

Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2)

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Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2)

Sophie Rolls and Tim Sunderland



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Foreword

The natural environment is essential to the lives of every one of us. This Natural England report, the second edition of Microeconomic Evidence for the Benefits of Investment in the Environment (or MEBIE for short), shows how the natural world directly improves our lives and the UK economy. The report describes how the natural environment attracts inward investment and generates consumer spending, enhances air and water quality, and improves people's physical health and mental well-being. Taking proper account of these benefits and managing our natural environment efficiently and effectively is therefore essential to ensuring sustainable growth into the future.

As the Chairman of Natural England, I believe that science and evidence must be at the heart of protecting the environment. With solid evidence we can make the best decisions for the long-term sustainable management of the environment. This report provides a succinct and accessible summary of the state of the present evidence base. In so doing it makes a cogent case for investing now in the natural environment so that society can reap the dividends for years to come.



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1 How to use this review

1a About the review

Introduction

- 1.1 Welcome to MEBIE 2! The original Microeconomic Evidence for the Benefits of Investment in the Environment (MEBIE) was designed to assist Natural England staff in understanding the benefits of the natural environment. It has been used widely, both within and outside Natural England, since it was first published in 2012.
- 1.2 This version of MEBIE incorporates over 100 new pieces of evidence, and a simplified format. It includes new chapters on Consumer spending, Pollination and Pest control, and existing chapters have been extensively revised.

What is this review for?

- 1.3 MEBIE is a guide to relevant evidence on the benefits of investment in the natural environment, with a particular focus on England. This is of interest to decision makers such as Local Authorities and Local Enterprise Partnerships. However, no claim is made to cover this area exhaustively and new research is continually emerging.

How can the review help you?

- 1.4 We have thoroughly reviewed the literature for the benefits of investment in the environment, and only included that which meets national government standards, so you can use the evidence presented here with confidence. MEBIE highlights potential benefits, reviews the evidence for them and gives references to support the case. It also highlights contextual limitations and uncertainties, to provide you with a well-rounded understanding of the issues involved. A methodology section is provided in Appendix 1 to provide transparency as to the depth of the review undertaken.

What are its limitations?

- 1.5 Often the perfect example you are looking for will not exist. In these cases you can use MEBIE to demonstrate the weight of evidence around a particular benefit. MEBIE can also point to relevant case studies that are useful in making the case. In many cases, explaining the argument based on the existing evidence and case studies may be sufficient. MEBIE does not provide you with the information needed to estimate the economic benefits of your specific project. It may be possible to undertake a value transfer, in which values are inferred from similar studies, and tools are available to assist with this¹, however it is highly recommended you seek advice from an economist before proceeding.

Why should you read the rest of this chapter?

- 1.6 An essential introduction to economic evidence can be found in [Section 1b](#). This will assist you in understanding the figures provided and presenting them correctly to stakeholders.

¹ For a review of available tools, please see Natural England and other parties (2013) Green Infrastructure – Valuation Tools Assessment: <http://publications.naturalengland.org.uk/publication/6264318517575680>.

- 1.7 **Section 1c** provides a useful orientation to the document structure so that you will be able to use it much faster and more effectively.

Feedback

- 1.8 Feedback on this review is very welcome. Please send comments and suggestions to sophie.rolls@naturalengland.org.uk.

1b Introduction to economic evidence

Purpose of this section

- 1.9 This evidence package is designed to help you make robust, evidence based arguments for the benefits offered by the natural environment, demonstrating that investment in the environment represents a rational use of limited funds. In order to do so however there are some economic terms and approaches you need to understand. This section provides a 'bare-minimum' account of these terms.

Counterfactual or baseline

- 1.10 All the economic evidence in this package refers to the benefits derived from an *improvement* in the natural environment, or the loss caused by *damage* to the natural environment. That is to say it's all about a **change** in the environment. For example, you can't put a value on Dartmoor, but you can value the difference in the benefits of freshwater from Dartmoor under two different management scenarios (for example increasing Dartmoor's woodland cover by 10 per cent, compared with keeping it at its current level). What we value is the project, not Dartmoor itself! This means that evidence is based on the difference between what happens because of the project and what would have happened anyway, which is known as the counterfactual or baseline position.

Impact and value

- 1.11 When dealing with economic evidence, it's very important to understand that numbers which refer to economic benefits can refer to two very different things – economic IMPACT (the effect on Gross Domestic Product, or GDP, whether positive or negative) and economic VALUE (the total effect on the welfare of the individual whether caused by changes to consumption of traded goods, or more intangible things such as the beauty of a landscape²). The economic value approach forms the basis of Cost Benefit Analysis, which is the UK Government's dominant decision making framework (HM Treasury 2003). The distinction between IMPACT and VALUE is very important so when quoting a figure from the evidence package be sure that you understand which it refers to.

Double-counting

- 1.12 When presenting economic evidence it is essential to avoid counting the same benefit twice, otherwise you undermine the credibility of your evidence base. For example, evidence about how much being near a park increases houses prices is likely to be based on the aesthetic benefits of the park and so these should not both be counted. Because of this, particular care should be taken when combining evidence from Chapters 3 and 4.

² For intangible or non-market goods, this value can be estimated using a variety of techniques such as revealed or stated preference approaches. Further detail on these approaches is available in HM Treasury (2003). The Green Book: Appraisal and Evaluation in Central Government. London, HM Treasury.

Timeframe

- 1.13 When quoting numbers, it's very important to be clear about the timeframe for the numbers you're quoting. For example, is a benefit of £1 million a one-off benefit, or is it likely to recur? And, if so, how long can it be expected to recur on the basis of the investment under consideration?

Environmental justice

- 1.14 There is good evidence that environmental benefits are unequally distributed through society, with disadvantaged groups having poorer access to the natural environment (for example, see Fairburn and Smith 2008 for a discussion of the situation in South Yorkshire). In policy terms environmental injustice might be an important motivating factor for an environmental intervention. For example, improved green space in a deprived part of the inner-city might lead to a better health improvement than in a wealthy area which was already well endowed with green space. This means that for some of the environmental interventions discussed, knowing as much as possible who the beneficiaries are is important.

Context for large numbers

- 1.15 Environmental benefits are often significant, and therefore involve large numbers. Some audiences may lack context for large numbers, and some are offered for context below:
- Total UK Government spending in 2012-13 = £674 billion (HM Treasury 2013).
 - Total UK Government spending on environmental protection in 2012-13 = £11.1 billion (HM Treasury 2013).
 - Bristol City Council budget in 2012-13= £366 million (Bristol City Council 2013).
 - Average house price in Bristol between April and June 2013 = £214,000 (average £385,000 for a detached house, or £183,000 for a flat) (BBC 2013).

1c How to use the review

- 1.16 This section provides an orientation to the structure of the review, which is designed to be used as a reference document, rather than read from cover to cover.

How to find what you are looking for

- 1.17 If you know what sort of evidence you are looking for, scanning the contents pages should allow you to quickly locate it. However, if you don't, turn to **Chapter 2** which provides short essays on key themes with links to the relevant evidence. **Chapter 3** provides evidence about traditional economic concerns. This evidence draws on a much broader suite of evidence about ecosystem services which is presented in **Chapter 4**, using a methodology adapted from Department for Environment, Food and Rural Affairs (2007). Sub-chapters within Chapters 3 and 4 are in alphabetical order.

Section structure

- 1.18 **Chapter 2** takes the form of thematic essays, but **Chapter 3** and **Chapter 4** are divided into sub-chapters presenting a particular benefit. Sections vary according to the needs of the evidence presented, but generally look like the following example.

1d Environmental benefit example

One or two sentence summary of the evidence.

Introduction

This section will explain the benefit under discussion, what is included and excluded and how it fits into economic theory.

Theory of change

This subsection will present the proposed benefit in terms of a theory of change which links an environmental improvement with a benefit to society (stylised example given below). If any of the links in the theory is broken (for example, if there is no evidence linking a proposed improvement with a resulting change in environmental service), this may bring into question the entire benefit being examined.



Can the benefit be quantified?

This subsection will consider whether it is possible to appropriately quantify the relationships in the theory of change, and the barriers to doing so. This provides essential context to the 'how strong is the evidence?' subsection, because the strength of the evidence needs to be considered relative to the field of knowledge it is in. For example strong evidence for causal links can be more difficult to achieve in the social sciences, than in the natural sciences.

How strong is the evidence?

This subsection will review the relevant literature and provide an assessment of the strength of the evidence connecting the theory of change, including any key uncertainties and contextual factors.

Evidence

This section will contain any evidence which can be used to support the case for a particular benefit. Robust quantitative and qualitative evidence will be presented. The wording of this section has been chosen carefully to identify the environmental benefits whilst representing the research accurately. The footnotes in the section are very important because they provide background to the information presented, and note any contextual limitations of the study.

Link with climate change

Where the case for the benefit is strongly related to climate change this section will explain the link and offer any relevant evidence. Climate change has been singled out as a priority because it is one of the most significant sustainability challenges of the 21st century and therefore receives a great deal of attention from *economic* as well as environmental policy.

References

References for each piece of evidence are conveniently presented at the end of each chapter, rather than at the end of the report.

References

BBC. 2013. "UK house prices: April to June 2013." Retrieved February 17, 2014, from http://news.bbc.co.uk/1/shared/spl/hi/in_depth/uk_house_prices/html/hb.stm.

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HM Treasury. 2003. The Green Book: Appraisal and Evaluation in Central Government. London, HM Treasury.

HM Treasury. 2013. Country and regional analysis: November 2013. HMT Public Spending Statistics. London, HM Treasury.

2 Relating evidence to significant themes

Introduction

2.1 This chapter summarises the evidence in the following sections around three significant themes: social welfare, economic growth, and climate change adaptation and mitigation. For further information, please refer the relevant chapters indicated in brackets (for example, 4c).

2a Social welfare

- 2.2 Social welfare refers to the overall happiness and life satisfaction of members of society. The primary focus of this report is on how the natural environment contributes to changes in social welfare. Measurements of economic VALUE refer to the extent to which a good or service contributes to raising levels of social welfare.
- 2.3 Social welfare is affected by not just access to material goods, but also by numerous intangible factors. The natural environment provides key material goods essential to welfare, such as food (4c). It provides important spaces for recreation and tourism (3e) and improves people's mental health (4f).
- 2.4 There is evidence that the natural environment provides physical health benefits through improvements in air quality (4a), noise (4g) and temperature regulation (4i). The natural environment can reduce the impacts of extreme events such as flooding, which negatively impact on people's welfare (4b, 4c).
- 2.5 The extent to which people benefit from the natural environment is partly evidenced by our desire to live near to it, reflected in higher house prices near greenspaces (3b).

2b Economic growth

- 2.6 There is a great deal of interest in the way in which the natural environment contributes to economic growth. For a more comprehensive review, please see the Defra and Natural England commissioned report, *Green Infrastructure's Contribution to Economic Growth: A Review* (eftec and Sheffield Hallam University 2013)³.
- 2.7 There is evidence linking the natural environment to improved physical and mental health outcomes (4a, 4f, 4g and 4i). Logically this should lead to improved productivity and reduced worker absence.
- 2.8 There is evidence that the natural environment contributes to the attractiveness of a local area and that this may attract people to the area, to live (3b), to shop (3a) and to recreate (3e).
- 2.9 There are examples where the natural environment offers much better value for public investment than the alternative. For example natural water filtration can be much cheaper than the alternative (4m); natural flood defence even more so (4b). Cost savings to the public purse due to investment in the natural environment could lead to a reduced need for taxation, which can translate into increases in economic output.
-

³ Available at: <http://randd.defra.gov.uk/Default.aspx?Completed=0&Location=None&Menu=Menu&Module=More&ProjectID=19056>.

- 2.10 The points above highlight some of the ways in which the natural environment may positively contribute to economic growth. The evidence in this review does not examine some critical issues linking the environment and economic growth, namely:
- Economic dependencies on limited natural resources such as coal and food products.
 - The capacity of the environment to absorb the wastes produced by the economy.
 - Other negative impacts of economic growth on the environment.
- 2.11 These interdependencies are likely to seriously impact on the extent to which the economy can grow sustainably into the future.

2c Climate change adaptation and mitigation

- 2.12 Climate change is a major long-term security threat to the economy. The Stern Review in 2006 estimated that the impacts of climate change were equivalent to losing at least 5 per cent of global Gross Domestic Product (GDP) each year, indefinitely (Stern 2006).
- 2.13 On a national level, the UK Government is committed to reducing emissions and has set in place legally binding carbon budgets to achieve reductions to 2027. The Government notes that investment in energy infrastructure, diversification and efficiency is critical to reducing emissions, saving money and insulating the economy against fossil fuel price shocks (HM Government 2013).
- 2.14 Land use change can reduce or increase the rate of carbon emissions, as well as sequester carbon (4e). Deliberate investment in the carbon sink function of land is therefore a priority for climate change mitigation.
- 2.15 Meeting carbon reduction targets will require significantly increased energy efficiency. Trees and plants can reduce the need for heating and cooling of buildings (4i). Using the natural environment can be a solution with lower energy cost.
- 2.16 Unfortunately, current cuts in carbon emissions are far from sufficient to keep average global temperature increase below 2 degrees, pointing to the need for increased effort in mitigation and adaptation (European Environment Agency 2010).
- 2.17 Climate change is set to make freshwater availability an issue for some regions of the UK, due to an increased risk of drought. It poses a significant threat to food production (4d). Using the natural environment to encourage water filtration and enhance food production is an option to help reduce these threats.
- 2.18 Flood risk has increased due to development on flood plains and an increasing amount of impermeable surfaces such as driveways. Climate change will further intensify this. Natural environment interventions can help to reduce this risk (4c).
- 2.19 Urban centres in particular may in future suffer from dangerous heat and air pollution. Some of the impact may be reduced by investment in the natural environment (particularly trees) (4a, 4i).

References

eftec and Sheffield Hallam University. 2013. Green infrastructure's contribution to economic growth: a review. Report to Defra and Natural England. London, July 2013.

European Environment Agency. 2010. The European environment - state and outlook 2010: synthesis. Copenhagen.

HM Government. 2013. Government Response to the Fourth Annual Progress Report of the Committee on Climate Change: Meeting the Carbon Budgets - 2012 Progress Report to Parliament. London, HM Government.

Stern, N. 2006. Stern Review on the Economics of Climate Change. London, HM Treasury.

3 Economic competitiveness

- 3.1 This chapter examines the evidence that the natural environment can enhance the economic competitiveness of a particular region. Economic competitiveness refers to the ability of a particular region to attract businesses and investment, and therefore encourage economic activity.
- 3.2 There are several ways this could occur. On a very local scale, the natural environment in an area may increase employee productivity. Consumers in greener areas may spend more locally. Tourists may be drawn to the area and spend money on accommodation and other activities.
- 3.3 If households or businesses would prefer to be located in greener areas, this is likely to show up in the amounts they pay to purchase or rent in the area. This chapter therefore includes a section on house prices, and also on regional investment (which includes investment in office buildings).

3a Consumer spending

There is a limited body of research that suggests that people spend more in locations with more natural features. Shoppers are likely to experience less stress in such places.

Introduction

- 3.4 There is some evidence that people's spending behaviour may be affected by the nearby environment. Shopping can be a highly stressful activity requiring a high degree of mental alertness. In the Mental Health chapter, it is demonstrated that greenspace is linked to reduced stress and attention fatigue. By reducing the level of fatigue experienced by consumers, it may be possible to attract them to certain less stressful shopping destinations, and to make their shopping experiences more enjoyable.
- 3.5 There is evidence to suggest that consumers in a positive mood spend more than those who are in a more negative mood, and are more satisfied with their experience with the retailer. Similarly, store employees are affected by the store environment, and have been shown to be more responsive to customers, and more satisfied with their employer, in a nicer retail environment (Joye, Willems et al. 2010).
- 3.6 Changes to consumer behaviour may result in changes in spending patterns, with consumers attracted to, and spending more in greener places. However, it does not change the amount of money they have available to spend. What is likely to occur therefore is a redistribution of income between regional locations, but no economic IMPACT at the national level.

Theory of change



Can the benefit be quantified?

- 3.7 Yes. In theory this benefit can be quantified by examining consumer spending behaviour in locations with differing levels of greenery, taking into account other variables that impact on consumer spending.

How strong is the evidence?

- 3.8 The evidence for this benefit is highly suggestive but due to the small number of studies, should not be regarded as conclusive. The evidence is drawn from studies investigating consumer perceptions in retail environments. These are largely based on experiments using photographs of different retail settings. It has been demonstrated that there is a strong correlation between people's predicted reactions based on photographs, and their actual reactions in store (Brenngman, Willems et al. 2012).

Evidence

- Research in the Netherlands found that the introduction of vegetation into a fashion store with a complex store interior (large quantity and variety of products, complicated store layout) was linked to feelings of pleasure and reduced stress amongst prospective shoppers. Feelings of

pleasure were found to be an important factor in determining whether or not the consumer would approach or avoid the store (Brenngman, Willems et al. 2012)⁴.

- Surveys across 26 different-sized cities in the USA found that shoppers reported being willing to travel further to visit, stay longer once there, and more frequently visit, business districts with trees. Trees were also linked with shoppers valuing products more highly, with willingness to pay for a selection of nine products increasing by 9.2 percent. Willingness to pay for parking was also higher for shopping areas with trees (Wolf 2005)⁵.

3.9 It should be noted that integrating greenery into the retail environment needs to be done on a case-by-case basis. Greenery can potentially reduce access to shops or products, hide shop frontage and advertising, and exacerbate crowding if situated incorrectly (Joye, Willems et al. 2010).

References

Brenngman, M., K. Willems, et al. 2012. "The impact of in-store greenery on customers." *Psychology of Marketing* **29**(11): 807-821.

Joye, Y., K. Willems, et al. 2010. "The effects of urban retail greenery on consumer experience: Reviewing the evidence from a restorative perspective." *Urban Forestry and Urban Greening* **9**: 57-64.

Wolf, K. 2005. "Trees in the small city retail business district: Comparing resident and visitor perceptions." *Journal of Forestry* **103**(8): 390-395.

⁴ This effect only applied to a 'complex' store interior, and not for stores with a simple uncluttered layout. The authors note that effects observed in fashion retail may not occur in other shopping settings (for instance supermarkets), where the shopping activity is more utilitarian rather than a form of entertainment.

⁵ Survey respondents were presented with two hypothetical scenarios using photographs of streetscapes with different vegetation. The survey had 161 respondents and a response rate of 10.1%, which is considered low, and also a higher proportion of upper middle class respondents than the US average. The products analysed were divided into convenience (for example, sandwich), shopping (for example, jacket) and specialty (for example, glasses) items.

3b House prices

House prices are influenced by a wide range of factors. Evidence suggests that the natural environment nearby may be one of these.

