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Updating the Woodland Valuation Tool:

A review of recent literature on the non-market values of woodland

Report to the Forestry Commission
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Contents

1. Background and focus of the report

Woodlands and forests constitute arguably the most diverse environments on earth; diverse not only in terms of the plethora of characteristics and habitats they embrace, but also in terms of the variety of benefits which they offer to people. For centuries forests have been valued as a source of timber for the fibre, construction and fuel industries. However, recent decades have seen a growing appreciation of the value of woodlands, as a source of a much wider array of benefits. Forests are important assets for the sequestration and storage of carbon and, therefore, they play a role in climate change mitigation. Woodlands also contribute to air filtration more generally, removing airborne pollutants and reducing related health risks. Similarly, woodlands help to improve the water environment, providing water purification (enhancing water quality and reducing the costs of treatment) and water regulation (including the reduction of flood risks). Forests also offer highly valued landscapes and views and superb recreational opportunities, in turn generating physical and mental health benefits to visitors. Woodland environments also provide habitat for many of the country's most treasured flora and fauna, thereby supporting biological diversity, which in turn both enhances the quality of recreational visits and generates benefits for woodland users and non-users, by ensuring the continued existence of species.

While this diversity of benefits is widely recognised, incorporating these values into decisions regarding the management and extension of woodland remains a challenge. While the value of some forest products, such as timber, is readily reflected within market prices, this is the exception rather than the rule. Most of the goods and services provided by woodlands have characteristics of public goods. To a large extent, they are not traded through markets and remain therefore unpriced. Benefits such as the removal of pollutants from air and water, flood control, or the provision of biodiversity and habitats are all delivered without the intervention of markets. While these non-market values have been shown to be very substantial, they are not reflected in market prices and, therefore, can easily be omitted from decision-making.

The provision of public goods, and in particular their funding from the public purse, has become of central importance to the policy process in recent years. Longstanding recognition of the principle of "public money for public goods" (H.M. Treasury, 2018)[1] combined with the regulatory opportunities afforded by Brexit, have resulted in this principle being incorporated into the UK Government's 25 Year Environment Plan (H.M. Government, 2018)[2] and its preparations for a forthcoming Agriculture

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[1] H.M. Treasury (2018) The Green Book: Central Government Guidance on Appraisal and Evaluation, H.M. Treasury, London, available at www.gov.uk/government/publications or directly at: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

[2] H.M. Government (2018) A Green Future: Our 25 Year Plan to Improve the Environment, H.M. Government, London, available at www.gov.uk/government/publications and directly at:

Bill (Defra, 2018)[3]. While much of the immediate focus of these changes is upon agriculture, the consequences of these changes are likely to have very significant impact upon woodland in the UK. Shifting agricultural support and towards public goods may provide opportunities for farm woodlands, and raise the profile of the woodlands as a major supplier of public goods.

As the emphasis upon public goods has risen up the policy agenda, so has interest in the measurement and valuation of those goods. The past five decades have seen the development of a range of methods for estimating the economic value of non-market benefits. These developments have been accompanied by a rapid growth in their empirical application across a range of non-market goods and services. One of the most common foci for such studies has been the valuation of woodland benefits and a substantial, if diverse, literature has accumulated around the world. The UK Forestry Commission has long played a substantial part in the development of this work and in 2015 commissioned a team of researchers to gather together and systematically review relevant studies of the economic value of non-market benefits of woodland (Binner et al. 2015)[4]. To enhance the use of this review within practical decision-making, the researchers brought the reviewed literature together as a 'Woodland Valuation Tool', a spreadsheet-based decision support tool, allowing decision makers to interrogate an assembled database of studies across a substantial range of dimensions designed to inform forest management across the UK.

The present report presents an update to that previous work. Specifically, it provides a review of the new literature concerning the economic value of non-market woodland benefits arising since the publication of the 2015 Binner et al. report. This e most recent review of literature has also been integrated into the Binner et al. (2017) report, to produce a more substantive document discussing the most current literature available (Binner et al., 2018). Additionally, an update of the Woodland Valuation Tool is provided, merging these new studies with those reviewed in the previous report. In combination, this is intended to provide up to date decision support for those involved in the management and extension of woodland, who wish to ensure that decisions are based upon an appraisal of the full gamut of benefits, which forests provide.

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https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

[3] Defra (2018) Health and Harmony: the future for food, farming and the environment in a Green Brexit, Cm 9577, Defra, London, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/684003/future-farming-environment-consult-document.pdf

[4] Binner, A., Smith, G., Bateman, I., Day, B., Agarwala, M., Harwood, A. (2015) *Woodland Valuation Tool*, University of Exeter and CSERGE. A revised version of this report is available as: Binner, A., et al., (2017) Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales, *Forestry Commission Research Report*, Forestry Commission, Edinburgh. Available at: www.forestry.gov.uk/publications

2. Structure of the report

The current report reviews and discusses the most recent literature focusing on the environmental goods and services provided by forests and their economic value to people. To maximize the size of the evidence base, the report covers both UK and international literature. To illustrate the links between forest natural assets and biophysical processes (which directly impact upon the provision of environmental goods and services) and the benefits that environmental goods and services provide in terms of people's welfare, the review relies on the wider Natural Capital framework (detailed in the following section) as the methodological and conceptual basis.

Within this framework, the bulk of the report focuses on our review of the recent literature. This opens with an overview of the valuation and biophysical evidence around the benefits provided by forests. Here, various summary statistics regarding the main characteristics of the reviewed valuation and biophysical studies are presented and discussed. Detailed reviews of the biophysical and valuation evidence are then presented, for each of the main environmental and social benefits provided by woodlands.

