation, 167, pp.50–56. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320713002541 [Accessed December 15, 2013].

Sullivan, J.J. *et al*. 2009. Distribution and spread of environmental weeds along New Zealand roadsides. , 33, pp.190–204.

Susdrain. 2014. Available from: http://www.susdrain.org/ [Accessed April 16, 2014].

Sustrans Greener Greenways. (No date). http://www.sustrans.org.uk/ncn/map/themed-routes-0/routes-nature-lovers/sustrans-greener-greenways [Accessed October, 2014].

Szita, É., Fetykó, K. and Kiss, B. n.d. Study of predatory arthropod assemblages on Hungarian highway verges. , p.83829.

Taranaki Regional Council. n.d. Shelter and timberbelt design. Available at trc.gov.nz (Accessed: 9 Jun 2014).

Torquay Herald Express. 2013. UPDATE: Warnings after fire beside railway line at Goodrington. Available at http://www.torquayheraldexpress.co.uk/UPDATE-Warnings-railway-line-Goodrington/story-19520914-detail/story.html [Accessed 9 June, 2014].

Townsend, P.A. and Levely, D.J. 2005. AN EXPERIMENTAL TEST OF WHETHER HABITAT CORRIDORS AFFECT POLLEN TRANSFER. Ecology 86(2), pp.466–475.

Turner, T. 2006. Greenway planning in Britain: recent work and future plans Landscape and Urban Planning 76 (1-4) , 240-251.

Tyagi, V., Kumar, K. and Jain, V.K. 2006. A study of the spectral characteristics of traffic noise attenuation by vegetation belts in Delhi. Applied Acoustics, 67(9), pp.926–935. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0003682X05001404 [Accessed January 31, 2014].

UK National Ecosystem Assessment. 2011. The UK National Ecosystem Assessment: Technical Report. UNEP-WCMC, Cambridge.

United States Department of Agriculture (USDA) Forest Service. 2003. *The Large Tree Argument: The case for large trees vs. small trees.* Davis, California: Centre for Urban Forest Research, Pacific Southwest Research Station.

USDA Forest Service, 2014. *i-Tree: Tools for Assessing and Managing Community Forests.* Available at: https://www.itreetools.org/index.php [Accessed 29 July, 2014].

Vermeulen, H.J.W. and Opdam, P.F.M. 1995. Effectiveness of roadside verges as dispersal corridors for small ground-dwelling animals : A simulation study. Landscape and Urban Planning, 31, pp.233–248.

Le Viol, I. *et al*. 2008. Plant and spider communities benefit differently from the presence of planted hedgerows in highway verges. Biological Conservation, 141(6), pp.1581–1590. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320708001316 [Accessed December 19, 2013].

Le Viol, I. *et al*. 2009. The contribution of motorway stormwater retention ponds to the biodiversity of aquatic macroinvertebrates. Biological Conservation, 142(12), pp.3163–3171. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320709003978 [Accessed January 22, 2014].

Vos, P.E.J. *et al*. 2013. Improving local air quality in cities: to tree or not to tree? Environmental pollution (Barking, Essex : 1987), 183, pp.113–22. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23194646 [Accessed January 24, 2014].

Warren, P.S. *et al*. 2006. Urban bioacoustics: it's not just noise. Animal Behaviour, 71(3), pp.491–502. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0003347205004379 [Accessed January 22, 2014].

Webb, J.R., Drewitt, A.L. and Measures, G.H. 2010. Managing for species: Integrating the needs of England's priority species into habitat management. Natural England Research Report NERR024.

Wheater, H. and Evans, E. 2009. Land use, water management and future flood risk. Land Use Policy, 26, pp.S251–S264. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0264837709001082 [Accessed January 22, 2014].

Wilson, S., Bray, B., Neesam, S., Bunn, S. and Flanagan, E. n.d. SUSTAINABLE DRAINAGE: Cambridge design and adoption guide.

Wolf, K.L. 2003. Freeway Roadside Management: The Urban Forest Beyond the White Line. Journal of Arboriculture 29 (3), 127-136.

Zhou, X.H, Brandle, J.R., Mize, C.W., and Takle, E.S. 2005. Three-dimensional aerodynamic structure of a tree shelterbelt: Definition, characterization, and working models. Agroforestry Systems 63 (2), 133-147.

Zwaenepoel, A., Roovers, P. and Hermy, M. 2006. Motor vehicles as vectors of plant species from road verges in a suburban environment. Basic and Applied Ecology, 7(1), pp.83–93. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1439179105000496 [Accessed December 19, 2013].

Appendix 1 – Methodology table

See standalone excel spreadsheet.

Appendix 2 – Results table

See standalone excel spreadsheet.