Introduction

- 3.10 People value both proximity to, and views of, the natural environment. For this reason they may be willing to spend more on properties that afford them this benefit, and the evidence for this is reviewed in this section. However, before presenting the evidence it is helpful to position it clearly in economic theory. Whereas an investment in a new technology can increase the efficiency with which goods are produced and therefore increase the size of the economy, property is not a productive asset. This means that property price increases are ***not an economic benefit*** in themselves. Increases in property prices merely transfer wealth from those buying property to those selling it, and can lead to poorer members of society being priced out of neighbourhoods in greener areas. Therefore increasing property prices does not make sense as a goal of economic or social policy.
- 3.11 There are however two reasons why increasing house prices might be good news. Firstly, it might be an ***indicator*** of increasing strength in the local economy (alternatively it might be part of a boom driven by unsustainable credit!) Secondly, if your concern is about the regeneration of a deprived area, rather than economic growth per se, you will be pleased that increasing prices show a relative improvement of your target area, relative to other localities. Improvements in property prices may be welcomed by Local Authorities if they increase the overall tax base, and by developers if they improve the retail price of their units.
- 3.12 This means that rather than a focus on economic IMPACT, property prices are of most interest as an indicator of economic VALUE. The fact that people are willing to pay more for properties with a view of, or close to, a natural environment is important evidence that they value it. This evidence might even have the potential to shed light on which types of natural environment people value most. It is difficult to be entirely sure which of the many benefits of the natural environment are captured by property prices, but it is likely that it is predominantly aesthetic and recreation benefits, as opposed to less obvious things such as flood control. Hence, the focus of much of the literature is on 'greenspaces', which often refer to parks and gardens managed for recreational use.

Theory of change



Can the benefit be quantified?

- 3.13 Quasi-experimental attempts to quantify the relationship between property prices and greenspace have been carried out and provide useful evidence, however it is very difficult to control for all the other factors that may impact on house prices. These include general movement in the property market or economy, other regeneration improvements to the area which are often made at the same time, new transport links, et cetera. This makes it difficult to identify whether a change in the quality or quantity of the environment in an area will directly result in a change in property prices. Proximity to greenspace is just one of several issues people take into account when purchasing property, with travel to work and the social make-up of the area a stronger influence (GLA Economics 2003).

How strong is the evidence?

3.14 Definitive evidence on the link between the natural environment and property prices is difficult to obtain, however the combination of both qualitative and quantitative evidence makes for a strong case. The strongest pieces of evidence come from hedonic pricing studies which look for statistically significant relationships between proximity to greenspace and property prices. In general terms, these provide strong evidence that there is a price premium for houses closer to greenspace and with a higher amount of greenspace nearby.

Evidence

- A hedonic pricing study conducted for the UK National Ecosystem Assessment found that on average, a one percent increase in the amount of greenspace in a ward was responsible for £2,020 (approximately one per cent) of the value of a house in England (Mourato, Atkinson et al. 2010)⁶.
- A study of house prices in Aberdeen showed that 'relative to a property located 450 metres away from a park, a property located on the edge of a park could potentially attract a premium of between 0.44% and 19%', depending on house and park type (Dunse, White et al. 2007)⁷.
- Similarly, a study of house prices in London found that 'on average a 1 per cent increase in the amount of greenspace in a ward can be associated with a 0.3 to 0.5 per cent increase in average house price (GLA Economics 2003)⁸.
- Interviews with property professionals show they expect higher prices for properties with park views, and near the park, in case studies of 8 significant English park redevelopment projects (CABE Space 2005)⁹.
- Physical and social context is important. Parks can be the focus of anti-social behaviour, and this is often associated with parks being poorly maintained and unsafe places to play. Where this is the case (Dunse, White et al. 2007), or this is perceived to be the case (CABE Space 2005), this will have a negative effect on property values, particularly on those immediately adjacent to the park, which may more than counteract any positive benefits.
- Troy and Grove (2012) find that in Baltimore, USA, there is a positive association between urban parks and property prices when crime rates are low, however in areas where the crime rate is 4 to 5 times higher than average, the association becomes negative (i.e. proximity to parks reduces property value)¹⁰.
- The sort of views which increase property prices are also quite specific – Garrod and Willis found that marshland and dense forest may reduce property prices (Garrod and Willis 1992). The actual impact will depend on numerous contextual factors including the size and quality of the greenspace, the local property market and economy.

⁶ Due to the large scale of the study, it was unable to control for differences in greenspace quality.

⁷ This study is useful because it includes smaller parks and uses Geographic Information systems to consider distance from the park. The large range of premiums for park edge properties is thought by the authors to be due to concern by house-purchasers about negative impacts of anti-social behaviour.

⁸ This result was produced by a statistical analysis of London's wards which compared house prices with a number of relevant variables (known as a hedonic pricing method). It concluded that the percentage of strategic greenspace (space bigger than urban parks, private gardens and common spaces) was the 5th most important variable after the number of people on income support, travel time to central London, NO₂ average concentrations, and density of properties.

⁹ Case studies are Mesnes Park - Merseyside, Queen Square - Bristol, Boston Square Sensory Park - Hunston, Hulme Park - Manchester, Mowbray Park - Sunderland, Mile End Park - London, King George Recreation Ground - Bushey, Lister Park – Bradford.

¹⁰ They also note that there is anecdotal evidence that more expensive neighbourhoods tend to invest more in their parks, so there may be a 'virtuous circle' where better kept parks reduce crime and maintain higher property prices.

- There is case study evidence which suggests that improvement in greenspace acts powerfully to alter the perceptions of an area, which can therefore support property prices and regeneration (CABE Space 2005).
- The development of a community woodland on the former Bold Colliery site in St Helen's is estimated to have directly and uniquely enhanced existing property values in the surrounding area by £15 million (Forestry Commission 2005)¹¹.

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¹¹ This estimate is based on a district valuer's report which values indicator properties at various times and makes judgments as to the appropriate adjustment to allow for property alterations, the development of the M62 link road, new development and accessibility to adjacent localities. It is the view of a property professional, rather than a repeatable experiment (which is not possible for case studies like this). The strongest evidence that something special is going on is that house prices in St Helen's over the period under review grew slower than the national average, but in the vicinity of Bold Colliery they grew faster.

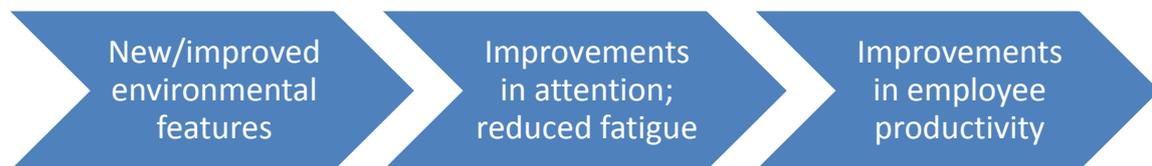
3c Labour productivity

Although plausible, there is a lack of evidence to suggest that the natural environment directly contributes to improvements in labour productivity. It may contribute indirectly via other factors which influence productivity, for instance through improvements to worker health.

Introduction

3.15 It has been suggested that investment in the natural environment boosts productivity at work. This may come about indirectly through the impacts of the natural environment on people's health generally, and these impacts are reviewed in the sections on **Mental health** and **Physical activity**. This section reviews the evidence for the narrower proposal that that quality of the natural environment **at the place of work** makes a difference to productivity. This includes the effect of nature in the indoor environment, views of nature from the windows, and accessible greenspaces in the grounds of the office or factory. There is a close relationship with Section 3d **Regional investment**, however the focus here is on the specific productivity benefit derived, rather than business behaviour as a result of the benefit derived.

Theory of change



Can the benefit be quantified?

3.16 Only with great difficulty. To quantify this would require an experiment comparing the output of employees with and without views of nature/access to nature, and this is unlikely to be able to fully remove any confounding factors that may also influence productivity.

How strong is the evidence?

3.17 The evidence specifically relating labour productivity to the natural environment is weak. There is a lack of evidence that shows a link between any short term attention improvements that may be generated, and actual employee output over the longer term. However, it is reasonable to think that such a relationship might exist. There is evidence that demonstrates that healthy employees take less sick leave and are therefore more productive.

Evidence

- The general basis for the importance of the environment to mental and physical health is made in the **Mental health** and **Physical activity** chapters. Indeed the Health Council of the Netherlands (2004) review of the evidence concludes that an attractive green environment, close to home and work provides the best opportunities to encourage exercise in the form of walking and cycling¹². The work environment therefore can have a role to play in improving employee health.

¹² For further discussion of this, it is recommended that you read Chapters **4f** and **4i**.

- People in England and Wales who report their health as 'not good' are highly likely to be absent from work on incapacity benefits (Bambra and Norman 2006)¹³.
- On the more specific issue as to whether office plants increase productivity, the evidence is less clear. There has been a great deal of research on the benefits of indoor plants. Some research in hospitals have found that people have higher levels of pain tolerance with plants present, and there has also been some research which finds benefits in terms of stress and attention levels in office type situations, although results are mixed (Bringslimark, Hartig et al. 2009). However, partly due to some weaknesses in the experiments reported, and partly due to the complex contextual nature of the issue both Bringslimark (2009) and the Health Council of the Netherlands (2004) regard the evidence as suggestive, but not proven with regard to a generalised causal link between indoor plants and productivity.

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Health Council of the Netherlands and RMNO. 2004. *Nature and Health: The influence of nature on social, psychological and physical well-being*. The Hague, Health Council of the Netherlands and RMNO.

¹³ This study only examines long term incapacity benefit recipients; however it is reasonable to assume that the results hold for short term sickness absences also.

3d Regional investment

Businesses are influenced by a range of factors when determining where to invest. There is some case study evidence that the quality of the natural environment, although not a key driver, may influence where businesses choose to locate and invest.

Introduction

- 3.18 There are several reasons why businesses might choose to invest in a region with a higher quality environment. The first is because a more pleasant workplace may help to attract and retain employees. The second is because employees may be more productive in a more pleasant workplace with natural views and greenspace access [evidence for this is discussed in Section 3c **Labour productivity**]. A third reason is that customers may be more likely to visit the area and spend there [evidence for this is discussed under Section 3a **Consumer spending**].
- 3.19 If businesses believe these benefits exist, demand for commercial and retail properties in greener areas is likely to be higher. This would then be reflected in the price of those properties. Additionally, if businesses are attracted to the area, increased business investment may lead to increased flow on impacts and overall economic activity in the region. If this comes at the expense of economic activity in other areas of the UK, the net economic IMPACT at the UK level may be negligible¹⁴. If however, the result is an increase in investment from overseas, total net economic activity within the UK will increase.
- 3.20 In order to understand the evidence in this section properly, and why increasing commercial property prices is **not** an economic benefit, please read the introduction to Section 3b **House prices**. These arguments apply equally to commercial property prices.

Theory of change



Can the benefit be quantified?

- 3.21 The relationships between proposed cause (views of and access to greenspace) and effect (increased property and rental values) could in principle be quantified although there are great challenges due to the number of contextual factors that would need to be controlled for. In practice the evidence is in the form of qualitative case studies.

How strong is the evidence?

- 3.22 The evidence in Section 3c **Labour productivity** and Section 4f **Mental health** makes it reasonable to suppose that employees may prefer work environments with views of and/or proximity to nature, and that it may contribute to making them healthier and more productive. There is additional evidence in Section 3a **Consumer spending** to suggest that there may be

¹⁴ A transfer of economic activity between regions has occurred, rather than a net increase in economic activity.

positive impacts on consumer spending. Case study evidence presented below suggests that a greener natural environment can indeed be attractive to business.

Evidence

UK/Europe

- A survey of real estate developers and consultants across Europe found that 95% of respondents believe that open space adds value to commercial property and would be willing to pay at least 3% more to be in close proximity to open space. Respondents rated access to open space the 5th most important criterion when selecting commercial property, after location, cost, public transport links, amenities but *before* prestige of address and building aesthetics (Gensler and Urban Land Institute 2011)¹⁵. It is also possible that it is not the open space in itself that is important, but rather the signal it sends about the status of the business in society.
- By contrast, Henneberry, Rowley et al. (2004) found that neither occupiers, nor developers nor property valuers expected improved landscape to affect property and rental values. However this was a scoping study undertaken in areas with low land value, and suggests that landscaping expectations are higher in higher value areas.
- On an economy-wide scale, Waltert and Schlapfer (2010)¹⁶ reviewed a number of regional economic and migration studies and found that regions with more landscape amenities (for example, forests, open spaces) tended to grow faster in terms of population than those with less. However, not enough evidence existed to draw conclusions about the link between those amenities and employment or incomes.

UK sub-national

- Canary Wharf chose to build Jubilee Park in the middle of its office development at a cost of £6 million. Businesses used the park to sell relocation to the wharf to their staff, and Canary Wharf Group are confident they will recoup their investment (CABE Space 2005).
- Arlington Business Parks has built an £800 million property portfolio offering offices in high quality greenspaces. These out of town parks command at least city centre retail values. Businesses using the office space consider the greenspace an important benefit (CABE Space 2005)¹⁷.
- A broadly mixed regeneration investment which included an element of landscaping, tree planting and rubbish clearance at Winsfield Industrial Estate in Cheshire was followed by a 13% increase in employment against a small decrease in employment in the local area (Centre for Local Economic Strategies and Groundwork UK 2007)¹⁸.
- A broadly mixed regeneration investment which included an element of landscape, tree planting and rubbish clearance in Portland Basin, Tameside, was followed by a 25% increase in employment against a background increase of 8.3% in the local area (Centre for Local Economic Strategies and Groundwork UK 2007)¹⁹.

¹⁵ A figure of 93% of respondents willing to pay an extra 3% is given for London. Case studies of New York Hamburg and London are also offered in this document.

¹⁶ The majority of studies examined in this review were from the USA, however it is reasonable to think that similar effects would be observed in the UK. Note that this assumes that all other factors affecting growth are reasonably similar between the regions, therefore results would not be relevant for a comparison between London and Cornwall, for instance.

¹⁷ Note that this is also at the expensive end of the commercial market for office space.

¹⁸ It seems likely that this study is evidence of an alternative theory of change, which is more about social signals and perceptions than about the benefit of greenspace per se.

¹⁹ It seems likely that this study is evidence of an alternative theory of change, which is more about social signals and perceptions than about the benefit of greenspace per se.

- Investment in Glasgow Green coincided with a rate of local new business formation that was much faster than that for Glasgow as a whole. Business located next to the regeneration of Glasgow Green felt that the location was attractive to customers and increased improved staff morale and retention (GEN Consulting 2006)²⁰.

References

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²⁰ The edge of the city centre location was also central, but the regeneration may have contributed to making the area feel like a viable investment proposition.

3e Tourism and recreation

Many tourist attractions and recreational activities are heavily driven by the natural environment. The economic VALUE of these activities to society can be significant. The economic IMPACT is also significant, but to a lesser extent as many of the activities (such as hiking) involve minimal expenditure.

Introduction

- 3.23 Tourism is an important industry in the UK, particularly in terms of regional employment. In 2008, an estimated 1.36 million people were employed in tourism (Deloitte and Oxford Economics 2010)²¹. This makes attracting tourism and recreation an important element of local authority economic development plans. Improvements in tourism and recreation performance by a local authority are relative, rather than absolute economic benefits, if they occur at the expense of local tourism or economic activity elsewhere. However, if the UK draws in tourism from overseas, this is an absolute benefit to the UK.
- 3.24 Nature based holidays may be based around activities such as walking, which although they may have great VALUE to those taking part, lead to limited economic IMPACT because they require little expenditure. Even expenditure on equipment is reasonably small – in 2004, the Marine Institute estimated that the average angler spent approximately €100 (around £80) per year on equipment, whilst the average birdwatcher spent just 70 euro cents per year (Marine Institute 2004).
- 3.25 Rural environment-based tourism may be particularly welcome because it is a growing economic sector in localities where many traditional agricultural and industrial sectors are declining (Shiel, Raymont et al. 2002). However, the environmental link can sometimes be somewhat tenuous - it is not necessarily the case that those taking part in rural tourism have particularly 'environmental values' or that rural tourism is more environmentally friendly than urban tourism. There is therefore not necessarily any virtuous circle between environmental tourism and environmental quality (Roberts and Hall 2004).

Theory of change



Can the benefit be quantified?

- 3.26 It is possible to quantify relationships for this benefit, and most of the research seeks to do exactly this. It is worth noting, however, that for the vast majority of studies the quantified link is based on responses to questionnaires by the public – hence the quantitative connections are based on what people say they would do, rather than what they are actually observed to do²². Additionally assessments of economic impact necessarily rely on assumptions about the linkages and flows of money in the economy, making them estimates.

²¹ Note that this is likely an overestimate, as there is no official sector classification for the tourism industry, and this estimate is a composite of 8 different sectors including bars, restaurants and sporting activities.

²² Observing what people actually do (also known as revealed preferences) is the stronger sort of evidence because people may miss-state their preferences when asked, either for social or strategic reasons, or because they are not clear themselves.

How strong is the evidence?

3.27 The evidence that the natural environment provides tourism and recreational benefits is relatively strong. However caution can sometimes be needed – it would be wrong, for instance, to assume that all rural tourism is particularly concerned with landscape or biodiversity quality. As an example, four wheel driving experience days are only loosely linked to environmental or landscape quality (Roberts and Hall 2004).

Evidence

Nationwide England or UK

- In 2012-13 the Monitor of Engagement with the Natural Environment (MENE) survey found that there were an estimated 2.85 billion visits to the natural environment in England. On average, each adult visited the natural environment 67 times. 27 percent of these visits involved some form of expenditure, with an average of £27 spent during these visits. Total expenditure is expected to lie between £17.6 and £24.5 billion in total (Natural England 2013)²³.
- Modelling for the UK National Ecosystem Assessment suggests that in 2000, there were 3.23 million day visits to the natural environment, valued at £10.04 billion. Under the most positive environmental scenario, this could potentially increase to £24 billion by 2060 (Sen, Darnell et al. 2011)²⁴. This is an economic VALUE estimate, not economic IMPACT, and is not directly comparable to the previous bullet point.
- It is estimated that RSPB reserves support more than 1,000 full time jobs in the UK, and because they tend to be on less favourable agricultural land, tend to lead to an increase in economic activity when acquired (Shiel, Rayment et al. 2002)²⁵.

England sub-national

- Leighton Moss RSPB reserve, and neighbouring sites in Silverdale, Lancashire, are estimated to attract visitor spending of at least £0.95 million per year to the local economy within 20 miles of the reserve. It is estimated that the reserve supports 59 full time jobs directly or indirectly (Rayment and Dickie 2001)²⁶.

²³ This estimate is based on an England-wide nationally representative survey. It can be considered the most robust data available on visits to the natural environment.

²⁴ The visit data presented is largely based on MENE survey results from 2010. Visit levels recorded by MENE have fluctuated between 2.49 and 2.86 billion per year over 2009-2013, so the estimated 2.86 billion visits in 2000 may be in the right range. Expenditure is generally equal to or less than the value of a recreational visit, so it is surprising that expenditure in 2012-13 was between £17.6 and £24.5 billion, yet in 2000 the total value of visits was estimated at just £8.85 billion. This suggests that either expenditure may be overestimated, or economic value may be underestimated. The study examined all the UK NEA 2060 scenarios, but only the Nature at Work scenario is presented here.

²⁵ This figure is based on direct employment, expenditure (including on contractors), grazing lets and agricultural tenancies and the impact of spending by employees, volunteers and visitors to the reserve. The methodology is conservative and appropriate.