The report focuses on a wide range of benefits provided by trees and woodland, including: recreation, air quality, climate, physical and mental health, biodiversity, water quality and water quantity (including flood alleviation). Each benefit category is examined in a separate section. In addition, a 'cross-cutting' discussion is also presented on the role of plant (tree) health in the provision of woodland-related benefits. Similarly, given that the majority of the population lives in towns and cities, a specific section is presented on 'Urban trees' and the importance of woodlands in urban settings.

Each of the review sections follows a common format. After a statement of the number of new studies available, a detailed review prefaces a summary of the valuation evidence (presented in full detail within the Woodland Valuation Tool). The summary offers some examples of reviewed valuation studies and it is presented in the form of a table, based on the following template:

Example:

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Forest Enterprise England (2016)	GBP 1.66–GBP 2.75	Per visit recreational value for a visit to UK forests	Existing valuation literature	GBP (2002)	Visitors

In the first column, the table reports the reference to the study under consideration (e.g. Forest Enterprise England [2016]). In the second column, information is given on an example of willingness to pay value reported by the study. This information is often reported as a marginal value. Valuation information is expressed in different currencies, depending on the study and it is not reported in current prices. The currency and the year when the valuation study was carried out (i.e. the year of reference for the reported willingness to pay value) are shown in the fifth column (e.g. GBP in 2002). Information on the environmental change, to which the willingness to pay value refers, is reported in the third column (e.g. per visit recreational value for a visit to UK forests). The last column on the right focuses on the sample of beneficiaries considered in the valuation work (e.g. visitors).

In each review section, the adequacy of the literature and any identified research gaps are first considered with respect to the material assessed in the present review period, before being reassessed alongside that reviewed in the previous (Binner et al.) report. The knowledge base is evaluated by considering the quantity and quality of literature focusing on the biophysical pathways of impact and the economic values. In addition, the assessment also considers the availability of decision support tools and the degree to which the evidence specifically focuses on urban settings, which is of particular interest, given that most of people live in towns and cities. A colour-coded (‘traffic light’) approach is considered in the assessment of the knowledge base; ‘green’ signals the availability of strong evidence, with few gaps; ‘orange’ indicates that some evidence is available, with significant gaps; and ‘red’ refers to the existence of major gaps in the literature.

This colour-coded assessment is based on a qualitative judgement of the available evidence and it draws upon the expertise of the authors. The colour-coded assessment that we present in each section is useful to indicate the available evidence and research gaps on forest benefits, at international and UK level. In particular, the colour-code relative to the valuation evidence is not an assessment of the applicability of international valuation studies to the UK context. Rather, it is an assessment of research gaps in the literature, assuming that the reviewed international studies could potentially be applicable to a UK setting, after the introduction of extensive adjustments. Adjustments are required because economic values are context-specific and sensitive to the preferences and socio-demographic characteristics (e.g. income) of the beneficiaries, as well as to the availability of substitutes and complements. Several approaches are available to adjust for differences in values across case studies. For more information on these, we re-direct the interested reader to Annex 1 in this report.

The last part of the present report draws the overall conclusions and presents an assessment of the research gaps and priorities for future research (the latter highlighting the potential usefulness of a meta-analysis of the assembled literature). Three Annexes are then presented. The first of these provides a plain English overview of the principal techniques used to estimate economic values for non-market woodland goods and services. Annex 2 provides a detailed bibliography of both the biophysical and economic valuation literature considered in the present review and incorporated into the updated Woodland Valuation Tool. Finally, Annex 3 provides definitions for the non-market good and services and production functions considered in the review.

Alongside this report, we also provide the updated Woodland Valuation Tool. We provide both a searchable and editable 'unlocked' version and a 'locked' version, which can be searched but not altered. While the former can readily be updated by the Forestry Commission, the latter is suitable for widespread dissemination and practical use for decision making support.

3. The Natural Capital Approach and the valuation of non-market goods and services

The need to bring non-market benefits and costs into economic analyses, complemented by a realisation of the interdisciplinary nature of the challenge of delivering environmental sustainable resilience, has led to growing interest in a unifying conceptual framework for economic and environmental decision making. In recent years, this has coalesced around the concept of a 'Natural Capital' approach to decision making. Figure 1 provides an illustrated overview of this framework.

Figure 1 The natural capital approach: Bringing the natural environment into economic decision making.

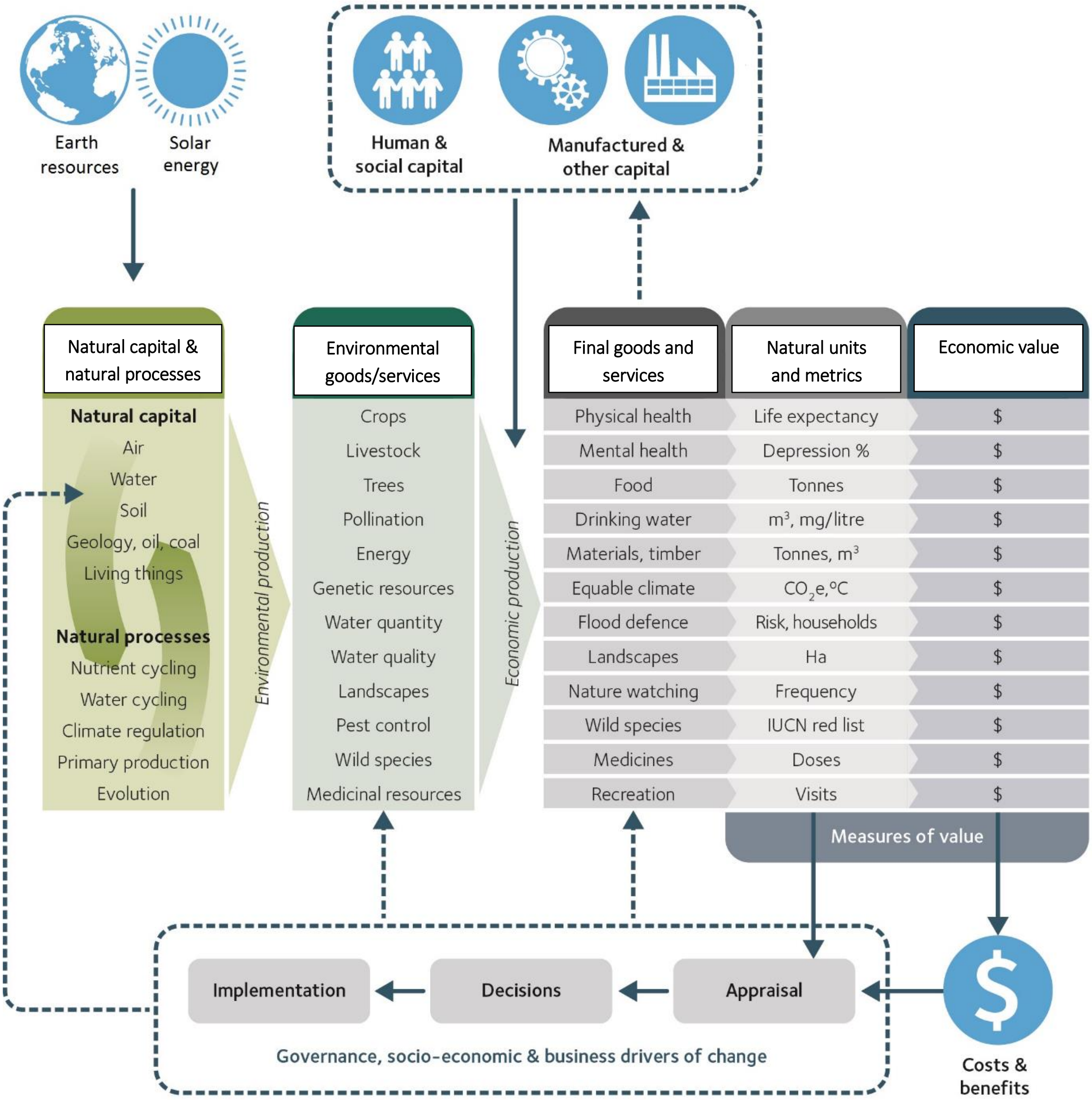

Figure 1

At the top left of the figure, we see the ultimate energy and material inputs to the natural environment (the sun and earth) generating nature's capital assets, such as air, water, fertile soils, etc. upon which all human wellbeing is dependent. On the left hand side of the figure, we also see the natural processes - or biophysical processes, as we will refer to in this report - such as climate regulation, water and nutrient cycling, which maintain the natural capital assets. For example, consider soil, water and seeds, which contribute, through a complex water and nutrient cycle, to the growth of forests.

Moving across the figure to the right, we see that the combination of natural capital and processes produces a wide array of environmental goods and services[5], such as trees, wild species or crops. While some of these environmental goods and services are of value in their own right (e.g. the wonder inspired by wild species), the major value to humans is derived through their combination with the services of a range of human, social, manufactured and other capital within economic production. This yields a plethora of highly valuable goods and services which are crucial to human wellbeing, including stable supplies of food and water, materials and defence from hazards, etc. These are referred to as final goods and services in Figure 1. There are different ways through which a given good or service can generate benefits to people. We will refer to these as production functions in this report. For instance, trees are an environmental good and they are used to produce timber, using labour input from a forester. Timber is then crafted by a carpenter, using tools to produce furniture, which is sold on to consumers, who gain welfare from its use. However, there are other possible channels through which individuals may benefit from trees. Trees can enhance the views that people enjoy from their homes and the vicinity to forested areas contributes to improve residents' quality of life.

As shown in the penultimate column of Figure 1, those final goods and services, which are of relevance for wellbeing, can be assessed through a wide variety of good-specific natural units and metrics. For example, the amount of carbon sequestered by forests can be measured by considering the tonnes of CO_2 emissions that are taken from the atmosphere. While these natural units are important measures of output and provision, the comparability of these metrics is challenging. This has therefore led to the development of a wide variety of methods for translating these metrics into common units, conveying information about the impacts on human wellbeing generated by changes in these goods and services. While in principle, these impacts could be assessed using any transferable, comparable unit of wellbeing, by far the most common approach is to use economic values (expressed in monetary terms) as the unit of account.

Economic values are already widely used in environmental assessments and indeed failure to use monetary units seems likely to result in the under-valuation of environmental benefits, which are often treated as if they are free and, consequently, over-used and under-provided for. Annex 1 provides a brief review of methods for the economic valuation of environmental changes. The use of economic values readily allows government and business decision makers to understand the costs and benefits of alternative investments. For government, this allows common unit comparison of potential

[5] When we talk about environmental goods and services we actually refer to *final* environmental goods and services. The literature differentiates between *intermediate* and *final* environmental goods and services: the first relate to environmentally produced goods and services that act as inputs to some other environmental process, while the second ones indicate environmentally produced goods and services that enter household or firm production functions without further biophysical translation. The latter are the environmental goods and services that people value and the ones we will be focusing on in this report.

environmental investments with spending in other areas such as transport, defence, etc. For businesses, this approach shows how changes in their own investments affect social values, the trade-offs between the two and the potential for altering this balance in ways that could generate social benefits, enhance the company's own status and improve its profitability (Bateman et al. 2015)[6].