²⁶ This review is based on a summary of a longer report by Cooper and Rayment. The expenditure figures are calculated based on surveys from people attending the reserve and apportioning their expenditure depending on whether the reserve was the main reason for visiting the area. The employment figures are based on estimated expenditure by visitors from outside the area, and expenditure by the RSPB and linkage and multiplier effects from both. They assume a local employment multiplier of £35,000 per full time job.

- It is estimated that £420,000 of the £1.68 million per year spent by visitors to the Dodd Wood and Whinlatter part of the Lakes was due to the presence of Ospreys (Dickie, Hughes et al. 2006)²⁷.
- Wren's Nest is a National Nature Reserve (NNR), designated for its geo-diversity interest in the Dudley area of the West Midlands. It has been estimated that access to the NNR with interpretive material is valued at £21.26 per household per year. Additionally, the ability to collect fossils from the site (with the proviso that important fossils were protected) was valued at £6.58 per household per year (Webber and Christie 2006)²⁸.
- It is estimated that tourists spend £191 million per year in North and West Norfolk and that this provides 7,870 full time jobs representing 17.5% of employment in the two districts. A survey of six sites on the coast associated with landscape and biodiversity estimated that the annual spend of visitors to these sites was £21 million which supports 442 full time jobs (Rayment, Lewis et al. 2000)²⁹.
- It is estimated that Symond's Yat Rock in Gloucestershire attracts £0.5 million of visitor spending to the Forest of Dean each year (Dickie, Hughes et al. 2006)³⁰.
- A survey of anglers on the Wye River found that 'scenery' was the most common influence affecting where anglers fished, just ahead of quality/abundance of catch. On average, the anglers surveyed were willing to pay £37.7 per year for river habitat improvements that significantly improved the quality and quantity of trout and salmon in the river (Thomas and Blakemore 2007)³¹. This is an economic VALUE estimate.
- It is estimated that access to the Jurassic Coast with interpretive material was worth £62.35 per household per year. Additionally public fossil collecting (with a code of conduct to protect important fossils) was valued at £57.73 per year (Webber and Christie 2006)³².
- It is estimated that the presence of choughs in the Lizard area of Cornwall attracted an additional £118,000 in tourist expenditure [in 2004], supporting the equivalent of 3.2 full time jobs (Dickie, Hughes et al. 2006)³³.

²⁷ This estimate is generated from an RSPB study in which visitors filled in questionnaires detailing what they had spent and whether seeing the Ospreys was the main reason for the trip, a reason, or irrelevant. The methodology is appropriate and conservative.

²⁸ This result is based on a choice experiment, in which a sample were asked to choose between different scenarios in which attributes and tax rate vary, thus allowing the calculation of an implicit price for the attributes. The survey methodology was appropriate.

²⁹ The methodology in this RSPB research is conservative and appropriate. The first set of figures which relate to West and North Norfolk are estimated from nationally available databases by Geoff Broom based on the Cambridge Economic Impact of Tourism Model (which has not been reviewed). The second set of figures which relate to the six sites is based on interviews at the six sites and then feeding these figures into the Cambridge Economic Impact of Tourism Model (which has not been reviewed). It seems highly likely that a significant percentage of tourism to the area is attracted by biodiversity and landscape quality, but because this research, which was carried out by the RSPB focused on sites of specific interest to wildlife enthusiasts it is not possible to generalize to the wider population.

³⁰ This result is based on the updating of results, from a reported study by Andrew Case in 1999, to 2005 visitor numbers and pounds. As such, it should be taken as indicative only.

³¹ There is some uncertainty about the representativeness about the study sample, as they were unable to survey anglers who were not members of local angling clubs. One-off visitors may have a lower willingness to pay for habitat improvements.

³² This result is based on a choice experiment, in which a sample were asked to choose between different scenarios in which attributes and tax rate vary, thus allowing the calculation of an implicit price for the attributes. The survey methodology was appropriate.

³³ This estimate is based on research by the RSPB but based on a study in which visitors filled in questionnaires detailing what they had spent and whether seeing the Choughs was the main reason for the trip, a reason, or irrelevant. The methodology appears appropriate and relevant.

Outside England

- It is estimated that between £1.4 and £1.6 million of the £38 million spent annually by visitors on the Isle of Mull is attracted by the presence of sea eagles. It is estimated that this economic impact supports 36 to 42 full time jobs on Mull (Dickie, Hughes et al. 2006)³⁴.
- A recreational visit to Silverstrand Beach, near Galway, Ireland, was estimated to be worth €22.23 (approx. £20) per visitor in 2011 (Barry, van Rensburg et al. 2011)³⁵. This is an economic VALUE estimate.
- Access improvements to two specific countryside walks in Ireland were valued at €12.22 (approx. £10.50) per walker per year for a lowlands walk, and €9.08 (approx. £7.80) for an uplands walk (Buckley, Van Rensburg et al. 2009)³⁶. This is also an economic VALUE estimate.

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³⁴ This estimate is generated from an RSPB study in which visitors to the Isle of Mull filled in questionnaires detailing what they had spent and whether seeing the Sea Eagles was the main reason for the trip, a reason, or irrelevant. The methodology is appropriate and conservative and fits well with a previous study and observed tourism spend.

³⁵ This is a very scenic Blue Flag beach with easy access to Galway city, so is likely to be at the higher end of values for recreational beach visits.

³⁶ These results are median values (i.e. 50% of the population surveyed was willing to pay €12.22 or more). A significant number of walkers surveyed were not willing to pay anything as they liked the trail in its current state. Only walkers on the trails were surveyed, therefore results cannot be generalised across the wider population.

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Webber, M. and M. G. Christie (2006). "The Social and Economic Value of the UK's Geodiversity." *English Nature Research Reports* **709**: 1–122.

4 Services provided by nature

- 4.1 This section provides evidence about the different services provided by nature. Specific services may be of interest to different policy makers and practitioners, so you may choose to focus just on those. Alternatively, you may be interested in overarching themes such as economic competitiveness, so [Chapter 2](#) and [Chapter 3](#) may be useful in identifying how the environment contributes to those themes.
- 4.2 It is important to note that not all services provided by nature are included here. The ones chosen are the ones which on the basis of current evidence are most important in the context of environmental projects. The ones selected are also those for which we have available scientific and economic evidence.

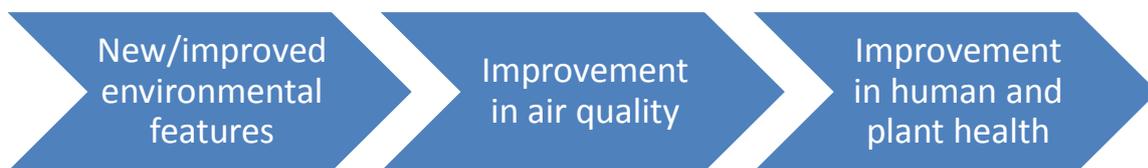
4a Air quality

Air quality issues can pose significant risks to human and plant health. There is strong evidence that vegetation, particularly trees, can contribute to air quality improvements.

Introduction

- 4.3 This section reviews the evidence that the natural environment can improve air quality. There is a clear link with Section 4I **Temperature regulation**, because some air quality problems are worse at high temperatures. Although air quality has improved, this trend is flattening or even reversing in some locations (Tiwary, Sinnett et al. 2009). It remains a significant problem, particularly in urban areas.
- 4.4 Air quality has important implications for human and plant health, and also affects the provision of a wide range of other ecosystem services.

Theory of change



Can the benefit be quantified?

- 4.5 Yes, the relationships can be quantified but the exact effects will be influenced by local contextual factors. Therefore modeling relies on reasonable average assumptions.

How strong is the evidence?

- 4.6 Research has shown a strong link between vegetation and air pollution, but the strength of the effect depends importantly on the vegetation type and the context. The evidence presented illustrates the links between the first two links in the theory of change, and then the second two. Very few studies link all three parts of the theory of change, with Tiwary, Sinnett et al (2009) being an exception. However, it is highly plausible to expect that an improvement in air quality caused by the natural environment would result in an improvement in human, plant and/or ecosystem health.

Evidence of environmental features affecting air quality

- Saebo, Popek et al. (2012) found that in field trials of common European trees and shrubs there was a strong correlation between PM accumulation, leaf hair density and waxiness of the leaves. There were 10-20 fold differences in the level of accumulation between species. The most effective PM accumulating species were found to be mountain pine, silver birch, stephanandra, skimmia, grey willow and Scots pine (Saebo, Popek et al. 2012)³⁷.
- Modeling of removal of pollution by trees across the urban areas of the United States estimated that they remove 711,000 tonnes of pollution from the air per year. This could be increased through increasing the density of tree cover – with 100% tree cover (i.e completely forested) providing 16% improvement in short term levels of ozone (O₃) and sulphur dioxide

³⁷ What is not clear from this study is exactly how much PM is removed over a given time period, as the study sampled leaves only once each year, and examined the PM on the leaf at that point in time.

(SO₂), 9% for nitrogen dioxide (NO₂) and 8% of particulate matter (PM₁₀) (Nowak, Crane et al. 2006)³⁸.

- A study in Chicago found that 19.8 hectares of green roofs (predominantly extensive, rather than intensive roofs) removed 1675kg of air pollutants, including 52% O₃, 27% NO₂, 14% PM₁₀ and 7% SO₂ over the space of a year (Yang, Yu et al. 2008)³⁹. This averages out at around 85kg per hectare of green roof per year. Similarly, Speak and colleagues found that 50 hectares of extensive sedum green roof in Manchester city centre could remove 0.21 tonnes of PM per year (Speak, Rothwell et al. 2012). They also found that alternative grass species could remove over three times more PM than the common sedum varieties used.
- Green walls were found to potentially reduce the concentration of NO₂ and PM in city streets surrounded by high rise buildings by as much as 15% and 23% respectively, and to be even more effective at low wind speeds. They were also found to be more effective than green roofs in street canyons due to the nature of air flows in the street (Pugh, MacKenzie et al. 2012)⁴⁰.
- Some trees release Volatile Organic Compounds, which can contribute to the production of O₃. However, they also intercept ultraviolet light, reduce temperature through shading and remove pollutants when they are deposited on tree surfaces. A modeling study from the North East of the United States found that urban forests will on balance reduce O₃ pollution (Nowak, Civerolo et al. 2000)⁴¹.

Evidence of air quality affecting human health

- Within high income countries, 2.5 percent of all deaths are estimated to be attributable to urban outdoor air pollution, specifically particulate matter (PM). This is due to PM causing an increased risk of cardiopulmonary conditions, respiratory infections and lung cancer (World Health Organization 2009)⁴². There is also growing evidence linking air pollution with pre-term births, reduced birth weight, lowered immune response and the development of conditions such as asthma in children (European Environment Agency 2013).
- Modeling found that 547 ha. of mixed greenspace within a 10 x 10 km square of East London (i.e. 5% of 100 square kilometres) could significantly reduce pollution with an estimated effect of two deaths and two hospital admissions avoided per year (Tiwarly, Sinnett et al. 2009)⁴³.

³⁸ O₃, PM₁₀, NO₂ and SO₂ and CO₂ were modeled and Hawaii and Alaska were excluded. Due to the assumptions made the figures are offered as a first order approximation. It is important to note that although the figures sound large they were typically only 1% air quality improvements during the day time during the in-leaf season. The US wide modeling shows the strongest benefits for areas with long in-leaf seasons and low rainfall – rather different circumstances to the UK.

³⁹ Extensive green roofs are relatively shallow and support mostly grasses, whilst intensive green roofs have deeper soils and can support small shrubs. The authors note that the values produced should be taken as approximations only, due to uncertainty surrounding some of the assumptions used.

⁴⁰ This study was produced using the atmospheric chemistry model CiTTYCAT, and includes a range of assumptions including local wind speeds and deposition rates to vegetation. Results should therefore be taken as suggestive of the likely benefits, but not as definitive results as they are not based on scientific observations.

⁴¹ The modeling exercise is necessarily built on simplified assumptions, but is detailed and carried in a peer-referenced journal. Although there are important differences, the climate of the North East United States is in many ways similar to that of the UK.

⁴² Predominantly countries in western Europe, including the UK. For a full list of countries, see WHO 2009. The estimate does not include those who are chronically ill due to air pollution, nor does it include the impacts of air pollutants other than PM.

⁴³ The modeling assumed that 75% of its green area was grassland, 20% Sycamore maple and 5% Douglas fir. It should be noted that a study comparing the method used in Tiwarly et al 2009 and an alternative pollution flux method found that the Tiwarly method produced results that were 2.5 times higher than the alternative method – for details see Tallis, M., G. Taylor, et al. (2011). "Estimating the removal of atmospheric particulate pollution by the

- A major piece of research on the Global Burden of Disease for the World Health Organization found that in 2010, there were 48,016 deaths in the UK attributed to air pollution. By comparison, there were 52,490 attributed to physical inactivity, and 18,833 attributed to alcohol and drug use (Murray, Vos et al. 2012)⁴⁴.
- The Department for Environment, Food and Rural Affairs estimates that air pollution (specifically PM) reduces the average life expectancy by 6 months and that this equates to a value of between £8.6 and £18.6 million per year, with a central estimate of around £16.4 million per year. This includes the amount people would be willing to pay to avoid the reduction in life expectancy, and the cost of additional hospital admissions (Department for Environment Food and Rural Affairs 2010)⁴⁵.

Evidence of air quality affecting plant and ecosystem health

- Air pollution can also impact on plant health and agricultural productivity. Evidence suggests that ozone pollution is a particular problem, with detrimental effects observed across Europe in most years. Within the Greater Thessaloniki area in Greece, crop losses due to ozone pollution were estimated at €42.5 million in 2002 (approximately £35 million), with particularly affected crops being cotton, spring wheat, sunflower, lettuce and tomatoes (Vlachokostas, Nastis et al. 2010)⁴⁶.
- In the UK, wheat crop losses due to ozone pollution were estimated at £90 million in 2000 (7 per cent of national wheat production), with East Anglia being most affected. For potatoes, the loss was estimated at £12 million (2 per cent of national potato production), with southwest England and Northern Ireland being most affected (RoTAP 2012)⁴⁷.
- Nitrogen deposition due to air pollution can increase crop growth, however it may also lead to plant nutrient imbalances and increased susceptibility to disease or pest attack (RoTAP 2012)
- Acid rain caused by sulphur dioxide and nitrogen dioxide emissions has been a major environmental problem for UK inland waters, however the situation is now improving (Kernan, Battarbee et al. 2010).
- Changes in soil acidity and chemical composition due to air pollution can have far-ranging effects on ecosystem services such as climate regulation, nutrient cycling, biodiversity support and regulation of water quality and quantity (RoTAP 2012).
- Nitrogen deposition has resulted in loss of plant diversity in sensitive priority habitats for conservation. By 2020 it is estimated that 48 per cent of the UK's sensitive habitats will exceed critical loads for nitrogen deposition (RoTAP 2012).

Link with climate change

- Higher temperatures lead to an earlier start and an increase in length and intensity of the pollen season (D'Amato and Cecchi 2008). They also lead to increased pollutant levels, increased long distance transportation of pollutants, and increased heavy precipitation events (which are associated with significant increased asthma) (D'Amato and Cecchi 2008).

urban tree canopy of London, under current and future environments." *Landscape and Urban Planning* **103**: 129-138.

⁴⁴ The authors note that there are many uncertainties associated with these estimates. They estimate a 95% probability that the actual number of deaths attributed to air pollution in 2010 lies somewhere between 38,507 and 58,608 (approximately +/- 10,000 deaths).

⁴⁵ Notice that this is an average figure so some communities will be affected much more strongly than others.

⁴⁶ The economic loss has been estimated as the value of the reduced yield, at producer prices. The authors note that this is a simplistic approach which does not account for the impact on consumers, nor the potential for farmers to adapt and change their crop composition to more ozone resistant crops.

⁴⁷ This particular analysis is subject to a range of uncertainties, including the difference in ozone tolerance between different crop cultivars, and the extent to which the quantity of lost production may be offset by higher ozone levels contributing to improvements in grain quality.

- Ground-level ozone pollution is worse at higher temperatures due to increased chemical reactions leading to its formation (US Environmental Protection Agency 2003). With constant emissions levels this can be expected to lead to increased illness and premature deaths (Ebi and McGregor 2009).
- However, warming temperatures could also lead to reduced susceptibility to upper respiratory infections due to warmer winters (D'Amato and Cecchi 2008).

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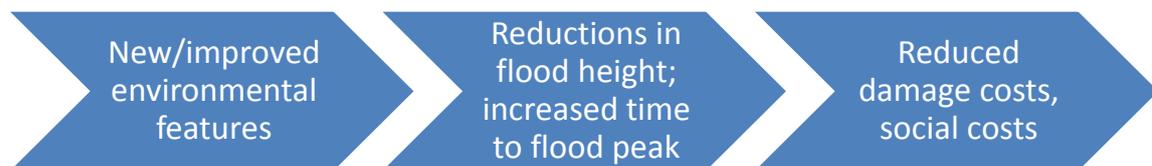
4b Coastal flood risk management

Traditional flood defences are expensive to build and maintain. Coastal environments such as saltmarshes offer a cost-effective alternative and provide additional benefits to biodiversity and recreation.

Introduction

- 4.7 This section reviews the evidence for flood risk management at the coast. Flood risk management from freshwater is discussed in Section 4d. Coastal flood risk management is a particular issue for England – 46 per cent of the English coastline is protected from coastal erosion and flooding by engineered sea defences (UKMMAS 2010). Futures research from the Government Office for Science and Technology found that continuing with existing flood risk management policies was not an option, because under virtually every scenario considered risks rose unacceptably (Foresight 2004).
- 4.8 Improved flood risk management leads to reduced costs of flooding and can by extension lead to reduced insurance premiums and increased property values⁴⁸. Additionally, being flooded significantly increases the risk of both physical illnesses such as gastroenteritis and mental ill health (Tunstall, Tapsell et al. 2006). Reacher (2004) found that adults who had suffered from flooding had four times the background level of psychological distress.
- 4.9 The managed realignment approach, in which new habitat is created in the inter-tidal zone between the high and low water lines, can have benefits for flood risk management, whilst at the same time providing habitat for fish nurseries and encouraging recreation. Visitors are attracted by the wide variety of plants and animals.
- 4.10 Salt marshes are a form of coastal wetland that act an important natural form of sea defence, by dissipating wave energy before it reaches the sea wall or other infrastructure/high ground behind it. However, many salt marshes have been lost due to ‘coastal squeeze’ where they are trapped between rising sea levels and hard man-made sea defences. Inter-tidal habitat re-creation therefore has a major contribution to make to cost effective flood defence at the coast; as does the conservation of, and allowing ‘natural roll back’ of, existing salt marshes (Collins, Empson et al. 1997)⁴⁹.

Theory of change



Can the benefit be quantified?

- 4.11 The economic figures which are normally offered relate to costs of engineering for coastal defence, and these can be quantified within reasonable error margins. The avoided costs of

⁴⁸ See the section on house prices to put this in economic context.

⁴⁹ This evidence is taken from a joint Environment Agency, English Nature and Cambridge Coastal Research Unit paper and contains academic references which have not been reviewed for this evidence package.

flooding can also be quantified, but these are likely to be less certain, particularly when they include wellbeing loss (economic VALUE) as well as direct economic loss (IMPACT).

How strong is the evidence?

4.12 There is reasonably strong evidence for the contribution of the coastal environment to reducing flood risk.

Evidence

- In 1997 it was estimated that an 80 metre wide zone of inter-tidal habitat fronting sea walls can save £4,600 per metre in sea defence costs (Collins, Empson et al. 1997).
- Alkborough Flats is a managed re-alignment scheme on the south side of the Humber estuary. The sea wall was deliberately breached to allow both permanent and irregular flooding of former farmland. In particular, the site is designed to trap tidal surge floodwaters and has delayed the need to raise flood defences elsewhere in the inner estuary. The Environment Agency's project appraisal report assessed the flood defence benefit as worth £12.26 million based on a time period of 100 years leading to a cost benefit ratio of 1:2.72. Further work which sought to quantify the other benefits of the scheme, particularly provision of habitat raise the cost benefit ratio to 1:3.22 (Everard 2009)⁵⁰.
- Modeling of the potential benefits of the adoption of a managed realignment approach to the Blackwater Estuary in Essex was undertaken. It found that the approach would reduce the maintenance costs of flood defences, significantly reduce nutrient discharge into the North Sea (reducing the eutrophication risk) and create important wetland habitat. Under very conservative assumptions the scheme was cost-beneficial over a 100 year time frame (Shepherd, Burgess et al. 2007)⁵¹.
- A second entirely separate modeling of the potential benefits of the Blackwater Estuary in Essex was also undertaken, but this one undertook a bespoke willingness-to-pay study for the habitat creation. The study identified reduced cost of developing hard defences, the value of the new habitats as fish nurseries, carbon sequestration, and the composite value of the new habitat (covering amenity, recreation and biodiversity). The study found benefits of £100 million after 25 years following increased use of managed realignment, where the level of realignment was designed to combine economic growth and environmental protection (Luisetti, Turner et al. 2008)⁵².

⁵⁰ I have not reviewed the Environment Agency project report from which the flood defence figure is taken. The flood defence figure cited is a net present value figure with future year's benefits discounted according to Green Book standards. The wider ecosystem service valuation is experimental in that it pushes the edges in finding values for things that would normally be considered too difficult and contains a number of very strong (i.e. questionable assumptions). However assumptions are all clearly spelled out, and none of the strong assumptions make a material difference to the cost benefit ratio. Additionally the approach taken is appropriately conservative and so I have no hesitation in recommending the use of the ratio.

⁵¹ The cost benefit analysis is constructed extremely conservatively, it is therefore likely that a realignment approach would be cost-beneficial on a much shorter time frame. For example, the costs of new secondary defences are included as part of the realignment scenario, but might not be needed. Furthermore, by today's standards, the study uses a very conservative price for carbon (£7 per tonne). The nutrient capture function and the habitat creation function of the project are not counted independently to avoid risk of double-counting. The study also doesn't take account of the global warming effect of the N₂O. The study includes a value for the habitat creation which is transferred from other literature and not reviewed (however it is important to note that a separate study which conducted a bespoke willingness to pay study for the value of habitat creation on the Blackwater estuary also finds managed re-alignment strongly beneficial - see the Luisetti study in the next paragraph).

⁵² The figure quoted is the difference between the Net Present Value of 'Hold the line' level which assumes no re-alignment and the 'Policy Targets' level in which economic growth is combined with environmental protection at the official HM Treasury discount rate over a 25 year timeframe. This figure increases to £221 million over 50 years and £444 million over 100 years, which is a reasonable time-frame for this sort of infrastructure. The analysis also shows that greater benefits would derive from higher levels of managed re-alignment. Note that this benefit does

- Modelling on the Humber Estuary found that a whole estuary managed realignment approach led to a benefit to society of £3.8 million over a 50 year time frame and £8.7 million over a 100 year time frame. These calculations are based on values for the habitat created, the value of the agricultural land, avoided carbon emissions, and wall maintenance and replacement costs (Turner, Burgess et al. 2007)⁵³.

Link with climate change

- Sea levels have risen by 1mm a year during the 20th century, and sea level is projected to rise by 18cm in London by 2040 and 36cm by 2080 (Department for Environment Food and Rural Affairs 2009).

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not include the cost saving from not maintaining the traditional infrastructure which would add another £1.2 million. The big advantage of this study is that values for habitat gains are based on a new bespoke choice experiment study which was well designed, including concerns about size and quality of the habitat and distance from the respondent's home.

⁵³ The figure quoted is the difference between the Net Present Value of 'Hold the line' level which assumes no re-alignment and the 'Policy Targets' level in which economic growth is combined with environmental protection at the official HM Treasury discount rate. The analysis also shows that greater benefits would derive from higher levels of managed re-alignment. The value for habitats driving this analysis is based on transfer from a meta-analysis of studies which value wetlands, which is the most robust way to derive a value without a new willingness-to-pay study. A figure of £22 per tonne of carbon was used, which is conservative compared with the figures currently recommended by the Department of Energy and Climate Change.

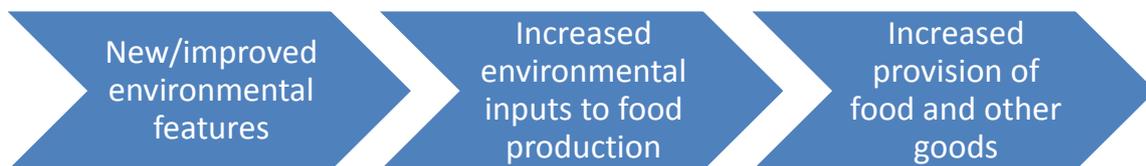
4c Food, water and other provisions

The natural environment provides essential food and water, as well as a wide range of other goods.

Introduction

- 4.13 This section provides some examples of goods provided by the natural environment for consumption or use by people. Obviously food and water are essential to life, so it would be meaningless to attempt to quantify their importance. There is also a limit to the amount of natural resources (land, water, sunshine, et cetera) we have available to produce these goods. It is possible however to increase the efficiency with which the natural environment produces goods, through changing other inputs such as human labour, technology or natural supporting services.
- 4.14 What this section does is provide some context around the scale of how people use the environment to produce a range of different foods, medicines and biochemicals, and the impact of environmental changes on this production.

Theory of change



Can the benefit be quantified?

- 4.15 Only on a small scale. It is possible for instance, to identify how much extra of a crop could be produced by adding a unit of additional input (water, soil, et cetera). However, it would be impossible and meaningless to attempt to quantify the total value of goods provided by the environment. Much of the evidence below refers to the economic significance of these goods, as quantified by the market value of the goods produced.

How strong is the evidence?

- 4.16 It goes without saying that people depend on the natural environment for a wide range of foods and other resources. Some of this evidence is presented below.

Evidence

- The Millenium Ecosystem Assessment notes a range of products and the organisms from which they are derived. These include: antibiotics from plants, molluscs, bacteria and ants; anti-fouling paints from sea moss and marine algae; industrial enzymes from primitive bacteria and fungi; and engineering materials from snails (Beattie, Barthlott et al. 2005).
- 17.2 million hectares, 70 percent of land in the UK, is used for agriculture. Gross Value Added (agriculture's contribution to GDP) was £8.6 billion, or around 0.65 per cent of total GDP in 2011 (Department for Environment Food and Rural Affairs, Department of Agriculture and Rural Development (Northern Ireland) et al. 2012).
- UK fish landings in 2008 were worth £596 million (Bateman 2011).
- Rain which infiltrates the ground is stored in underground aquifers. This groundwater is particularly valuable because it is normally pure and needs little treatment. Groundwater directly provides one third of the water we drink and is vital source of water for rivers and wetlands (Environment Agency 2007).
- Since 1940, 48.6 percent of all small molecules for cancer treatment have been derived from natural products (Newman and Cragg 2012).

- Crops Wild Relatives, and rare breeds, provide an essential genetic bank for producing food in novel circumstances (Foresight 2011) Additionally plants or fungi which are not normally considered crops may have potential for food (Juárez-Montiel, León et al. 2011) or as forage.
- Around 2.2 million tonnes of topsoil is eroded annually in the UK. It is estimated that this results in lost production worth £9 million per year (Department for Environment Food and Rural Affairs 2009)⁵⁴.
- In 2010, 50 percent of fish stocks assessed were being harvested unsustainably. UK seabed trawl landings per unit of fishing power⁵⁵ have declined by 94 percent in the past 118 years, reflecting the increased effort required to catch smaller numbers of fish (Bateman 2011). Essentially, unsustainable fish harvesting has resulted in a decline in the ability of the fish stock to regenerate and support future fish supply.
- There is a risk that non-sustainable harvesting of natural products for biochemicals, natural medicines and pharmaceuticals may negatively impact on the environment. In the US, for instance, the search for supplies of the anticancer drug paclitaxel resulted in conflict because a primary source of the drug was the old-growth forests of the Pacific Northwest, also home to the endangered spotted owl (Kingston 2011).
- There are few studies into the effects of less intensive farming, but those that exist support the view that less intensive farming leads to increased infiltration to groundwater aquifers due to greater presence of features such as grass buffers and hedgerows, and healthier soil (O'Connell, Beven et al. 2005). Wetlands also play a role in aquifer recharge (World Resources Institute 2008).

Link with climate change

- Modelling done for the UK National Ecosystem Assessment suggests that with climate change, northern areas of the UK are likely to benefit from increased agricultural production, whereas farms in the south of England are likely to be negatively impacted. Beef cattle and sheep production across southern England are likely to decline (Bateman 2011)⁵⁶.
- Climate change poses multiple threats to the ecosystems on which farming relies including changes to growing seasons, droughts and floods, increased heat stress in livestock, more storm damage and increased risks of pests and diseases (Department for Environment Food and Rural Affairs 2009). It may also reduce organic matter in soils (Jenkinson, Adams et al. 1991), which would lead to loss of fertility, water holding capacity and poorer soil structure, exacerbating pollution and flooding.
- Climate change may reduce the recharge of aquifers, leading to the consequent lowering of groundwater levels. It may also lead to higher demand for water by households and for crop irrigation (Environment Agency 2008).

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⁵⁴ These figures originate from an Environment Agency report and have not been reviewed for this report.

⁵⁵ A measure of the commercial productivity of fisheries.

⁵⁶ This model is based on historical data which may not be a strong predictor of future farm responses to changing climate. It also does not include future technological innovation and the impacts of this on farm management.

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4d Freshwater flood risk management

There is strong evidence that natural features such as forests can contribute to reductions in water runoff and velocity. This is heavily dependent on the individual catchment context, including slope, vegetation type, soil condition and broader catchment hydrology.

Introduction

- 4.17 This section reviews the benefits the natural environment can offer in reducing flooding from rainwater. Many of the interventions that will reduce flood risk also have the potential to support water quality through reducing diffuse pollution - see Section 4m [Water quality](#) for more detail.
- 4.18 Around 5.2 million houses in the UK are at risk of flooding. The average annual cost of flooding in England is estimated at over £1 billion. Analysis by the Environment Agency suggests that if investment in flood protection is maintained at present levels of £800 million per year, by 2035 there will be an additional 350,000 properties in England at significant risk of flooding (Environment Agency 2009).
- 4.19 Improved flood control leads to reduced costs of flooding and can by extension lead to reduced insurance premiums and increased property values⁵⁷. Additionally, being flooded significantly increases the risk of both physical illnesses such as gastroenteritis and mental ill health (Tunstall, Tapsell et al. 2006). Reacher (2004) found that adults who had suffered from flooding had four times the background level of psychological distress.
- 4.20 There have been significant problems in recent years with intra-urban flooding – in which the drainage systems within the urban area are overwhelmed by rainstorms (Parliamentary office of Science and Technology 2007). These flood events have been made worse by changes to the urban realm such as increased hard landscaping and the paving of driveways (Parliamentary office of Science and Technology 2007).
- 4.21 Intensification of farming since the Second World War has led to a number of changes to the farmed environment which increase the rate of run-off. These include loss of hedgerows, overgrazing, channelized rivers, and winter crops leading to bare and compacted soil (O'Connell, Beven et al. 2005). It is estimated that agriculture makes flooding worse by £234 million annually (Jacobs 2008)⁵⁸.

Theory of change



⁵⁷ See the section on house prices to put this in economic context.

⁵⁸ This assessment is based on an Environment Agency judgement based on their record that 14% of flood damage is attributable to agriculture – this will almost certainly be an understatement because it is based only on hill-slope flooding. On this basis 14% of the damage caused by flood and the money spent to prevent floods is attributed to agriculture.

Can the benefit be quantified?

4.22 In principle the relationships could be quantified, but the number of contextual factors means that there is currently, and is likely to remain, significant uncertainty around quantification. Three factors are particularly influential – scale, catchment unique characteristics, and natural climate variability (Pattison and Lane 2011).

How strong is the evidence?

- 4.23 Evidence about flooding is inherently complex and contextual and therefore strongly generic statements and formulas are not available. However, a review of the evidence shows that there can be important flood mitigation benefits.
- 4.24 Parrott, Brooks et al. (2009) note that this benefit can occur in two ways: by reducing the quantity of water runoff (flood generation) or by slowing the movement of water through the watercourse (flood propagation). Slowing the movement of water can increase flood warning times and allow people time to take action to reduce damages. It should be recognised however, that flood events are unlikely to be prevented by changes to the natural environment, due to the relatively small effects these are expected to have on overall flood scale.

Evidence

Agriculture

- There is some evidence which supports a correlation between upstream soil damage and large floods. (Holman et al. 2003) found significant soil degradation in the catchments which flooded in 2000 and suggest that flooding may be caused by a combination of soil degradation and prolonged wet weather. Additionally (O’Connell, Beven et al. 2005) report that (Boardman et al. 2003) found a statistically significant relationship between autumn sown cereals and local muddy floods.
- There are good opportunities to reduce run-off from farms through measures such as grass buffers, temporary ponds, appropriate ditching and decanalisation. Although there is no proven rule that organic and other less intensive forms of farming will always reduce flood risk, in general terms less intensive farms have less of the factors which support faster run off. The few UK studies and those from abroad support the view that less intensive farming leads to reduced flood risk due to greater presence of the features above and healthier soil (O’Connell, Beven et al. 2005)⁵⁹.
- Many blanket bogs have been drained through the cutting of drainage ‘grips’. Reblocking these grips on a blanket bog in Wales was found to result in lower peak flow rates during storms. The water table rose and water flows from the bog became more stable (Wilson, Wilson et al. 2011).

Trees

- There are different ways in which trees may contribute to flood control. Conifers, for instance, use a great deal of water and increase the capacity of the soil to absorb water (Nisbet, Silgram et al. 2011). By increasing infiltration rates in forest soils, trees can have significant impacts on flooding - modelling since the O’Connell review in Pontebren in Wales suggest that **in this context**, a shelterbelt at right angles to the slope could reduce field scale flood peaks by 40% (Jackson, Wheater et al. 2008)⁶⁰.

⁵⁹ Although the literature is insistent that application must consider the context in every case.

⁶⁰ The context is hillsides in Wales which are heavily stocked with sheep, have heavy clay soils and significant artificial drainage. The results are for a significant row of trees (80m x 15m). These results are based on a comparison between modeled data and field results.

- Urban forests intercept rain water and reduce peak run off. This is most effective for smaller storms but the effect is reduced for larger storms in which canopies become saturated. The effectiveness will vary according to local climate, tree species and time of year (broadleaved trees have no leaves during winter storms) (Xiao, McPherson et al. 1998).
- Test plots in Manchester demonstrated that over a year, the addition of a street tree could reduce stormwater runoff by between 50 and 62 percent in a 9 square metre area, compared with asphalt alone (Armson, Stringer et al. 2013)⁶¹.
- Trees can contribute to greater hydraulic roughness of floodplains, slowing water flow. Modelling around the River Parrett in South West England found that floodplain woodland could slow water velocity within the woodland, increasing the water level by up to 270 mm and increasing flood storage by 71%. For the two areas modeled flood peak was slowed significantly – the water’s travel time was increased by 30 and 140 minutes (Thomas and Nisbet 2007)⁶².
- Research in the Scottish Borders, UK, found that the soil permeability of aged broadleaf forest was between 5 and 8 times greater than the neighbouring grassland. This gives it a much greater capacity to infiltrate high intensity rainfall (Archer, Bonell et al. 2013)⁶³.
- In the River Laver catchment, modelling suggested that the creation of 40 hectares of woodland across 4 sites could delay the progression of a 1 percent annual probability flood by almost 1 hour. This would desynchronise flood flows from a tributary and reduce flood peak height by 1-2% (Nisbet and Thomas 2008).
- A comparison between the Wye and Severn catchments in Wales found that the Wye (moorland pasture) had consistently more pulse events⁶⁴ than the Severn (48-67% afforested), and also had higher maximum pulse heights. Pulse events on the Severn tended to be less extreme but longer duration (Archer 2007)⁶⁵.
- Although it is logical that increased farm runoff and local flooding would feed into larger flood events there is as yet little direct evidence for it. This is because dealing with larger floods is made more complex because the key issue is the extent to which water from tributaries arrives at the vulnerable site at the same time, meaning that action which reduces local flooding could make a larger flood event worse (O’Connell, Beven et al. 2005). This means that some areas which shed water rapidly may be necessary to ensure flood waters reach the critical region out of phase.
- An Environment Agency whole catchment modelling project for the River Parret in Somerset concluded that, although other measures could be beneficial, major rainstorm events would require significant detention of water at upstream locations (Park and Cluckie 2006). This would require new infrastructure which could be green, grey or a mixture, but positive impact on flood risk would require a catchment wide approach.

⁶¹ This test was conducted using three test plots, each 9 square metres. They contained either asphalt, asphalt and one street tree, or grass. The authors note that the year of test was drier than average.

⁶² This study is based on small scale modeling and concludes that significant benefits could be available if the approach was scaled up. This brings it into tension with a whole catchment modeling project for the same river which found that new forestry could make a difference but that very significant areas would be need to be given over to woodland to make an impact: Park, J. and I. Cluckie (2006). Whole catchment modelling project. Technical Report to the Environment Agency.

⁶³ Hill gradients varied between 1% and 22%, and included part of the floodplain of the Eddleston Water, a tributary of the River Tweed.

⁶⁴ A pulse event refers to a rise above a threshold flow. For this project they examined pulse events above multiples of the median flow, for instance pulse events above 5 times the median flow.

⁶⁵ The author notes that the success of this analysis depends on the two paired catchments having a very similar hydrological response. This is difficult to prove.

Sustainable Urban Drainage Systems

- Sustainable Urban Drainage Systems (SUDS) cover a mixture of approaches which filter or retain water near where it lands offering flood protection and biodiversity benefit. Reviews have found these to be cost-effective flood control mechanisms (Duffy, Jefferies et al. 2008).
- Research in Scotland found sustainable urban drainage systems (SUDS) were a cost-effective method of delivering drainage which met the requirements of current environmental legislation. The term SUDS covers a mixture of interventions but normally include detaining water above ground close to where it fell, as in this case. In particular capital costs of traditional drainage are more than double the capital costs of SUDS, annual maintenance costs are 20 – 25% cheaper for SUDS and SUDS is around half the cost over a 60 year life span (Duffy, Jefferies et al. 2008)⁶⁶.
- A study in Cambridgeshire found that SUDS measures in a residential suburb reduced both the flow and volume of stormwater entering the drainage system. This was achieved at a lower cost and with reduced maintenance effort than a traditional stormwater system (Royal Haskoning 2012).
- A monitored rain garden in the USA with a 0.49 hectare catchment was found to remove 973 cubic metres of stormwater runoff per year (Flynn and Traver 2013)⁶⁷.