The lower part of Figure 1 shows the use of this information in decision and policy making. Economic estimates of costs and benefits are assessed (sometimes alongside metrics of particular interest) and appraisals of the net value of a given action are made. Best practice requires that alternative uses of the resources concerned should also be considered, to assess the opportunity cost of going ahead with any particular investment. Appraisals can also capture the distribution of costs and benefits across society - an issue which is often of particular interest to decision makers. Other key appraisal issues include: the challenges and approaches of implementation (what are the consequences of implementing a decision in different ways, for example through regulation or various forms of incentives) and assessments of the responses to change that people are likely to adopt (i.e. avoiding the error of thinking that people's behaviour will not alter as circumstances change). These appraisals provide a major input to the decision making process, which should also consider any wider issues (including information gaps in the appraisal process, the degree of risk and uncertainty involved etc.). Once a decision is made, it is then passed for implementation, for example, by introducing the regulations, incentives and behavioural response measures identified at the appraisal stage. Depending on the decision taken, its implementation can affect the goods and wellbeing generated by the economy, as well as the natural capital and environmental goods and services upon which it draws, thereby influencing future policy and business decisions so that the overall system is dynamic and feeds-back into itself.

4. Methodology: From valuation research to the Woodland Valuation Tool

For the purposes of the project, the research team at the University of Exeter conducted a literature search through Google Scholar. Keywords such as "valuation", "woodlands" and "forests" were used and the literature search was restricted to the time window of interest (2015 to present). In this search, both economic valuation studies, as well as studies with a natural science orientation, were considered. As explained in the previous sub-section, this is because economic valuation relates biophysical changes to impacts on human welfare, measured in monetary terms. Thus, economic analysis is only ever as good as the natural science on which it is based. In total, the new sample included 45 valuation studies and 28 biophysical studies, mostly academic literature and only in part

[6] Bateman, I.J., Coombes, E., Fitzherbert, E., Badura, T., Binner, A., Carbone, C., Fisher, B., Naidoo, R., Watkinson, A.R. (2015) Conserving tropical biodiversity via market forces and spatial targeting, Proceedings of the National Academy of Sciences (PNAS), 112 (24) 7408–7413, doi: 10.1073/pnas.1406484112

grey literature, to provide more robust evidence. A complete list of the references used in this project is reported in Annex 2.

Information on each study was systematically inputted to the Woodland Valuation Tool Excel spreadsheet. For a detailed description of the Woodland Valuation Tool spreadsheet and its components and sections, the interested reader should refer to Binner et al. (2015). Here, we only present a summary description of the main functionalities and structure of the Tool, which will be useful for the purpose of better understanding the following sections of this report.

The Woodland Valuation Tool synthetises information about the valuation and biophysical evidence linked to the provision of goods and services in forest ecosystems. It presents separate tabs for the valuation and biophysical studies. The valuation literature is classified by final environmental good or service and production function, following the categories considered in the US EPA classification, as presented in Landers and Nahlik (2013)[7] (summarized in Table 1). A short description of each final environmental good and service and production function considered in the review is presented in Annex 3. A more detailed description of the specific goods and services and production functions examined in each of the reviewed studies will also be provided in the section of this report labelled "6. Detailed review of woodland biophysical and valuation evidence by benefit area".

[7] Landers, D.H. and Nahlik, A.M. (2013). *Final ecosystem goods and services classification system* (FEGS-CS). United States Environmental Protection Agency, Washington DC.

Table 1. Final environmental goods and services and production functions considered in the Woodland Valuation Tool (taken from Binner et al. 2015)

Final environmental goods and services	Production functions																	
	Timber products	Food (agriculture and subsistence)	Industrial production	Pharmaceuticals	Hydropower	Drinking water	Transportation	Flood alleviation	Urban heat islands	Carbon sequestration	Housing	Physical health	Mental health	Recreation	Artistic	Learning	Spiritual and cultural	Non-use value
Water quality		✘	✘		✘	✘	✘				✘	✘		✘	✘	✘	✘	✘
Water quantity		✘	✘		✘	✘	✘	✘			✘			✘	✘	✘	✘	✘
Air quality			✘															
Climate		✘	✘					✘	✘	✘	✘	✘		✘				
Flora, fauna and fungi	✘	✘		✘							✘	✘	✘	✘		✘	✘	✘
Environmental amenity											✘	✘	✘	✘	✘	✘	✘	✘
Sound and scent											✘	✘	✘	✘	✘	✘	✘	✘
Views			✘								✘		✘	✘	✘	✘	✘	✘
Soil		✘	✘								✘			✘		✘	✘	✘
Timber and fibre	✘	✘	✘	✘							✘			✘	✘	✘	✘	

Table 1

In addition, the Woodland Valuation Tool classifies studies according to different beneficiaries, including the general public, recreational users, government and institutions, farmers, industry/producers, etc. Further information collected on each valuation study includes:

- the year of the publication of the study
- a more detailed description of the final environmental good and service considered
- the country, region and geographical scale where the valuation evidence was collected
- the valuation method employed
- the sample of individuals used for the valuation exercise
- information on the environmental change measured and the economic value associated to it
- Information about the unit of measurement for the valuation, value currency and year when the valuation was carried out.
- payment vehicle employed in the valuation exercise

- additional notes regarding variables of interest controlled for in the valuation process, including variables defining the good and service or the beneficiaries - both potentially affecting the perception of forest benefits
- any additional note of interest to better understand the study and results

Regarding the biophysical literature, information was classified by final environmental good and service of reference, following the classification outlined in Table 1.

5. Overview of the valuation and biophysical evidence around the benefits provided by forests

A summary of the main characteristics of the valuation studies reviewed in this report is presented in Table 2, while for the evidence collected on the biophysical literature, a summary with descriptive statistics is provided in Table 3.