Green roofs

- Green roofs intercept rain water and reduce peak run off. This is most effective for smaller storms but the effect is reduced for larger storms in which roofs become saturated. The effectiveness will vary according to type of roof and local climatic conditions (Mentens, Raes et al. 2006).
- Modelling conducted on Manchester found that adding green roofs to all buildings in town centres, retail and high-density residential areas could reduce run off by 17.0 – 19.9% (Gill, Handley et al. 2007).
- Over 27 months, a green roof test bed in Sheffield was found to retain 50% of total runoff. For significant storm events with a likelihood of occurring less than once per year, the green roof retained 43% percent of all rainfall on average, although this was highly variable (Stovin, Vesuviano et al. 2012)⁶⁸.
- A 43 year old intensive green roof in Manchester was found to retain 51.2 percent of all rainfall. Organic content in the soil had accumulated over time, which improved water retention (Speak, Rothwell et al. 2013)⁶⁹.

⁶⁶ The study methodology is robust and conservative and the figures inputted are based on real costs. The major cost omitted from the study is the cost of the (surface) land taken up by SUDS, but this is clearly flagged. On the other side of the balance sheet however, the traditional engineering system which serves as a cost comparison would require additional treatment to meet regulatory standards and this cost was not included. Neither were the aesthetic and biodiversity benefits of the SUDS system. A full blown cost-benefit analysis which included these would be useful, but this study is a useful comparison of engineering and maintenance costs. The study does not appear to use Green Book standard discount rate because it applies the standard 3.5 per cent for the full 60 years of its life time costs analysis, and this should drop to 3 per cent for the second 30 years, but this will not significantly alter the findings. The study was paid for by the developers of the site (Taylor Wimpey Developments Ltd), but this is clearly marked.

⁶⁷ This particular rain garden was 405 square metres in area. It should be noted that the rate of pollutant removal would be expected to reduce over time due to sedimentation, if this was not removed.

⁶⁸ The authors found that it was not possible to develop a robust predictive model using the data obtained, as the relationships between the soil substrate, previous weather conditions, rainfall intensity and runoff were complex.

⁶⁹ Intensive green roofs generally have a deeper substrate layer, greater than 15 cm. The authors note that the research was conducted in an unusually wet year – this may lead to underestimation of retention rates.

Link with climate change

- The problem of rain water floods is likely to have already been exacerbated by climate change because all regions of the UK have experienced an increase in the amount of winter rain that falls in heavy downpours. For all regions an increase in winter rainfall and a decrease in summer rainfall is projected by the 2040s. Winter rainfall in the Northwest of England is projected to increase by 6% in the 2020s, 10% in 2040s, and 16% in the 2080s increasing flood risk (Department for Environment Food and Rural Affairs 2009)⁷⁰.
- Climate change may also lead to reduced soil organic content (Jenkinson, Adams et al. 1991), which would exacerbate flood risk.

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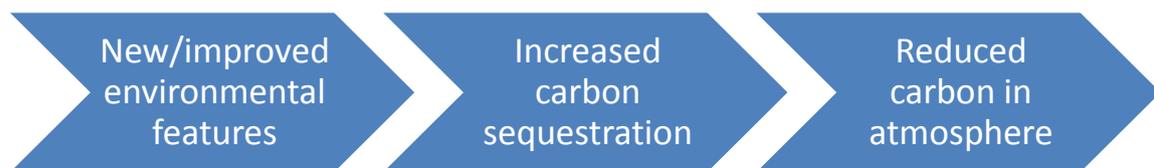
4e Global climate regulation

There is strong evidence that a range of different natural environments can play an important role in sequestering carbon emissions. Conversely, damaging those environments can result in further emissions being produced.

Introduction

- 4.25 Climate change poses a major risk to the environment and the economy. The Stern Review in 2006 estimated that the impacts of climate change were equivalent to losing at least 5 per cent of global Gross Domestic Product (GDP) each year, indefinitely (Stern 2006). Current cuts in carbon emissions are far from sufficient to keep average global temperature increase below 2 degrees, pointing to the need for increased effort in mitigation and adaptation (European Environment Agency 2010).
- 4.26 Other sections of this review have highlighted the way in which the natural environment can help us adapt to climate change, but our ability to adapt is limited. This means that mitigation of climate change remains a challenge. This section contains the evidence that investment in the environment can help us mitigate climate change, often at the same time as adapting to it.

Theory of change



- 4.27 A second theory of change is also important here – degrading soil and vegetation can result in the emission of significant amounts of previously stored carbon into the atmosphere. This is a major issue, particularly for peatlands. Land management activities can also lead to increased emissions of other greenhouse gases, particularly methane and nitrous oxide.

Can the benefit be quantified?

- 4.28 Yes, relationships can be quantified, but the science indicates that sequestration and emission rates are complex and context dependent. International transfer of economic values is facilitated by the fact that the social cost of carbon⁷¹ is the same wherever it is emitted in the world, however some forms of pricing carbon, such as the UK non-traded price are country specific.

How strong is the evidence?

- 4.29 The evidence for this benefit is stronger for some ecosystem types such as forests, than others, including many marine systems. There are important research gaps in evidence of the current scale of carbon storage and carbon management in many habitats (Alonso, Weston et al. 2012).

⁷¹ Pricing carbon emissions is an attempt to include the damage done by carbon within our economic decision making framework. The social cost of carbon is an attempt to work out the cost of the damage done by each tonne of carbon. In contrast the non-traded price is based on the costs imposed on the economy by emitting that tonne of carbon given the UK's climate change reduction commitments (i.e. mitigation cost). It is called the non-traded price because it is used for sectors outside the European Carbon Trading mechanism.

Evidence

Farmland

- It has been estimated that the UK's environmental stewardship schemes reduce emissions by between 0.44% and 0.49% of the 1990 Kyoto baseline over a 100 year time frame. This benefit is largely due to the move to less intensive land management - for instance, reduced fossil fuel inputs, reduced deep tillage, and the use of undercrops (Department for Environment Food and Rural Affairs 2007)⁷². This amounts to net savings of 1.0 million tonnes of carbon dioxide (CO₂) equivalent from Entry Level Stewardship (worth £53 million) and 4.1 million tonnes of CO₂ equivalent from Higher Level Stewardship (worth £211 million) with a combined total of 5.1 million tonnes of CO₂ equivalent (worth £264 million) (FERA 2010).

Forests/woodlands

- It is estimated that 595 million tonnes of CO₂ is stored in UK forests, and net uptake per year is between 9 and 15 million tonnes. Substituting wood for fossil-fuel intensive materials such as concrete, and in energy generation can offer substantial additional benefits in terms of greenhouse gas emissions (Morison, Matthews et al. 2013).
- The woodfuel strategy for England set a target of bringing 2 million tonnes of woodfuel to market annually, entirely from un-harvested material available in English woodlands. It estimates that this would save 400,000 tonnes of fossil fuel carbon and supply 250,000 homes with energy (Department for Environment Food and Rural Affairs 2007).
- An enhanced woodland creation programme involving planting 23,200 hectares could deliver abatement of approximately 15 megatonnes of CO₂ per year by the 2050s⁷³; representing 10% of total emissions at that time (if we assume emissions have fallen as required by the Climate Change Act). Mixed woodlands for multiple objectives can deliver abatement at less than £25 per tonne of CO₂, which is significantly less than the £100 per tonne cost effectiveness threshold set by the Committee on Climate Change (Read, Freer-Smith et al. 2009).
- Valatin and Starling (2010) estimate that in 2009 the value of carbon sequestered by UK woodlands was £680 million. This is additional to the value of the carbon already stored in existing woodlands. Two thirds of the carbon sequestered was in Scotland. On a per hectare basis, woodlands are estimated to sequester 5.2 tonnes of CO₂, with an average value of £276 per hectare per year (Valatin and Starling 2010)⁷⁴.

Grassland

- Grassland restoration can result in sequestration of carbon emissions at between 4.03 and 11.62 tonnes of CO₂ equivalent per hectare per year. By contrast, conversion from grassland to arable land can produce additional emissions of between 3.48 to 6.23 tonnes of CO₂ equivalent per hectare per year (Alonso, Weston et al. 2012).
 - Similarly, conversion of blanket bog to improved grassland is estimated to result in increased carbon emissions of 8.68 tonnes of CO₂ equivalent per hectare per year, or 22.42 tonnes of
-

⁷² These figures do not take into account displacement of food production, either within the UK, or overseas, which could radically change the outcome. This points to the need to consider demand for food products as well as production methods. The results also assume no reversion to previous practices, and reversion is quite likely when the current schemes come to an end, suggesting we need to consider countryside management over a longer timeframe.

⁷³ The 23 200 ha per year is based on 14 840 ha of additional planting per year on top of the assumed ongoing 8360 ha.

⁷⁴ Note that this analysis uses the Department for Energy and Climate Change central social value of carbon of £53/tCO₂ in 2009.

CO₂ equivalent per hectare per year for conversion to cultivated grassland. Conversion of deep lowland fens is estimated to have a similar impact of 20.58 and 26.17 tonnes of CO₂ equivalent per hectare per year emitted for improved and cultivated grassland conversions respectively (Alonso, Weston et al. 2012)⁷⁵.

Greenspace

- A 2.16 hectare landscaped green belt in Leipzig, Germany was estimated to sequester between 38 and 223 tonnes of CO₂ per hectare over 50 years, net of construction and maintenance emissions. The higher value represents a scenario with high tree growth rates, and low mortality. However, if the green belt was planted with lawn only, this was estimated to **produce** between 2.52 and 6.54 tonnes of CO₂ per hectare over the same period (Strohbach, Arnold et al. 2012)⁷⁶.
- Carbon stored above ground in vegetation in the city of Leicester is estimated at 231,521 tonnes, with 97% of that being stored in trees (Davies, Edmondson et al. 2011).

Marine

- Coastal and marine ecosystems are vital global carbon stores. Saltmarsh, in particular is important. Unlike the ocean's vast carbon stores, which are beyond direct human management, carbon storage and sequestration by salt marshes can be improved through management, including managed realignment of sea walls (Andrews, Samways et al. 2008).
- Salt marshes are estimated to store 2.1 tonnes of CO₂ equivalent per hectare per year on average, and sea grasses also have the potential to sequester large amounts of carbon, with estimates of 0.2 to 2 tonnes of CO₂ equivalent per hectare per year (Alonso, Weston et al. 2012)⁷⁷.
- The Isles of Scilly contain 23.5km² of kelp, 3.1km² of seagrass and 383.1km² of phytoplankton habitat. Total annual sequestration of carbon via photosynthesis is estimated at 136,495 tonnes of carbon per year, predominantly from phytoplankton, followed by kelp then seagrass. The total value of this carbon sequestration is estimated at £53.8 million over 100 years (Mangi, Davis et al. 2011)⁷⁸.

Peatlands

- Peatlands in England contain an estimated 584 million tonnes of carbon. Degradation of peatlands through drainage, burning, agriculture and peat extraction results in this carbon being released to the atmosphere. If the full amount of carbon stored in peatlands was released to the atmosphere, this would be equivalent to 2.14 billion tonnes of CO₂, or five times England's total annual CO₂ emissions (Natural England 2010).

⁷⁵ Most of these estimates are based on the results of a single study, and should therefore be used with caution.

⁷⁶ Note that this analysis did not include consideration of the impacts of future climate change on tree growth and mortality rates. Climate change may also affect maintenance requirements (for instance, supplemental watering during drought, or storm debris removal).

⁷⁷ Most of these estimates are based on the results of a single study, and should therefore be used with caution.

⁷⁸ This is likely to be a significant underestimate, as it uses a flat 3.5% discount rate over 100 years, and also uses a maximum carbon price of £23/tonne. The UK government recommended carbon price for the non-traded sector was £57 per tonne in 2011, rising to £293 in 2100. However, it also does not account for production of N₂O by saltmarsh, which may reduce the net sequestration effect.

- Peatland restoration in England could deliver emissions reductions of up to 2.4 million tonnes of CO₂ equivalent per year. At the central non-traded carbon price of £52 per tonne of CO₂ equivalent this is a benefit of £124.8 million per year (Natural England 2010)⁷⁹.

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⁷⁹ The complicating factor is that peat bogs also emit methane, at different rates depending on factors such as the water level. More research is needed in this area but the balance of probabilities is that is that peatland restoration will be carbon beneficial.

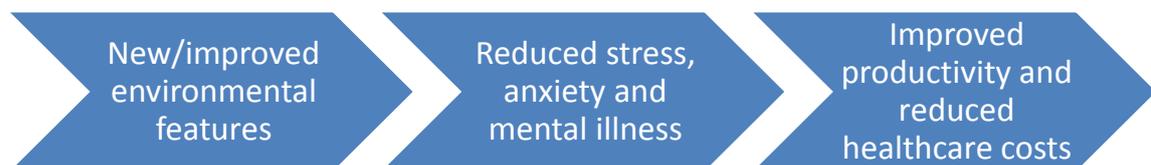
4f Mental health

There is good evidence that people with better access to the natural environment tend to be happier and less prone to mental illness. Insufficient evidence exists to explain exactly why this effect occurs, as several pathways may be involved.

Introduction

- 4.30 This section presents evidence that exposure to natural environments has psychological benefits, particularly with regard to stress levels and mood. This includes the psychological benefits of exercise taken in a natural environment as opposed to in an unnatural one.
- 4.31 Evidence of a positive effect on mental health is important because mental health is a major health issue in England with a strong negative impact on the economy. Tackling chronic stress is important because it plays a major role in the causation and development of common physical and mental illnesses, and the problem has been intensifying in recent decades (Health Council of the Netherlands 2004)⁸⁰.
- 4.32 The economic and social costs of mental illness in England are estimated at £105.2 billion for the year 09/10. This includes direct costs of healthcare of £21.3 billion, and £30.3 billion in lost output (Centre for Mental Health 2010)⁸¹.
- 4.33 A rigorous sample based survey suggests 1 in 6 people in the UK have depression or chronic anxiety disorder with just under 1 in 4 people suffering from some form of mental illness (McManus and Bebbington 2009)⁸².

Theory of change



- 4.34 Note that this is a highly simplified theory of change, as the natural environment may impact on people's mental health both directly and indirectly (through for instance, encouraging physical activity and social interaction, both of which are linked to mental health). In addition, as shown above, the theory of change could potentially also be taken a step further to examine the flow-on impact of a happier, healthier population, in terms of improved productivity and reduced medical expenditure. This is not examined in this review.

⁸⁰ The comments in the report refer primarily to Dutch society, but may be reasonably applicable to the UK. On the basis of these comments the report argues that chronic stress should have a profile in public health policy similar to that of alcohol and smoking.

⁸¹ Note that the £105.2 billion figure is an economic VALUE estimate and so cannot be compared to GDP figures. The approach taken includes valuing unpaid work and also quality of life years lost and therefore must be regarded as a best estimate, and in future could be improved upon in terms of methodology and data availability. However the approach taken is appropriate and conservative.

⁸² The nearly 1 in 4 figure is actually 23% and includes people suffering from post-traumatic stress disorder, suicidal thoughts, suicide attempts and self-harm, psychosis, anti-social and borderline personality disorders, attention deficit and hyperactivity disorders, eating disorders, alcohol misuse and dependence, drug-use and dependence, gambling and behavioural problems.

Can the benefit be quantified?

4.35 Quantification of these relationships is complex because of the very individual nature of mental distress, and difficulties defining and comparing levels of mental distress across different people. The only robust empirical route is through a longitudinal study examining changes in people's mental health over time. This would have to be quasi-experimental, because randomly assigning people to groups over the long term would contravene ethical requirements. This however limits the ability of researchers to control for all the relevant variables influencing mental health.

How strong is the evidence?

4.36 The evidence for the natural environment contributing to mental health is strong. Much of the existing research is cross-sectional, examining differences in mental health across groups of individuals. Some longitudinal research examining differences in the mental health of individuals across time is also available, and combined, these two forms of evidence are convincing.

4.37 The exact pathways through which the natural environment contributes to mental health are unclear. Ward Thompson, Roe et al. (2012) suggest that there are three pathways through which the natural environment can contribute to improvements. The first is directly through the restorative benefits provided by exposure to nature, and the second is indirectly through providing a space for positive social contact. The third pathway is through providing a space for physical activity.

Evidence

Exposure to nature

- There is strong evidence, from a large number of high-quality studies that nature promotes recovery from stress and attention fatigue, and that it has positive effects on mood, concentration, self-discipline, and physiological stress (Health Council of the Netherlands 2004) [for examples see (Kaplan and Kaplan 1989); (Berman, Jonides et al. 2008), (Ulrich 1984) and (Ulrich, Simons et al. 1991)].
- In healthy people, the stress hormone cortisol is at its peak level in the morning and declines during the day. The rate at which it declines reflects the level of stress the person is exposed to throughout the day (less stress results in a faster rate of decline). An exploratory study of disadvantaged residents of Dundee, UK, found that people living in areas with more greenspace had cortisol levels in their saliva which declined significantly faster than in those people with less access to greenspace. The same people also reported lower levels of self-perceived stress (Ward Thompson, Roe et al. 2012)⁸³.
- Alcock, White et al. (2014) used British Household Panel Survey data between 1991 and 2008 to examine the mental health of 1,064 British residents who moved house during that time. Of these people, 594 moved from less to more green areas, and 470 moved from more to less green areas. Each respondent reported their mental health each year using the Generalised Health Questionnaire. Respondents living in more green areas reported average mental health higher than those in less green areas. Respondents in less green areas who moved to greener areas reported an improvement in mental health in the first year, which was sustained in the following two years. Respondents in more green areas who moved to less green areas reported a decline in mental health in the year prior to the move, followed by rapid adaptation and a return to previous mental health (Alcock, White et al. 2014)⁸⁴.

⁸³ This was an exploratory study with 25 participants aged between 35 and 55, none of whom were in employment. Results therefore may not be applicable to the wider UK population. Ward Thompson, Roe et al. 2012 selected this group for study because research suggests that greenspace has a disproportionately beneficial effect on the health of deprived communities.

⁸⁴ Respondents completed the General Health Questionnaire to determine their mental health status. 'Greenness' was derived from land cover identified in the Generalised Land Use Database for the 4km² land parcel in which the

- In a Norwegian study of patients in a heart and lung rehabilitation centre, men with unobstructed mountain views from their private room noted increases in self-reported mental health over a 4 week period, compared with men in rooms with an obstructed view. The same effect was not found for women (Raanaas, Patil et al. 2011)⁸⁵.
- A study examining two comparable neighbourhoods in Ghent, Belgium found that the people living in the neighbourhood with more greenery (including private gardens and street trees) were happier than those in the comparison neighbourhood. However, satisfaction with the amount of neighbourhood greenery was not directly significant in determining happiness. Instead the relationship was found to be less obvious – the amount of greenery influenced the green view from an individual's living room window, which was highly correlated with the level of neighbourhood satisfaction, which in turn was highly correlated with individual happiness levels (Herzele and Vries 2012)⁸⁶.
- The Mappiness project developed at the London School of Economics uses an iPhone application to track individual's happiness over time and across locations. This found that average happiness was 60.7 (scored out of 100). This increased by 2.3 points when an individual was outside, and a further 6 points if the individual was in a marine or coastal area (compared to an urban area). All other land cover types and outdoor activities also increased happiness, but to a lesser extent (MacKerron and Mourato 2013)⁸⁷. Social interactions were controlled for in the analysis.
- Children in Swedish preschools with vegetated outdoor play areas were found to be more attentive than children without such play areas. Hyperactivity and impulsivity were also found to be reduced in children with vegetated play areas (Martensson, Boldemann et al. 2009)⁸⁸.
- Evidence from Australia suggests that greenspace quality may be more important to mental health than its quantity. People living near moderate or high quality public open spaces were found to be twice as likely to report low psychological distress as those living near low quality spaces. Usage of greenspace, and number and size of greenspaces was not significantly related to mental health (Francis, Wood et al. 2012)⁸⁹.

Social interactions

- Researchers in the Netherlands found that the amount of greenspace was correlated with people's feelings of loneliness and perceptions of social support, and that this in turn was correlated with self-reported propensity for psychiatric illness. However, there was no

individual's home was located. The interesting results for people moving from green to less green areas could possibly be explained by individuals being overly pessimistic about the effects of moving house, and recovering quickly when this is realised.

⁸⁵ It is unclear from the study if men spent a higher proportion of their time in their rooms rather than in communal areas, and whether this contributed to the gender disparity. The study examined a short time period only and therefore did not identify whether the differences hold once patients leave the centre.

⁸⁶ The results of this study were based on a relatively small sample of less than 200 people. It is also possible that the neighbourhoods differed in ways which were not observed in the study, therefore influencing the results.

⁸⁷ This study did not use random sampling, as all participants were self-selected. This may influence the results. The direction of causation is also difficult to prove – the study authors note that people may choose certain locations depending on their mood.

⁸⁸ This study involved 200 Swedish children and 11 preschools. Attention, hyperactivity and impulsivity were assessed by their teachers using the Early Childhood Attention Deficit Disorders Evaluation Scale. Children in preschools where children were outdoors all day were excluded from the analysis.

⁸⁹ Survey respondents were people who moved into new residential developments in Perth, Western Australia. They completed a standard Kessler 6 questionnaire on mental health, which separated them into two groups – those with low risk of psychological distress, and those with medium-high risk. Public open space quality was objectively measured using 10 attributes including walking paths, shade, water features, bird life and playgrounds.

evidence of an increase in actual social contacts or social support received in areas with more greenspace (Maas, Dillen et al. 2009).

Access and physical activity

- Between 1999 and 2005, a Swedish longitudinal study of over 10,000 residents was conducted, which found that greenspace attributes had no independent relationship with mental health. However, the study found that women who were physically active in 1999 and lived near 'serene' natural environments were 80 per cent less likely to have poor mental health in 2005, compared with those who were neither physically active nor living near 'serene' environments. A similar result was found for men, but this was not statistically significant (i.e. it may have been due to chance). Participants who were physically active on a regular basis but not living near 'serene' environments were only 10 per cent less likely to have poor mental health in 2005 than those who were not physically active, suggesting that the interaction between physical activity and the natural environment is important in determining mental health outcomes (Annerstedt, Ostergren et al. 2012)⁹⁰.
- On the specific issue of whether exercise in greenspace had mental health benefits greater than indoor exercise, a systematic review of the evidence for the mental health benefits of taking exercise in greenspace found significant reductions in anger, fatigue and depression, but concluded that there was not yet enough evidence to make generalized statements of universal benefit (Bowler, Buyung-Ali et al. 2010).
- Guite et al. (2006) performed a study in Greenwich, London, looking at the local environment in its broadest sense (i.e. fear of crime, noise etc) and concluded that being dissatisfied with access to open greenspace is related to mental ill-health in a statistically significant manner⁹¹.

Effects of increased naturalness

- The evidence in this area is not as developed as for the benefits of greenspace in general, but there is a study which found increased psychological benefit for greenspaces with high levels of biodiversity (Fuller, Irvine et al. 2007)⁹². Additionally a study in Montpellier, France found that 72% of respondents preferred natural to ornamental greenspaces (Caula, Hvenegaard et al. 2009)⁹³.
- Conflicting evidence from Sweden found study participants were able to identify areas of greater biodiversity (defined as species richness), yet these areas were actually most

⁹⁰ The study excluded respondents who moved house within the 6 year time period, but did not reassess the available greenspace in 2005. It is unlikely that this would make a significant difference to the results, as urban greenspace availability is not likely to have changed much over that period.

⁹¹ In this study the survey was not sent randomly, but based on a previously held theoretical model of domains which might influence mental health. A wide range of possible confounding variables was considered. Given practical and ethical constraints this may be as close to a genuine experiment as is possible for long-term study.

⁹² This study assessed biodiversity and self-reported psychological responses on a robust basis in parks in Sheffield. It found that park-users perceptions of plant biodiversity were strongly related to objective measures, for birds there was the appearance of a relationship, but it wasn't strong enough to be statistically significant, and for butterflies there was no clear relationship. The degree of psychological benefit was positively related to the species richness of plants. Obviously, it was not possible to control whether people with a greater propensity to psychological benefit from greenspace choose to visit more biodiverse parks, so this is a potential confounder. The findings suggest that park management emphasizing a mosaic of habitats would benefit biodiversity and the psychological wellbeing of park visitors.

⁹³ This peer-reviewed study was based on a self-completed study distributed to community centres in Montpellier. Appropriate comparisons between those completing the survey and population were made and the sample proved to be broadly comparable to the population, but contains a smaller percentage of people with lower levels of education. The study also found that for those most interested in urban biodiversity, and for those that make the most use of greenspaces, providing information about the importance of greenspaces for biodiversity increased willingness to pay for natural greenspaces.

disliked. Ornamental park landscapes were found to be more desirable (Qiu, Lindberg et al. 2013)⁹⁴.

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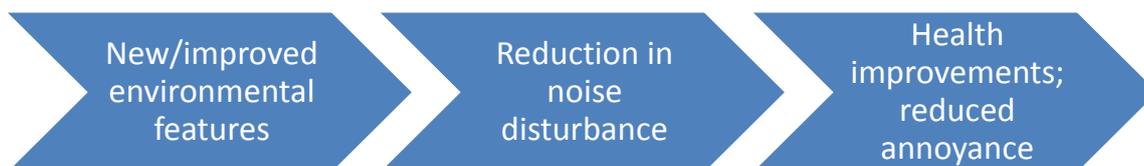
4g Noise

Noise can have ongoing impacts on people's health. In the right context, environmental features can effectively muffle unwanted sounds.

Introduction

- 4.38 This section reviews the evidence that the natural environment can contribute to noise reduction. Noise is defined as 'unwanted sound' and a review of the evidence shows that it interferes in complex task performance, modifies social behavior and causes annoyance. In children, chronic aircraft noise exposure impairs reading comprehension and long-term memory and may be associated with increased blood pressure (Stansfeld and Matheson 2003).
- 4.39 Evidence indicates that exposure to road traffic noise is linked to an increased risk of hypertension, heart disease and heart attack in adults. The WHO estimates that 1.8 percent of all heart attacks in Western Europe can be attributed to road traffic noise, and that more than 1 million healthy life years are lost each year due to traffic-related noise (WHO Regional Office for Europe 2011)⁹⁵.
- 4.40 Tassi, Rohmer et al. (2013) demonstrated that chronic exposure to nocturnal railway noise (average of 39 decibels) is linked to chronic daytime sleepiness, lowered alertness and poor attention to sustained tasks. Study participants had been exposed to the noise for over a decade, on average, and showed no sign of having become accustomed to it (Tassi, Rohmer et al. 2013)⁹⁶.
- 4.41 The World Health Organization guidelines for Europe recommend that people should not be subjected to night-time noise levels greater than 40 decibels (the approximate sound level of a library); in Europe almost 34 million people may be exposed to more than 50 decibels at night (approximate sound level of a conversation at home) (European Environment Agency 2010).
- 4.42 A study of the impact of noise on house prices in Birmingham found that a 1 decibel increase in road traffic noise reduces the selling price of a property by between 0.18 and 0.55 per cent. Over the lifetime of the property, a decrease in noise levels from 56 to 55 decibels would be worth £31.49 per household per year (Day, Bateman et al. 2007)⁹⁷.

Theory of change



⁹⁵ The authors note that these estimates are based on a limited number of studies, and do not account for some other contextual factors that may be correlated with road traffic (for example, air pollution).

⁹⁶ This study compared two similar groups of French residents, 20 of whom had lived for a long time near a railway track, and 20 of whom lived in a comparable, quiet area. This is a relatively small study and results should therefore be treated with some degree of caution.

⁹⁷ These results are specific to the Birmingham property market, and should not be extrapolated to other locations. However they do indicate that noise can impact on property values.

Can the benefit be quantified?

4.43 Yes, with caution. The reduction in noise levels as a result of environmental features can be quantified, however it is highly context dependent. Care needs to be taken in extracting the impact of noise on health from other impacts on health that may occur at the same time due to being in more natural areas.

How strong is the evidence?

4.44 The evidence is strong that the natural environment, particularly vegetation, contributes to noise reductions, and that this has health benefits. However the effect depends on the specific context and location.

Evidence

- The presence of vegetation, and soft rather than hard surfaces, reduces the extent to which sound carries around urban areas (Bolund and Hunhammar 1999). Soft lawns and dense tall vegetation reduce the extent to which sound carries, although sources differ in their quantification of this effect. Lawns reduce noise by reducing reflection of the sound wave, an effect which accounts for the quietness experienced after snowfall. Tall vegetation absorbs lateral short wave-length sound (Barth and Schmid 2001).
- Fang and Ling identify that key factors affecting the noise attenuation provided by tree belts are: visibility (denseness of the trees/foilage), belt width, tree height, and the height of the noise source and receiver. They find that a tree belt 3.6 metres wide, 4 metres high, and with visibility of 2 metres could reduce the sound level by 4 decibels for a noise source/receiver 1.2 metres high and 28 metres away (Fang and Ling 2005)⁹⁸.
- Modelling of green roofs has demonstrated that they can reduce road traffic noise within a house, and the effect is strongest at higher vehicle speeds. In a typical built-up street with heavy traffic, a green roof could reduce sound levels by 8 decibels compared with a rigid roof (Van Renterghem and Botteldooren 2009)⁹⁹.
- Green walls have been demonstrated to provide sound attenuation benefits equivalent to other building materials and furnishings. This effect depends on the type of vegetation and substrate used, and the density of the plantings (Hien Wong, Yong Kwang Tan et al. 2010).
- Courtyards on the quiet side of building can reduce the level of road traffic noise annoyance by providing some quieter outside space. A study in Sweden found that the quality of the courtyard in terms of 'naturalness' and features such as benches and playgrounds *as well as* the noise level had a significant impact in reducing noise annoyance (Gidlöf-Gunnarsson and Öhrström 2010)¹⁰⁰.
- People exhibit strong preference hierarchy with regard to sound exposure, with mechanical sounds liked least, followed by human sounds and with natural sounds preferred. More natural greenspace, particularly with a significant shrub layer, can encourage the production

⁹⁸ This estimate was based on common Taiwanese hedge trees, so may not be directly transferable to the UK situation. Visibility at 2 metres means that a white object held 2 metres within the tree belt could be seen outside the tree belt.

⁹⁹ This assumes a saddle-backed roof with a 30 degree slope, and a single lane road with traffic travelling at a constant 70km/hour.

¹⁰⁰ The study was based on questionnaire responses in four cities areas in Stockholm and Gothenburg. Appropriate controls were put in place with regard to sound levels on the noisy and on the quiet sides of the building, similar types of traffic, similar types of houses, and ensuring that there were no patterned differences to age or country of origin. Courtyard quality was assessed in terms of presence of outdoor furniture, playgrounds for children, presence of flowers in pots or beds and the aspect (very important that far North). At 63 – 68 decibels (the higher level assessed) 42% of residents reported annoyance with low quality courtyards and only 29% with high quality courtyards).

of bird song at the same time as providing habitat for wild bird species (Irvine, Devine-Wright et al. 2009).

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4h Pest control

A limited amount of evidence suggests that natural predators can be effective pest control on agricultural crops, however there are limitations to this approach.

Introduction

- 4.45 An important part of farming is controlling unwanted pests which can damage crops and reduce yields. Traditionally this is done by means of the application of pesticides, which commonly kill beneficial invertebrates as well as the target pest species. Crop protection costs can vary between £94 and £592 per hectare, or between 23 and 45 per cent of all variable costs (Department for Environment Food and Rural Affairs 2013). Besides the cost, pesticides can have a range of negative environmental and human health impacts if incorrectly applied (Health and Safety Executive 2014). The risk of this occurring is lower in small scale protected cropping systems, such as poly-tunnels for soft fruit.
- 4.46 Integrated Pest Management (IPM) is a broad approach encompassing the use of threshold levels to determine when pests require control, monitoring of pest numbers, prevention of pests through techniques such as crop rotation, and biological control through the application of predator species (such as ladybirds). This approach can be effective in protected cropping systems where conditions can be tightly controlled and introduced predator species can be contained. This is more problematic for field crops (Centre for Alternative Land Use 2011).
- 4.47 Beneficial natural predator species can be encouraged through the provision of shelter, alternative prey, flower-rich habitat and an appropriate environment (Holland and Ellis 2008), particularly grassy habitats such as field margins (Holland, Storkey et al. 2014).

Theory of change



Can the benefit be quantified?

- 4.48 The benefit can be quantified but is likely to be highly dependent on the specific crop and climate context. This includes factors such as natural predator species present, other prey availability, use of any alternative crop protection measures, and general climate conditions that may affect both predator and prey species. Natural predators cannot be controlled and applied to fields like traditional pesticides, and therefore introduce an element of uncertainty into the farming system. This, combined with risk aversion on the part of farmers, has meant that the encouragement of natural predators as part of a pest control strategy has not been widely adopted (Holland, Oaten et al. 2008), outside of enclosed cropping systems.

How strong is the evidence?

- 4.49 In some situations, there is good evidence that pest control by natural predators may offer a benefit to agricultural productivity and profitability. To date, the evidence has focused specifically on aphids.

Evidence

- Natural predators were found to remove 99 per cent of aphids from wheat test plots in Dorset and Hampshire, UK. Aerial predators such as flies offered rapid and effective control, whereas crawling predators had a slower and less significant, but complementary impact. The

presence of field margins significantly increased the level of pest control provided by aerial predators (Holland, Oaten et al. 2012)¹⁰¹.

- Across the UK and Europe, the bird cherry-oat aphid is a common pest on cereal crops. In Sweden, natural control of the bird cherry-oat aphid by ground-dwelling beetles and spiders was found to be responsible for a 303 kg increase in spring barley yields per hectare. This represents a 15 percent yield increase on conventional farms, and a 30 percent increase on organic farms, compared to when no natural predators were present. Natural predators can also reduce the amount of insecticide required to control aphid infestation (Ostman, Ekbom et al. 2003)¹⁰².
- In New Zealand, predation of aphids by natural predators on organic fields was found to be worth on average US\$35 per hectare per year in avoided costs, compared to when natural predators were artificially excluded. On conventional fields the contribution of natural predators was found to be insignificant due to the use of pesticides (Sandhu, Wratten et al. 2010)¹⁰³.

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¹⁰¹ The study was conducted using square metre treatment plots within 14 different fields of winter wheat.

¹⁰² It is worth noting that this particular aphid is also a problem in the UK. The authors note that high yield losses might be expected during the conversion from insecticides to biological control, as insecticides will have reduced the population of beneficial natural enemy species.

¹⁰³ There was wide variation in the amount of aphid predation between fields, with five out of 15 organic fields not recording enough natural predation to avoid incurring pest control costs. None of the conventional fields recorded enough natural predation to avoid incurring pest control costs.

4i Physical activity

The evidence that access to the natural environment contributes to increases in physical activity is inconclusive. This benefit should be considered as possible but unproven.

Introduction

- 4.50 Being physically active is strongly linked to improvements in health and wellbeing. Some of this evidence is presented below. However, this section primarily examines the evidence that the natural environment (particularly managed greenspaces such as parks) impacts on the amount of physical activity undertaken by individuals. The link between the natural environment, mental health and physical activity is discussed in Section 4f **Mental health**.
- 4.51 In 2008, only 39 percent of men and 29 percent of women aged 16 and over met the UK Chief Medical Officer's minimum recommendations for physical activity (Aresu, Becares et al. 2009)¹⁰⁴. There is an established causal link between physical activity and at least 20 different chronic health conditions, including coronary heart disease, stroke, cancer, type 2 diabetes, mental health problems and musculoskeletal conditions (Department of Health 2011). A one percent decrease in the UK sedentary population is estimated to result in 848 fewer deaths per year, and 30,363 fewer illnesses (Mourato, Atkinson et al. 2010).
- 4.52 In 2006-07, an estimated £0.9 billion was spent by the NHS on physical inactivity related ill-health (Scarborough, Bhatnagar et al. 2011). It is estimated that by 2050, 60% of adult men, 50% of adult women and 25% of children under 16 could be obese and that this would cost the National Health Service (NHS) £10 billion a year and wider society £49.9 billion a year (Foresight 2007)¹⁰⁵. Any increase in the amount of physical activity undertaken could therefore lead to significant social and economic benefits.

Theory of change



Can the benefit be quantified?

- 4.53 In principle, the health outcomes of increased levels of activity can be quantified (on an appropriate average basis) and this can then be linked to health outcomes and economic values. Tools to do this for walking and cycling have been developed by the World Health Organisation (see <http://www.heatwalkingcycling.org/>). The difficulty lies in quantifying the relationship between the new or improved environmental features and any change in activity levels, particularly given the need to allow for substitution effects (i.e. people changing exercise locations, but not the total amount of activity undertaken).

How strong is the evidence?

- 4.54 The evidence that changes in the natural environment impact on physical activity levels is mixed, particularly in the UK. A review for the UK National Ecosystem Assessment found that there was 'no conclusive evidence on the strength of the relationship between the amount of greenspace in

¹⁰⁴ At least 30 minutes of moderate or vigorous activity 5 times per week or more.

¹⁰⁵ Figures at 2007 prices.

the living environment and the level of physical activity' (Mourato, Atkinson et al. 2010: 65). This finding is supported by Lachowycz and Jones (2010) who found that out of 50 papers reviewed, 20 reported positive results linking greenspace and physical activity, 28 reported no relationship or weak/mixed results, and the remaining 2 reported a negative link between greenspace and physical activity.

- 4.55 This particular area of research is still relatively under-developed, and many studies use relatively crude or inappropriate measures of greenspace and physical activity, which may affect the results obtained (Lachowycz and Jones 2010). A large amount of the research to date is cross-sectional, so it may show a possible relationship between physical activity and the natural environment, but not whether or not the natural environment causes a change in physical activity.
- 4.56 The majority of adult physical activity occurs at home, travelling to/from work, or at work. It could be considered that these are more functional or goal-oriented forms of activity, and therefore less likely to be affected by the environmental surroundings in which they take place (Mytton, Townsend et al. 2012). Factors such as safety and convenience may be potentially stronger influences.