The majority of the reviewed valuation studies focus on a rather narrow range of final environmental goods and services, related to flora and fauna or the environment in general. Examples include: tree species, aspects related to the naturalness of forests or the passive protection of forest biodiversity, as well as forest structural characteristics – such as forest stands, height, age or the presence of deadwood. A significant amount of studies also considered the role of forests in regulating the climate and sequestering carbon emissions from the air. In proportion, much less attention was paid to water quantity and especially water quality in forest ecosystems. Similar conclusions can also be drawn based on the reviewed biophysical literature. Forest scientists largely focused on biodiversity, which is critical to support woodlands' health and resilience, carbon sequestration and the provision of all other forest-dependent environmental goods and services. As for the case of the reviewed valuation studies, also the biophysical studies place less attention to soil functionality, water quality and quantity and views.

In terms of the channel through which individuals enjoy the goods and services supplied by forests (production function), a substantial number of reviewed valuation studies focused on the recreational enjoyment of woodlands. In addition to recreation, particular emphasis is also placed upon the non-use benefits that individuals obtain from forests, which include the appreciation of forest conservation for its own sake (even if the person is not intending to visit the woodland in the future) or for the enjoyment of others or future generations. Non-use benefits include, for example, the wellbeing that people derive from knowing that forests are in good condition and play an important role in carbon sequestration or habitat creation for wildlife. In addition, our review showed that individuals obtain benefits through the consumption of timber and non-timber products supplied by forests, including food products. Forests also provide important benefits in terms of physical health opportunities, flood alleviation or higher residential quality of life. If people's place of residence is located within close proximity to a forest, residents can additionally enjoy beautiful views, better air quality or more peace and tranquillity. To a lesser extent, the reviewed studies focused on the benefits that individuals receive from forests in terms of better quality of drinking water for people. In several cases, it was not straightforward to associate one given final environmental good and service to one unique production function. Where multiple production functions could be linked to the good and service under consideration, our informed judgement was applied to classify the study into one category or the other. Where applicable, in the Woodland Valuation Tool, we reported information on the multiple production functions potentially involved.[8]

Regarding the beneficiaries, in most cases the studies focused upon the preferences of the general public. Other lesser foci include the benefits that specific groups (e.g. visitors, decision-makers or the industry sector, as well as urban residents) obtain from woodlands.

Concerning the methodology, most of the reviewed studies relied on a rather small set of valuation approaches. To identify the value of different forest goods and services for people, over the last couple of years, researchers have particularly relied upon the choice experiment technique or the contingent valuation method. This is in line with the fact that most of the reviewed studies have focused on measuring the benefits of environmental changes that have not yet occurred (e.g. recreational benefits of future, hypothetical forest changes) and on the assessment of values that do not arise from the use of the good (e.g. benefits that people obtain from knowing that a forest is preserved in good condition, even if they will not have the chance to visit it). In all these cases, alternative methods, based on observed behaviour, are not available and stated preference methods (including choice experiments and contingent valuation techniques) are often the only options available. The reviewed studies, in some other cases, also relied on available valuation tools (e.g. i-Tree). Some studies have additionally considered market prices, surrogate markets (travel cost or hedonic price method), avoided costs, as well as reviews, secondary valuation literature or meta-analyses. Few of the reviewed valuation studies have employed other approaches, including replacement cost methods, as well as bio-economic models.

When reporting monetized willingness-to-pay (WTP) values in the Woodland Valuation Tool, the team also recorded information on the nature and magnitude of the environmental change which the value refers to. This potentially allows us to better explain the huge variability in the values reported across the reviewed studies. Indeed, it is likely that the consideration of a broad range of different possible environmental changes, sometimes involving aggregate and multiple improvements and sometimes only marginal variations, can lead to very different values being reported for similar goods. We believe that adding information on the specific environmental changes associated with the specific values

[8] This information is reported in the 'Notes' column of Master Tab 2 of the Woodland Valuation Tool Excel spreadsheet

reported, can be helpful to work out the marginal value, which should offer a more detailed knowledge base to better guide decision-makers in the forestry sector.[9]

Regarding the geographical remit, approximately one third of the reviewed studies took into consideration case studies in the UK, while the rest of studies focused on case studies in other countries in Europe and to a lesser extent, in other parts of the world, including North America, Africa or Asia. Given the short time-frame considered for the review (2015 to present), extending the evidence base to UK and non-UK studies was necessary to collect a sufficient number of observations. Later in the report, we will discuss the advantages and disadvantages of including international valuation studies in the review. The geographical scale considered by the reviewed studies is frequently 'national,' or 'regional', with some examples of multi-country studies. Only a smaller number of studies focused on local settings, as well as on cities and urban areas.

Table 2. Summary statistics of the main characteristics of the reviewed studies on forest valuation [a]

	No. Observations = 78 *No. Studies = 45*
Final ecosystem goods and services	
Flora & Fauna	36.0%
Environment (general)	21.3%
Air quality	21.3%
Water Quantity	6.7%
Views	5.3%
Timber and fibre	5.3%
Soil	2.7%
Water Quality	1.3%
Production function categories	
Recreation	25.3%
Non-use value production	16.9%
Carbon	16.9%
Food production (agriculture, subsistence, fisheries)	8.4%
Industrial and commercial production	7.0%
Flood alleviation	7.0%
Physical health	7.0%
Housing services	5.6%
Plant health	2.8%
Pharmaceuticals	1.4%
Drinking water	1.4%
Beneficiaries	
General public	65.6%
Recreational users	14.1%
Government or industry	10.9%
Urban populations	6.6%

[9] Such information was recorded, where available, in the 'Values' column of the Woodland Valuation Tool.