Evidence

- Baumann and Bull (2007)¹⁰⁶ examined existing literature reviews on environmental attributes correlated with physical activity. They found that proximity to recreation facilities, attractive destinations, land use composition, urban 'walkability' scores and aesthetics were all correlated with physical activity.
- A study in Bristol, UK found that people who reported difficulty in accessing greenspace were 22% less likely to report physical activity at recommended levels, than those who found it very easy to access. The likelihood of reporting participation in physical activity at recommended levels was 48 percent lower for those who visited greenspaces 2-3 times per month, compared to weekly or more. Increasing distance to greenspaces was associated with less physical activity (Hillsdon, Jones et al. 2011)¹⁰⁷.
- By contrast, Hillsdon et al. (2006) found no significant relationship between distance to parks, quality of parks, and activity levels in Norwich, UK, amongst middle aged adults (aged 45-74) (Hillsdon, Panter et al. 2006)¹⁰⁸.
- Using data from the Health Survey for England, Mytton, Townsend et al. (2012)¹⁰⁹ found that people living in the greenest quintile of England were 24 percent more likely to achieve the recommended levels of physical activity, than those who live in the least green quintile. However, no positive association was found between the amount of greenspace and specific physical activities such as walking, which may be more likely to occur in greenspace. In fact, those living in the least green quintile were significantly more likely to walk than those in the greener quintiles.

¹⁰⁶ Most of the research examined came from the USA or Australia, however it seems reasonable that the attributes identified would also be relevant to the UK.

¹⁰⁷ This study relied on self-reported physical activity levels. It also looked at only the probability of achieving recommended activity levels, not any increase/decrease in physical activity that might occur.

¹⁰⁸ This study considered both distance to and quality of local greenspaces, and found no significant relationship with activity levels, even when level of deprivation and car ownership was controlled.

¹⁰⁹ This study used the Generalised Land Use Database to map greenspaces. This is a somewhat basic measure and does not account for the quality of the greenspace. Survey respondents were not asked about the locations of their physical activity, so it is unclear if those living in greener quintiles actually spent more time being physically active in greenspaces, or in other locations. The finding that those living in less green quintiles are more likely to walk could possibly be explained by lower rates of car ownership, as greenspace tends to be less present in areas that are economically deprived.

- Cohen's (2007)¹¹⁰ research in deprived predominantly ethnic minority areas of Los Angeles found that residents said that parks were the most important place to exercise and that only 13% of park users lived more than 1 mile from the park. However, this research took place in Southern California, which for climatic reasons is likely to have an outdoor exercise culture.
- Nielsen and Hansen's (2007)¹¹¹ study in Denmark found a statistically significant relationship between access to a garden or local greenspace and lower levels of stress and obesity. However, they concluded that the strength of the effect was too strong to be explained only by visits to these spaces and that this may be an indicator of an area more conducive to spending time outdoors and active travel.

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¹¹⁰ This study found that only 6 per cent of residents reported using a health club for exercise, which highlights the importance of parks to poorer communities who may not be able to afford access fees. The study relates park facilities to demographic groupings and has an appropriate stratified random sampling model, however due to the study location, it may be limited in its relevance to the UK.

¹¹¹ The study controlled for housing condition, employment, level of education, ownership to dwelling, age, gender, household type, second home and bicycling for work.

4j Pollination

Pollination services provided by the natural environment are critical to the survival of a range of wild plants, and the yield of many commercial crops.

Introduction

- 4.57 Pollination services are provided by a variety of species such as bees, butterflies and hoverflies. Natural pollinators need to be considered as distinct from managed pollinators such as commercially produced bumblebees and honey bees. Commercial pollinators are now considered to be essential to the production of tomato, seed and strawberry crops in glasshouses, and can be very significant for soft fruit produced in poly-tunnels (strawberry, raspberry, blackberry and blueberry). Natural pollinator species still play an important role in the production of unprotected crops, particularly for crops such as oil seed rape, beans and open field soft and tree fruit. They are also vital for the reproduction of many wild plant species and the habitats these plants support.
- 4.58 While the use of commercial factory-reared bumblebees has risen significantly over the last 20 years, and these insects are now used to pollinate open, unprotected crops in many countries, this has corresponded with a well-documented decline in wild pollinators since the 1960s (Breeze, Bailey et al. 2011). A reduction in natural pollination can lead to increased input costs for farmers, who will need to purchase commercially reared pollinators or employ commercial crop pollination services to maintain yields. This has implications for UK food security and affordability.

Theory of change



Can the benefit be quantified?

- 4.59 The benefit of pollination can be quantified using field experiments. This benefit cannot be easily generalised however, as it is likely to be affected by the specific pollinator and plant species involved, weather conditions and other factors such as disease. In contrast to the use of commercial pollinators, where the use of a set number of hives can be shown to increase yields, and thus profits, by specific amounts, the benefits of natural pollinators are harder to quantify.

How strong is the evidence?

- 4.60 Robust, quantified evidence of this benefit exists, although it is limited and specific to particular situations.

Evidence

- 4.61 For a comprehensive review of the evidence of the contribution of insect pollination, see Vanbergen, Heard et al. (2014), Status and value of pollinators and pollination services, Report to the Department for Environment, Food and Rural Affairs, March 2014.
- Breeze, Roberts et al. (2012) note evidence that insect pollination is important to maintaining the genetic diversity of plants and the spread of rare habitats. Insect pollination also contributes to wider biodiversity through the provision of insect pollinated plants which in turn provide food, shelter and other resources to animals.

- Honeybees are effective pollinators of most crops, however other species can be more effective with specific plants. Honeybees, for instance, are ineffective at pollinating tomatoes which require buzz-pollination (vibration of the flowers to release pollen) by bumblebees (Delaplane and Mayer 2000).
- On oilseed rape, solitary bees were found to be significantly more efficient at transferring pollen, with 71 per cent of visits to a flower resulting in pollen transfer to the stigma. By comparison, 35 per cent of bumblebee, and 34 per cent of honeybee visits resulted in pollen transfer. However, visits by honeybees tended to be more frequent than other bees when in the vicinity of hives or large areas of alternative foraging habitat (Woodcock, Edwards et al. 2013).
- Fruit set refers to the transition of flower to fruit, and is highly related to final crop yield. In cherry orchards in Germany, fruit set was found to be highly correlated with wild bee visitation (largely solitary bees), but not with honeybee visitation. This was thought to be due to the greater pollination efficiency of solitary bees. When the proportion of high diversity habitats for wild bees within 1 km of the orchard increased from 20 to 50 per cent, this led to an increase in fruit set by 150 per cent (Holzschuh, Dudenhoffer et al. 2012)¹¹².
- 848,946 hectares of crops in the UK are pollinated by insects, with an estimated market value of £1057.8 million. This represents 19.3 per cent of total UK farm gate value. The area of insect-pollinated crops has been growing steadily since 1984, particularly due to rises in the crop area of oilseed rape and field beans (Breeze, Bailey et al. 2011)¹¹³.
- Garratt, Breeze et al. (2014) conducted field experiments on apple orchards in Kent, UK, and found that insect pollination of both Gala and Cox apples resulted in greater yields than wind pollination alone. This was estimated to be worth an additional £11,900 in output per hectare for Cox and £14,800 per hectare for Gala apples, compared with wind pollination¹¹⁴.
- A study in Canada found that there was a strong relationship between seed set (determining crop yield) in oilseed rape fields, and the abundance of bees. Fields with moderate to high bee abundance had close to maximum yields. Bee abundance was found to increase with the presence of uncultivated land around the fields. Total crop profits were maximised when 30 per cent of the landscape was uncultivated (Morandin and Winston 2006)¹¹⁵.

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¹¹² This result is specific to cherry production. Other plants have flowers with different shapes and nectar availability, which influences the species of bee that will pollinate them effectively.

¹¹³ Farm gate value refers to the price of produce when it is sold from the farm. Output is valued at 2007 farm gate prices, and should be taken as an upper estimate because where the particular crop cultivar was not specified in production figures, it was assumed to be insect-pollinated. The value presented should not be interpreted as the value that might be lost if insect pollination ceased, as some production would still occur in the absence of insect pollination (due to wind pollination, for instance).

¹¹⁴ Output is valued at 2013 farm gate prices, and takes into account changes in both quantity and quality of apples produced. The value is likely to overstate pollination benefits, as increases in other inputs may also achieve an increase in yields.

¹¹⁵ This study did not include harvesting and transport costs in the analysis. These may be higher with greater yields and more uncultivated areas.

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4k Social cohesion

There is good evidence suggesting that the natural environment contributes to social cohesion. This appears to be particularly the case for well-maintained greenspaces.

Introduction

- 4.62 Social interactions can impact on people's health and overall wellbeing. Increased interaction between people may also lead to reduced crime and improved community resilience in the face of natural hazards. This section examines the evidence that the natural environment contributes to increased social interactions, and thereby to increased social cohesion.
- 4.63 Social cohesion describes the extent to which people within a community share similar values, and trust and support one another for the common good. A more socially cohesive community may experience a range of benefits, including health, safety, and improved collective resilience.
- 4.64 There is peer-reviewed evidence to suggest that social cohesion reduces crime, even when deprivation is controlled for (Hirschfield and Bowers 1997). A nationally representative US study of adults over 50 found a strong decrease in the risk of stroke for individuals living in more socially cohesive communities, even after controlling for demographic and psychological characteristics (Kim, Park et al. 2013).
- 4.65 In Australia, social cohesion was found to contribute to bushfire preparedness by giving people the support and resources to confront the bushfire risk, and by increasing the prominence of the issue through more people talking about it (Prior and Eriksen 2013)¹¹⁶. The same effect could be expected to occur for other natural hazards.

Theory of change



Can the benefit be quantified?

- 4.66 To a certain extent, yes. It is possible to quantify some social benefits, and to link this to exposure to the natural environment. However, a number of factors other than social interactions may also contribute to these outcomes. Additionally, the benefit of the social interaction is likely to be affected by the individuals involved, the content, quality and timing of the interaction, among other factors.
- 4.67 In principle, decrease in crime due to increased social cohesion can be monetised, and there are official values for the economic and social costs of crime. Current UK government values used are £1.8 million per homicide, £3,925 per burglary, and £1,750 per common assault (Home Office 2011).

How strong is the evidence?

- 4.68 The evidence that the natural environment contributes to social cohesion tends to be specific to particular case studies and locations, and very little UK evidence exists. However, the case studies seem highly suggestive of the potential benefits of the natural environment.

¹¹⁶ This study examined at-risk areas within two different Australian cities, Hobart and Sydney.

Evidence

- A study of the impact of greening vacant lots in Philadelphia, USA was conducted between 1999 and 2008. This found that greening was correlated with statistically significant reductions in gun crime and disorderly conduct. The authors suggest that criminal activity may be discouraged in areas which are seen to be well maintained (Branas, Cheney et al. 2011)¹¹⁷.
- Another study in Philadelphia found that an abundance of vegetation in general was associated with lower rates of assault, robbery and burglary, but not thefts (for example, pickpocketing/shoplifting, which may be more opportunistic). This effect held even after neighbourhood socio-economic status was considered (Wolfe and Mennis 2012)¹¹⁸.
- In Baltimore, USA, a similar study found that a 10 percent increase in tree cover was associated with a 12 percent decrease in crime. The crime reducing effect was far stronger for trees on public rather than private land. In a few small areas however, the effect was reversed, with increased tree cover being associated with increased crime. The authors suggest that this is due to different types of vegetation and management, with low and overgrown areas offering better crime opportunities. This may in turn cause people to avoid these areas and further encourage crime (Troy, Grove et al. 2012)¹¹⁹.
- In Los Angeles, the number of parks within half a mile was found to be a strong predictor of increased collective efficacy (a measure of social capital reflecting cohesion among neighbours and willingness to work for the common good) (Cohen, Inagami et al. 2008)¹²⁰.
- When studying two different urban parks in Nijmegen, the Netherlands, researchers observed that very few interactions between strangers actually occurred. Any interactions tended to be incidental, as individuals did not generally go to the park with the intention of meeting new people. Occasional 'small talk' did occur however, and was viewed positively by those involved. The authors suggest that these positive interactions may contribute towards building trust amongst different groups (Peters, Elands et al. 2010)¹²¹.
- Although park spaces can be unhelpfully dominated by one ethnic group leading to exclusion and inter-community tension, Gobster reports evidence from Chicago that suggests that parks can be active agents promoting inter-community relations in a way which is almost unique in urban life (Gobster 1998).

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¹¹⁸ Vegetation abundance was assessed using remote satellite imagery, and therefore was unable to consider factors such as how well the vegetation was maintained, or the visibility it allowed.

¹¹⁹ The authors note that their model may be affected by omitted variables, and therefore the 12 percent decrease in crime due to a 10 percent increase in vegetation may be an overestimate of the impact of vegetation.

¹²⁰ It is worth noting that the surveyed population was 58% Latino, and Latino ethnicity was found to be positively correlated with collective efficacy. The authors noted that parks in Los Angeles also tend to be well maintained.

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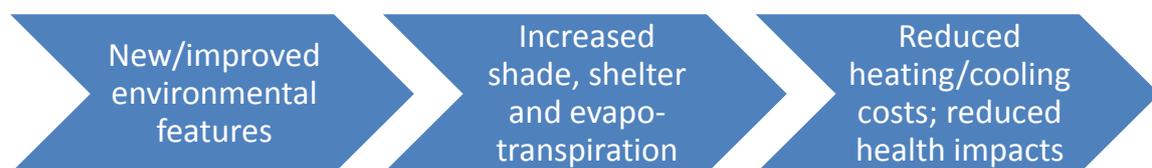
4I Temperature regulation

Evidence suggests that the natural environment makes a contribution to regulating the local climate and reducing temperature-related health and environmental impacts. Future climate change may make this benefit particularly significant.

Introduction

- 4.69 Temperature regulation of indoor and outdoor spaces is essential for human health and wellbeing. In the UK, an estimated 25,598 to 57,355 people die each year due to the cold, with disadvantaged groups in society being disproportionately affected. An estimated 1,142 people die each year due to heat-related illnesses (Hames and Vardoulakis 2012).
- 4.70 In the context of climate change, managing high temperatures is recognized as being a key concern, particularly for the elderly and other at-risk groups. Respiratory and cardiovascular diseases are made worse at higher temperatures, and this is partly due to interactions with air pollution, which also becomes worse at high temperatures. In England in summer 2006, there were an estimated 75 additional deaths per week for each degree of increased temperature (Armstrong et al. 2010, cited in Public Health England 2013).
- 4.71 The Urban Heat Island effect is the term used to describe the situation where urban centres become significantly warmer than the surrounding countryside, particularly at night. During heat waves in August 2003 and July 2006, night time temperatures in London were 6-9 degrees Celsius higher than those in rural locations south of London (Greater London Authority 2006). The Urban Heat Island effect is caused by the large area of heat absorbing surfaces, high energy use and reduced wind speed (Bolund and Hunhammar 1999) and leads to night-time temperature remaining high, increasing human health risk (Kovats 2008).
- 4.72 Higher temperatures affect not only human health, but plant and animal health as well. River water temperatures, for instance, are expected to rise by 2 to 4°C by 2050, and this can impact on the health of freshwater wildlife such as trout and salmon (Environment Agency 2011).
- 4.73 This section reviews the evidence that the natural environment can make an important contribution to regulating local temperatures, reducing the heating and cooling costs of indoor spaces, and reducing health impacts.

Theory of change



How strong is the evidence?

- 4.74 The evidence that the natural environment can positively impact on local climate is strong. As with all other benefits, context is important.

Evidence

- Green infrastructure makes a number of important contributions to local climate regulation. Watery areas can help to stabilise temperatures. A single large tree can transpire 450 litres of

water in a day which uses 1000 mega joules of heat energy, making urban trees an effective way to reduce urban temperature (Bolund and Hunhammar 1999).

- Urban parks are on average 1 degree cooler than built up areas during the day (Bowler, Buyung-Ali et al. 2010), but the type of park does matter – parks with hard paved surfaces and few trees or shrubs can be hotter (Chang, Li et al. 2007).
- Rising temperature in rural areas may threaten valuable biodiversity, such as salmon and trout. An experiment in the New Forest found that river shading from trees prevented water temperature from reaching the lethal limit for brown trout, and maintained water temperatures at around 5 degrees Celcius below those in rivers surrounded by open grassland (Broadmeadow, Jones et al. 2010).
- Modelling of the impact of trees on a two-storey office building in Scotland found that using trees as a shelterbelt could potentially reduce office heating energy use by 3.64 kilowatts per square metre of floor area (18.1 percent of total heating energy use) over the heating season from October to April (Liu and Harris 2008)¹²².
- Green roofs have been found to significantly reduce energy use in poorly insulated buildings, however offer little advantage in modern buildings designed to 2006 UK building regulations. Retrofitting is a realistic option for many older buildings, especially the 50 percent of total UK building stock constructed prior to 1965 (Castleton, Stovin et al. 2010).

Link with climate change

- The central estimate of average summer temperature increase in the South East of England is 1.6 degrees during the 2020s, 2.3 degrees in the 2040s, and 3.9 degrees in the 2080s (Department for Environment Food and Rural Affairs 2009)¹²³.
- Gill, Handley et al. (2007) found that a 10 percent increase in the amount of green cover in high-density residential areas in Manchester could prevent climate change induced temperature increases of up to 3.7 degrees Celsius by 2080. By contrast, a loss of 10 percent of green cover could result in surface temperature increases of up to 7 degrees Celsius by 2080. However the authors note that climate change-induced drought may reduce the effectiveness of vegetation in regulating temperature (Gill, Handley et al. 2007).
- A later study, also in Manchester, found that only a 3.7 percent increase in tree cover was realistically possible due to existing buildings, roads and other structures. However this could prevent increases in local temperatures of between 0.5 to 2.3 degrees Celcius by 2080, depending on the housing density (Hall, Handley et al. 2012)¹²⁴.
- The Climate Change Risk Assessment suggests that there could be between 580 to 5,900 additional heat-related deaths per year by 2050 in the UK. However, it is also expected that there could be a decline in the number of cold-related deaths, in the order of 3,850 to 23,900 per year (Hames and Vardoulakis 2012)¹²⁵.

¹²² The strength of this effect will be heavily influenced by the local temperature, wind speed and design of the shelterbelt, so is not directly transferable to other locations.

¹²³ This has been estimated by the Department for Environment, Food and Rural Affairs, based on comparison of world leading climate projection models. The figures presented are for the 'medium emissions' pathway. The warming is projected against a 1961-1990 baseline which means that some of it has already happened. These results are based on the central estimate which effectively assumes business as usual with regard to carbon emissions globally.

¹²⁴ As with Gill, Handley et al. (2007), climate change may reduce the effectiveness of vegetation in regulating temperature.

¹²⁵ The wide range of the estimates presented in this report is a reflection of the high level of uncertainty associated with the likely impacts of climate change on heat and cold-related deaths, and the extent to which people are able to adapt to the change in temperatures. As such it should be taken as indicative only.

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4m Water quality

The water quality benefits of the natural environment are reasonably well evidenced. Features such as woodlands and wetlands are particularly useful assets.