Valuation method	
Choice Experiment	26.9%
Market prices	16.2%
Contingent Valuation	14.1%
Tools (e.g. i-Tree)	11.5%
Meta-analysis/Benefit Transfer	5.1%
Avoided Costs	3.8%
Reviews and discussion studies	2.6%
Secondary valuation literature	2.6%
Carbon price	2.6%
Visitors' spending	2.6%
Hedonic Price Method or similar approaches	2.6%
Travel Cost Method	2.6%
Contingent Valuation and Choice Experiment	1.3%
Replacement costs	1.3%
Cost models/Project costs	1.3%
Quality-Adjusted Life Years (QALY)	1.3%
Official Statistics	1.3%
Bio-economic modelling	1.3%
Miscellaneous (mix of methods not included above)	3.8%
Geographical remit	
Other countries in Europe	42.2%
Outside Europe	22.5%
UK	35.2%
Geographical scale	
National	25.7%
Regional	25.7%
City/urban	20.3%
Local	14.9%
Multi-country	10.8%
various (possibly different scales, but not specified – esp. for review studies)	2.7%

Table 2

[a] the percentage figures reported in this table are calculated over the total number of observations rather than the total number of studies, given that each reviewed study could generate more than one observation.

Table 3. Summary statistics regarding the focus of the reviewed biophysical studies on forests [a]

	No. Observations = 51 *No. Studies = 28*
Final ecosystem goods and services	
Flora & Fauna	33.3%
Environment (general)	7.8%
Air quality	21.6%
Water Quantity	7.8%

Views	3.9%
Timber and fibre	13.7%
Soil	3.9%
Water Quality	7.8%

Table 3

[a] the percentage figures reported in this table are calculated over the total number of observations rather than the total number of studies, given that each reviewed study could generate more than one observation.

6. Detailed review of woodland biophysical and valuation evidence by benefit area

6.1. Recreation

On the topic of forest recreation, 17 additional valuation studies were added to the 29 valuation studies previously identified in Binner et al. (2017), for a total of 46 valuation studies currently detailed in the Woodland Valuation Tool.

Review

The importance of forests for recreation is a relatively well understood topic. In our review of the biophysical evidence, we found two studies focusing on how trees are connected to recreation. Baral et al. (2016) and Seidl et al. (2016) highlighted that forests are important to supply scenic and natural landscapes, which are appreciated by recreationists. As such, these authors also argue that forest structure and management regimes can affect visitors' experience. For instance, people might like the presence of dead trees along trails less than the presence of live stands.

Knowledge about the recreational values provided by forests to people is also relatively well understood. The opportunity to practice outdoor recreational activities is considered to be one of the main services supplied by woodlands to people. In England, the number of total annual visitors to woodlands is estimated to be 73 000 000, providing a net asset value linked to recreation and public access of forests, which is worth GBP 147 940 000 per year (Forest Enterprise England 2016). The estimated value of a recreational visit to forests has been reported to oscillate between GBP 1.66 and GBP 2.75 (in 2002 prices). Similarly, Holt and Rouquette (2017) relied on the average expenditure per visitor, based on the Monitor of Engagement with the Natural Environment (MENE) survey, to identify the recreational value associated with the creation of a new forest in Marston Vale (England). The authors equate this value to GBP 6.91 per person, per year.

In a recent choice experiment study conducted in Scotland, Glenk, McVittie and Faccioli (McVittie and Faccioli 2017)[10] have focused on the preferences of forest users for woodlands attributes - including forest type, tree height, tree age structure and amount of deadwood present. Willingness to pay figures are not yet available from this work, which is why this reference has not been included in the Woodland Valuation Tool. However, preliminary results show that sampled respondents prefer higher (to lower) number of tree species in a woodland; taller and more mature (to shorter and less mature) trees; single-aged (to multi-aged) forests; and greater (to lower) amounts of deadwood.

Another useful source for recreational values at UK level is the Outdoor Recreation Valuation (ORVal) tool. ORVal provides information that is useful to government, businesses and communities to better understand the benefits that are derived from accessible greenspace (including forests) in England and Wales. This tool was developed by Day and Smith (2018) at the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter with funding support provided by DEFRA and is available at: http://leep.exeter.ac.uk/orval.

The ORVal tool is based on a sophisticated model of recreational demand for outdoor greenspace, estimated from data collected in the annual Monitor of Engagement with the Natural Environment (MENE) survey (Natural England 2017) [11]. The model can be used to estimate the levels of visitation to existing or newly created greenspaces and to derive monetary measures of the value that households attach to the recreational opportunities provided by those sites. ORVal makes probabilistic predictions about how likely it is that people with particular characteristics, in particular locations, visit a particular greenspace, given the characteristics of the greenspaces available and the cost of travelling to them. For estimating the recreation value of new sites, the welfare gain for each individual is calculated by adding a new site to the overall set of sites available for individuals to visit. That welfare gain is converted into an equivalent monetary amount and then aggregated over the whole England and Wales adult population and over an entire year.

Because ORVal is linked to information on land cover types, it is possible to estimate information on the recreational value provided by specific habitats, including woodlands. Based on this, ORVal estimates that each trip to a woodland in England and Wales is worth GBP 3.33 on average. ORVal allows to disentangle information on the recreational value of a trip to a woodland site by type of woodland (including whether it is a coniferous, broadleaved, young or felled forest) and based on whether the greenspace is a park or a path.

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[7] McVittie and Faccioli (2017). Natural Capital Accounts: Progress report on primary valuation studies, Scotland's Rural College, 33 pages, available at http://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/NCA%20Primary%20Valuation%20Progress%20171009.pdf.

[11] Natural England (2017) Monitor of Engagement with the Natural Environment: Technical Report to the 2009-2016 surveys.

ORVal has three key functions:

(1) It allows users to explore the usage and welfare values that are generated by currently accessible greenspaces. Welfare values can be viewed at individual site level or aggregated by regions.

(2) It allows users to estimate how usage and welfare values might change if the characteristics of a recreational greenspace were changed.

(3) It allows users to draw new recreation sites on the map, define their characteristics and estimate the usage and welfare values that might be generated by creating that new greenspace in that particular location.

ORVal has recently been incorporated into the UK Treasury's Green Book, the official government guidance for project appraisal and evaluation (HM Treasury 2018)[12] and features in the government's 25 Year Environment Plan.

Outside the UK, several other recent studies have focused on the valuation of forest benefits. Among these, some studies have focused upon understanding visitors' preferences for forest landscape views. Through a contingent valuation study, Molina et al. (2016) investigated the value that recreational users place upon improvements in landscape characteristics in Spain. Estimates ranged from EUR 4.21 to EUR 25.84 per person, per ha. The lowest values were estimated for improvements in mining, industrial and intensive agricultural areas, while the highest values were linked to improvements in riparian forests, mixed hardwood forests, mountain peaks in forest area and Mediterranean open coniferous forests with understory. Similarly, Häyhä et al. (2015) found that the value of the recreational appreciation of landscape views in Trentino (Italy) is EUR 77 per visitor, per ha, per year, based on a benefit transfer exercise.

Other studies have also focused on visitors' preferences for forest habitat and woodland expansion more broadly. For example, Abdullah et al. (2015) estimated the recreational value of forest conservation in a national heritage site in Malaysia to be between RM 55.86 and RM 62.25 per year, based on a contingent valuation exercise. By focusing on users' values for habitat characteristics, Roesch-McNally and Rabotyagov (2016) found that people would be willing to pay between USD 0.10 and USD 0.13 per household, per year for a 1% increase in mature forest acreage and between USD 4.71 and USD 12.64 per household, per year for a 1% increase in habitat for salmon. Varela et al. (2017), using a choice experiment, found that the general public in Catalonia (Spain) would be willing to pay EUR 0.36 per person, per year for a 1% increase of the Aleppo pine forest area suitable for recreation.

[12] HM Treasury (2018) The Green Book: Appraisal and Evaluation in Central Government, London, UK.

In our review, we found that some other studies focused on preferences for specific structural and ecological attributes of forests. Filyushkina et al. (2017) designed a choice experiment to study the general public's preferences for tree characteristics in recreational forests in Denmark. The results of their study indicate that people would be willing to pay DKK 14.48 per person, per visit to see a broadleaved forest and DKK 19.92 per person, per visit to see a mixed woodland (with respect to a coniferous forest). Relative to visiting a forest with newly established stands, respondents would be willing to pay different amounts to visit a forest depending on the height of trees. The value of a forest with low trees was estimated to be DKK 41.52 per person, per visit, a forest with high trees was estimated to be worth DKK 47.70 per person, per visit, while a woodland with trees of varying heights was found to be valued DKK 57.40 per person, per visit. With respect to a forest with equal tree species or tree heights across stands, the general public would prefer a forest with different tree heights (willingness to pay: DKK 9.20 per person, per visit), or different tree species (willingness to pay: DKK 9.08 per person, per visit).

Similarly, Giergiczny et al. (2015) developed a choice experiment to estimate recreational users' preferences for forest structural characteristics in Poland. Instead of estimating monetary values, the authors inferred people's preferences by estimating their willingness to travel extra km to visit a forest with the described characteristics. Results showed that visitors particularly appreciate woodlands with mixed forest type (different tree species) and different stand age, especially if more mature forests are present. Below we summarize some examples of values provided in Giergiczny et al. (2015).

Table 4. Recreational values reported in Giergiczny et al. (2015)

Change from		**To**	**Extra km that a person would be willing to travel to see the described change**
coniferous forest	→	mixed forest type with 2 species	13.28
coniferous forest	→	mixed forest type with 5 species	18.25
coniferous forest	→	forest with 1 broadleaved species	-10.96
coniferous forest	→	forest with 4 broadleaved species	4.42
stand age: 40 years	→	stand age: 70 years	11.33
stand age: 40 years	→	stand age: 100 years	22.36
even-aged forest	→	two-aged forest	3.63
even-aged forest	→	uneven aged forest	10.41
no ground vegetation height	→	medium height vegetation	4.82
no ground vegetation height	→	high vegetation height	-9.77
regular tree spacing	→	quasi-regular tree spacing	3.44
regular tree spacing	→	irregular tree spacing	7.53
regular forest edges	→	irregular forest edges	6.89

regular forest edges	→	irregular forest edges (with ecotone)	0.57
low deadwood	→	medium deadwood	4.07
low deadwood	→	high deadwood	-7.88
same forest type and stand age	→	same forest type, different stand age	6.69
same forest type and stand age	→	different forest type and stand age	18.36
no residue from harvesting/ thinning	→	medium residue from harvesting/ thinning	-0.62
no residue from harvesting and thinning	→	high residue from harvesting and thinning	-27.88
no understory	→	medium understory	3.88
no understory	→	high understory	8.56
no silviculture	→	shelterwood	-13.49
no silviculture	→	seedtrees	-29.05
no silviculture	→	clearcutting	-50.42

In addition to focusing on the environmental attributes of forests, Giergiczny et al. (2015) also considered recreationists' preferences for the services available for visitors in woodlands. They found that visitors would be willing to travel 26.18 extra km to find a forest with picnic infrastructure and 34.68 extra km to find picnic sites and interpretative walking trails (as opposed to no tourist infrastructure). Similarly, through a choice experiment, Czajkowski et al. (2017) found that increasing the tourist infrastructure in forests, including parking spaces, paths and trails and picnic sites is valued EUR 8.63 per household, per year.