Introduction

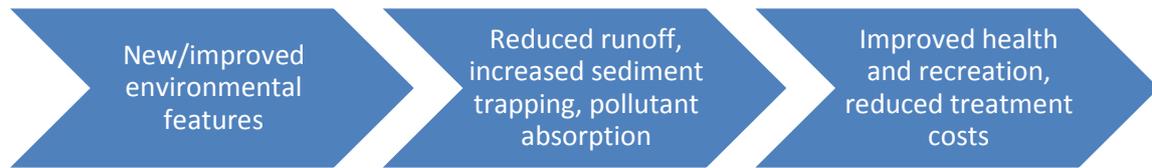
- 4.75 Clean water is critical to human health and the wider health of the natural environment. Water pollution can lead to communicable disease, infections, recreational impacts (especially for swimming, fishing and boating), and environmental impacts such as algal blooms and shellfish deaths, which cause subsequent revenue losses.
- 4.76 Between 2004-05 and 2008-09, water companies in England spent £189 million removing nitrates and £92 million removing pesticides from water supplies in order to meet drinking water standards (National Audit Office 2010). Since 1975, 146 groundwater sources used for public supply have been closed because of quality problems (United Kingdom Water Industry Research 2004, cited in Environment Agency 2007).
- 4.77 The Water Framework Directive is a European Union directive aimed at improving water quality in surface and groundwater bodies. 74 per cent of groundwater bodies, and 41 per cent per cent of natural surface water bodies in the UK were rated as having good chemical status in 2009 (European Commission 2012)¹²⁶. The average household was found to be willing to pay between £28.7 and £47.4 per year to achieve improvements in water quality under the Directive. This would be worth £587 to £969 million per year for England as a whole (NERA Economic Consulting and Accent 2007)¹²⁷.
- 4.78 When rainfall runs off the land, it carries pollutants into watercourses. In urban areas, polluted run-off is a major cause of diffuse pollution (pollution from multiple sources, which is collectively significant) (Hatt, Fletcher et al. 2008). Agricultural run-off is a key concern in rural areas, and the annual cost of agricultural diffuse pollution in the UK is estimated at £238 million (Jacobs UK Ltd 2008)¹²⁸.
- 4.79 This section contains evidence relating to the environment's contribution to purifying water.

¹²⁶ Good chemical status for surface waters is assessed based on acceptable concentrations of over 30 different pollutants found in water. For groundwater the target is no pollution at all.

¹²⁷ This study examined six different scenarios to achieve different levels of water quality improvement over time. It focused specifically on recreational, aesthetic and non-use benefits of improvements in water quality (people benefit from the knowledge that water quality has improved, even without seeing or directly benefiting from it). It did not consider commercial, agricultural or water supply benefits. Respondents were willing to pay £28.7 for the 'less stringent objectives' scenario (up to 80% of water bodies at high environmental quality by 2027) and £47.4 for the 'maximum benefits' scenario (100% high quality by 2015).

¹²⁸ It is important to be clear that environmental interventions could mitigate, not remove this cost. This figure is an addition of two parts. The first part is figures given by Jacobs for lower water quality in rivers: £62 million, Lakes:£27 million, Coastal bathing water: £11.10 million and estuaries:£3.01 million. The calculations are made on the basis of 'best available data' and reasonable assumptions and then value transfer from stated preference studies. The second part is estimates of the costs to the water industry of removing contaminants at £129 million annually for England and Wales (figure would be higher if Scotland and Northern Ireland were included). This estimate is based on OFWAT data and reasonable assumptions of the percentage of the pollution that should be attributed to agriculture. Given the data available the approach is conservative and appropriate, and the 'true' value is probably considerably higher. The source research for the values transferred has not been reviewed for this study.

Theory of change



How strong is the evidence?

4.80 The evidence that the natural environment contributes to improved water quality is good. This is particularly the case for woodlands, wetlands and other forms of vegetation. As with other benefits, context is important.

Evidence

Green roofs

- Green roofs are most effective at reducing runoff in the smaller more common storms, because they tend to become saturated during major storms. However, most of the diffuse pollution load entering the drains is from these more common storms, and so green roofs have an important role to play in reducing this (Mentens, Raes et al. 2006).

Wetlands

- There is good evidence that wetlands bordering rivers are an effective method of preventing diffuse pollution from entering surface water (Gambrell 1994; Gilliam 1994)¹²⁹.
- If the UK wetland stock was increased by 10 per cent, the additional water quality benefit is estimated to be worth £292 per hectare per year for inland wetlands, and £1793 per hectare per year for coastal wetlands (Morris and Camino 2011)¹³⁰.
- Research into ecological improvements to the river Elbe in Germany concluded that restoring 15,000 hectares of wetland would prevent nitrogen entering sensitive watercourses, providing a nitrogen retention benefit of between €6.9 and €20.5 million. When combined with estimates of the wildlife benefit from willingness-to-pay surveys this led to a benefit: cost ratio for the proposed intervention of between 2.5:1 and 4.2:1 (Meyerhoff and Dehnhardt 2007)¹³¹.

Woodlands

- There is strong evidence to support woodland creation, in appropriate locations, to achieve water management and water quality objectives. Woodlands contribute to tackling diffuse pollution through acting as a barrier and intercepting pollutants before they reach water courses. They help to trap and retain nutrients and sediment in polluted runoff. Targeted

¹²⁹ Gilliam 1994 is based on research conducted in the United States. The author quotes studies pointing to 90% effectiveness for nitrogen and 50% for Phosphorous. The author states that wetlands are, in his view, the most important method of influencing diffuse pollution entering surface water in many parts of the US.

¹³⁰ Note that these estimates were generated from data largely from other European countries, so may not be entirely accurate in the UK case, particularly given higher population densities and higher GDP per capita.

¹³¹ Willingness- to-pay means that researchers assessed what customers would be willing to pay for that biodiversity benefit in a hypothetical market. The methodology was appropriate and conservative. It is important to note that the bulk of the benefit in the benefit: cost ratios is from the willingness to pay for biodiversity, rather than the nitrogen retention. A sensitivity analysis shows the benefit: cost ratio to be always above 1:1 even if you halve the benefits or double the costs.

woodland buffers along mid-slope or down-slope field edges, or on infiltration basins, appear effective for slowing down runoff and intercepting sediment and nutrients, but the evidence base is limited (Nisbet, Silgram et al. 2011)¹³².

- Restored as well as mature buffer zones can be effective at reducing runoff (Vellidis, Lowrance et al. 2002). They are most effective when the runoff water must pass through the root zone, and least effective where rivers are recharged significantly from groundwater (Lowrance, Altier et al. 1997).
- Urban forests intercept rain water and reduce peak run off. This is most effective for smaller storms, but the effect is reduced for larger storms in which canopies become saturated. The effectiveness will vary according to local climate, tree species and time of year (broadleaved trees have no leaves during winter storms) (Xiao, McPherson et al. 1998).

Other

- Sand and soil based filters are an effective means of removing pollutants from urban runoff (Hatt, Fletcher et al. 2008)¹³³.
- Sustainable Urban Drainage Systems (SUDS), such as detention pools, are an effective method of removing pollutants from water and do not collect levels of pollutants which would require notified disposal (Heal, Hepburn et al. 2006; Napier, Jefferies et al. 2009).
- A monitored rain garden in the USA with a 0.49 hectare catchment was found to remove 973 cubic metres of stormwater runoff, 422 kg of total suspended solids, 783 kg of total dissolved solids, 2 kg of nitrogen and 1 kg of phosphorous per year (Flynn and Traver 2013)¹³⁴.
- Test plots in Manchester demonstrated that over a year, the addition of a street tree could reduce stormwater runoff by between 50 and 62 percent, compared with asphalt alone. Grass reduced stormwater runoff by 99 percent compared with asphalt (Armson, Stringer et al. 2013)¹³⁵.
- Any measures which increase rainwater infiltration are likely to reduce the number of occasions under which sewerage systems are overwhelmed by large volumes of water with resultant water quality issues (Environment Agency 2007).

Catchment-scale initiatives

- Many blanket bogs have been drained through the cutting of drainage 'grips'. This degrades the bog, increasing sediment runoff and reducing water quality. Reblocking these grips rewets the peat. The Sustainable Catchment Management Project (SCaMP) in Lancashire and the Peak District has blocked over 85km of grips and reduced grazing pressure on the bogs. Monitoring over five years has shown a statistically significant reduction in dissolved organic carbon (DOC) entering streams and causing discolouration. In the Goyt sub-catchment, DOC levels fell by 45 per cent (Anderson and Ross 2011).
- Catchment Sensitive Farming (CSF) is an approach to minimising agricultural pollution by a range of measures including establishing grass buffer strips near streams, changing planting times to work with seasonal rainfall patterns, and carefully controlling fertiliser application.

¹³² However the Forest and Water guidelines advise against using conifer woodland in nitrate vulnerable zones with less than 650mm annual rainfall – they evaporate so much water that they can concentrate the nitrogen.

¹³³ This study found leaching of phosphorous but suggested that it was probably native to the soil used, rather than a failure of the filter to capture pollution from the runoff.

¹³⁴ This particular rain garden was 405 square metres in area. It should be noted that the rate of pollutant removal would be expected to reduce over time due to sedimentation, if this was not removed.

¹³⁵ This test was conducted using three test plots, each 9 square metres. They contained either asphalt, asphalt and one street tree, or grass. The authors note that the year of test was drier than average.

Water quality monitoring demonstrated that the CSF programme in England reduced pollutant loads by up to 30 per cent in targeted sub-catchments (Environment Agency 2011)¹³⁶.

- In order to meet its drinking water requirements under the US Safe Drinking Water act, New York City opted to seek a waiver on the filtration requirement by investing in a comprehensive watershed protection programme in the Catskills-Delaware watershed, which supplied 90 per cent of the city's drinking water. New York spent \$1.5 billion over 10 years to avoid \$6 billion in capital costs and \$300 million annual operating costs (Postel and Thompson 2005)¹³⁷.
- In 2010 New York City published a plan to improve water quality in the New York Harbor System through reducing Combined Sewer Outflows following storms. The approach aims to use SUDS, including street trees, swales, bio-infiltration, and blue and green roofs, to capture the first inch of rainfall on 10 per cent of the impervious area in combined sewer watersheds over 20 years. It is estimated that this will reduce combined sewer overflows by 1.5 billion gallons a year. The report estimates that a mixture of SUDS and grey infrastructure will allow it to meet its objectives for \$5.3 billion as opposed to a purely grey strategy costing \$6.8 billion (New York City 2010)¹³⁸.
- Similar problems are faced in London; every year 12 million tonnes of untreated sewage enter the Thames because of storm overflows, with discharges 50 – 60 times a year. In August 2004, heavy rainfall led to pollution events that killed tens of thousands of fish, left sewage debris and significantly increased E. Coli levels and so enteric disease (Environment Agency 2007)¹³⁹.

Link with climate change

- All regions of the UK have experienced an increase in the amount of winter rain that falls in heavy downpours. For all regions an increase in winter rainfall and a decrease in summer rainfall is projected by the 2040s, increasing the risk of polluted run-off (Department for Environment Food and Rural Affairs 2009). This makes climate change mitigation a key action to prevent diffuse pollution becoming worse. A significant amount of climate change is already 'locked in', so interventions using the natural environment to absorb pollution will be increasingly important in coming decades.
- Climate change is likely to lead to increased use of pesticides (Boxall, Hardy et al. 2010). Nutrient inputs may decrease, however increased temperature, reduced summer rainfall, and increased winter rainfall and the increased use of irrigation may increase transmission leading to increased water pollution (Boxall, Hardy et al. 2010). Climate change may also reduce soil organic content (Jenkinson, Adams et al. 1991), which would exacerbate problems of polluted runoff. Without mitigating action this would increase human exposure to agricultural contaminants (Boxall, Hardy et al. 2010).

¹³⁶ Whilst changes in nutrient loads were variable across sub-catchments, pesticide loads decreased consistently across all the catchments studied – total annual pesticide loads fell by 26 per cent.

¹³⁷ Notice that just the annual operating costs of the filtration plant would cost more than the ecosystems approach, without the capital expenditure. The effectiveness of this programme is based on US Environmental Protection Agency continuing to grant the waiver on the filtration requirement, which may get more difficult as development in the Catskills-Delaware increases and stricter federal drinking water standards are introduced. The scheme has led to important economic, environmental and recreational benefits within the watershed, as well as the benefits to New York. It is important to note how different the context is from the UK though; more than three-quarters of the watershed is forested.

¹³⁸ Note that these are pre-project estimated costs, rather than project evaluation costs. Blue roofs are roofs that can hold water and release it after the storm surge. Other expected benefits of using SUDS are a reduced urban heat island effect, energy conservation, carbon sequestration and improved air-quality. Higher property values are also cited, but see the section on property prices to put this in economic context.

¹³⁹ Note that the natural environment may be able to help, but grey infrastructure is realistically still the most viable method to solve issues of this scale.

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5 Glossary

Climate change adaptation – The process of adapting to current and expected impacts of climate change.

Climate change mitigation – The process of limiting the negative impacts of climate change through reducing emissions of greenhouse gases.

Confounding – Research often seeks to ascertain the relationships between two variables, but this process can lead to misleading results if there is a missing variable that affects the results. This is known as the confounder or confounding variable. For example it is possible to show that IQ results are closely related to shoe size if you fail to consider age - children have smaller feet and score lower on IQ tests.

Controls, controlled – When there is a potential confounding variable (see above) research attempts to ascertain the actual relationship between two variables by ‘controlling’ for the confounding variable. In the example given above shoe size would only be compared with IQ results within the same age group, thus controlling for this confounder.

Ecosystem services – Ecosystem services are the functions of the natural environment, that directly or indirectly provide benefits for people.

Impact (economic) – Economic impact is the extent to which a proposed intervention increases the size of the traded economy, commonly measured using GDP or GVA. Careful consideration of whether the new economy activity is new or displaced is important. See Introduction to Economic Evidence for further explanation.

Theory of change – A theory of change (also known as a logic chain or causal model) demonstrates how an activity leads to a particular outcome (for instance, how planting a tree leads to human health improvements).

Value (economic) – Economic value refers to the full effect of a change on social welfare, regardless of whether this effect is felt through the market. So an increase in air pollution where you live constitutes a loss of economic value, even if this doesn’t affect the value of your house.

Value transfer – The process of inferring the size of an economic benefit or cost at the site under consideration from previous research at another site, paying careful attention to contextual changes. Sometimes called benefits transfer when only benefits are under consideration.

Willingness-to-pay – This is an economic technique used to value goods that are not traded in markets. Surveys are conducted in which people are asked how much they would be willing to pay to obtain the good.

Appendix 1 Methodology

Literature reviewed

Literature which is relevant to the evidence base for the economic benefits of the natural environment was reviewed for this evidence package. Much of this was economic literature, but natural and social science literature is also included.

Methodology – economic literature

Peer reviewed literature was preferred where available. All economic research articles were fully reviewed, and the footnotes next to the reference provide transparency as to the extent of review. Literature was accepted or rejected based on whether it met Treasury Green Book standards (HM Treasury 2003) for economic evidence. However, be warned, some of the economic articles have been deconstructed and only the evidence which is defensible and useful has been included. Therefore quoting from a study does not mean that all of the study is defensible and useful.

Methodology – natural and social science literature

For natural and social science literature selection was based on the research quality hierarchy, where peer reviewed academic journals are given the greatest weight, followed by government research and then evidence from third-party organisations. The text highlights what particular pieces of research have controlled for, to help you assess the strength of the evidence¹⁴⁰. Again the footnotes provide transparency as to the depth of review. This second evidence package has greatly benefited from peer reviews provided by the following Natural England staff:

- Blane, Edward
- Burn, Alistair
- Butterworth, Tom
- Cathcart, Rob
- Collins, Tim
- Green, Mike
- Lusardi, Jane
- Money, Russ
- Morecroft, Mike
- Stone, Dave
- Waters, Ruth
- Wyatt, Gordon

¹⁴⁰ Sometimes in research the relationship we are looking for between two variables is obscured by a third relationship we call the confounding variable. For example it is possible to draw a graph which relates shoe size to IQ provided children are included! We can avoid this confusion though by 'controlling' for age which means that we only compare shoe size and IQ for people of the same age. Once this is done the apparent relationship disappears.

Selecting evidence

Selection of evidence to make the case requires judgment, and cannot easily be reduced to an automatic hierarchy. For example a peer-reviewed article from Canada may be less powerful than a government document from the UK, if the issue under concern is expected to vary contextually. Where international evidence refers to human characteristics which are thought to be shared globally¹⁴¹, these have been included as part of the evidence. The review also incorporates international evidence which refers to biological properties of the natural environment and is not expected to vary significantly. However, where the research refers to societal and social factors, which can be expected to vary significantly from place to place, they are not included as a core part of the evidence for the logic chain, but may be referred to as interesting. With regard to examples and figures, English based case studies are preferred, but where this is not possible, international ones have also been used.

Research has been included on the basis that it is of good quality. There is therefore a great deal of literature which was reviewed for this evidence package which is not referred to in this document. Clearly, with such a large subject, time limitations have also meant that not all the relevant literature has been reviewed.

Relationship with biodiversity, landscape and culture

This package is focused on environmental services which provide benefits of significant policy interest. For this reason landscape and biodiversity feature primarily as inputs to the services, rather than in their own right¹⁴². This means that the package does not engage with the intrinsic value of nature and biodiversity. In principle the package could include research into 'non-use values' – (value placed on the existence of species and landscapes irrespective of their usefulness to those interviewed), but this is beyond the scope of this version (2.0).

Furthermore benefits have only been included if economic quantification is at least under discussion. For example the contribution of green infrastructure to social cohesion is difficult to quantify but under discussion, whereas the spiritual benefits of access to nature are not¹⁴³. Equally, personal and cultural attachments to particular landscapes may produce important wellbeing benefits, but there is not currently a significant discussion about valuing this economically.

It is important to be clear that in an English context the term 'natural' environment requires significant qualification. Some of our most valued landscapes are the product of hundreds of years of modification and cultivation. Here, 'natural' environments have been, and continue to be, heavily shaped by people.

¹⁴¹ This means that the literature proposes that this human characteristic is cross-cultural which implies a shared root in human evolution.

¹⁴² The importance of biodiversity for providing ecosystem services is complex. Some species provide particularly services directly (for example, pollination) in which case it is sensible risk management to retain a range of species which can deliver the service. Other services are provided by whole ecosystems, nevertheless there may be a strong link between a species and ecosystem service – for example many of the properties of blanket bog are dependent on Sphagnum moss. Some ecosystem processes such as productivity or decomposition increase as diversity increases: Potts, S. G., J. C. Biesmeijer, et al. (2010). "Global pollinator declines: trends, impacts and drivers." *Trends in Ecology & Evolution* **25**(6): 345-353.

¹⁴³ Which should not be taken to mean that the spiritual benefits of access to nature are not important, or that it is wise for decision making to ignore that which is difficult to quantify or subject to uncertainty. The opposite is the case, and work to improve decision aiding frameworks is required. However, the focus of this evidence package is on quantified evidence which can feed in to the currently dominant decision aiding frameworks, particularly economic impact, cost : benefit analysis and value for money assessments.

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