Others among the reviewed studies focused on trying to understand visitors' preferences for increased accessibility to forests. Roesch-McNally and Rabotyagov (2016) designed a choice experiment and found that the general public's willingness to pay for increasing public access to forests in Oregon and Washington (USA) is between USD 38.23 and USD 56.36 per household, per year. Ojea et al. (2016) conducted a review of international valuation studies and found that the average global value of accessing forests for recreational purposes was USD 218 per ha, per year. Elberg Nielsen et al. (2016) estimated, through a choice experiment, that the value of improved access (through roads and paths) to forest in Denmark is between DKK 68 and DKK 574 per household, per year. Bartczak (2015), in her choice experiment, found that the general public displayed negative preferences for restricting the number of visitors to the Białowieża forest (Poland). The value of reducing the number of daily visitors to 7 500 or 5 000 was estimated to be PLN -23.10 per household, per year and PLN -10.19 per household, per year, respectively.

Some of the reviewed studies also focused on potentially negative externalities (in terms of noise or litter), which can result from high public accessibility to a forest site. Czajkowski et al. (2017), by means of a choice experiment in Poland, found that the value of substantially reducing the amount of litter in Polish forests was worth EUR 17.69 per household, per year. Calleja et al. (2017), by means of a contingent valuation study conducted in the Retiro Park in Madrid (Spain), found that visitors would be willing to pay EUR 6.36 per person to reduce noise and increase tranquillity.

Apart from Calleja et al. (2017), only Lupp et al. (2016) focused on the recreational values of woodlands in urban areas. By means of a mix of camera traps for counting the number of visitors, interviews and travel cost information (based on the price of daily tickets and the price per km travelled), the authors calculated the value of two urban woodlands in the Munich metropolitan area (Germany); depending on the forest considered, this value was estimated to be between EUR 2 913.57 and EUR 15 440 per ha, per year.

Generally, all reviewed valuation studies tended to focus on recreation in its broadest sense and specific recreation activities were only considered on a few occasions. This is the case of Häyhä et al. (2015), who relied on information on permit prices to estimate the value of recreational hunting (calculated to be EUR 10 per ha, per year) and of recreational mushrooming (estimated to be EUR 6 per ha, per year) in Trentino (Italy).

Valuation Summary

Below we provide a summary table, detailing some examples of recreational values presented in the reviewed studies, as described in this section.

Table 5. Summary table with some examples of recreational values reviewed in this report (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Forest Enterprise England (2016)	GBP 1.66–GBP 2.75	Per visit recreational value for a visit to UK forests	Existing valuation literature	GBP (2002)	Visitors
Molina et al. (2016)	EUR 8.87–EUR 25.84	Per ha value of landscape improvements in Spain (riparian forests, mixed hardwood forests, mountain peaks in forest area and Mediterranean open coniferous forests with understory)	Contingent valuation	EUR	Tourists
Häyhä et al. (2015)	EUR 77	Per visitor, per ha and year value of recreational appreciation of landscape views in Trentino (Italy)	Benefit transfer	EUR (2002)	Visitors

Abdullah et al. (2015)	RM 55.86–RM 62.25	Per person and year value of biodiversity conservation in a heritage site in Malaysia	Contingent valuation	RM (2014)	General public
Roesch-McNally and Rabotyagov (2016)	USD 0.10–USD 0.13	Per household and year value of a 1% increase in mature forest acreage in the US	Choice experiment	USD	General public
Varela et al. (2017)	EUR 0.36	Per person and year value of an increase by 1% of Aleppo pine forest area suitable for recreation in Catalonia (Spain)	Choice experiment	EUR (2011)	General public
Filyushkina et al. (2017)	DKK 19.92	Per person and visit value of visiting a mixed (with respect to a coniferous) forest	Choice experiment	DKK (2015)	Visitors
Giergiczny et al. (2015)	18.25 extra km	Extra km that each visitor would be willing to travel (on average) to find a mixed (5 species), with respect to a coniferous, forest	Choice experiment	Distance in km, one way (2013)	Visitors
Czajkowski et al. (2017)	EUR 8.63	Value per household and year for an increase in tourist infrastructure in forests in Poland	Choice experiment	EUR (2010)	General public
Holt and Rouquette (2017)	GBP 6.91	Per person and year recreational value linked to the creation of a new forest	Official statistics (MENE survey)	GBP (2015)	Visitors
Day and Smith (2018)	GBP 3.33	Per person and trip recreational value of visiting a woodland	Travel cost method	GBP (2018)	Visitors
Ojea et al. (2016)	USD 218	Per ha and year value of accessing forests for recreational purposes	Meta-analysis	USD (2008)	
Elberg Nielsen et al. (2016)	DKK 68–DKK 574	Per household and year value of improved access (through roads and paths) to forest in Denmark	Choice experiment	DKK (2005)	General public
Bartczak (2015)	PLN -23.10	Per household and year value of restricting the number of daily visitors to the Białowieża forest (Poland) to 7 500	Choice experiment	PLN (2011)	General public

Calleja et al. (2017)	EUR 6.36	Per visitor (one-off) value of tranquillity (noise reduction) in the Retiro Park (Madrid, Spain)	Contingent valuation	EUR (2015)	Visitors
Lupp et al. (2016)	EUR 2 913.6 EUR 15 440	Per ha and year value of two urban woodlands in the Munich metropolitan area (Germany)	Miscellaneous	EUR (2016)	Visitors

Research gaps

The material reviewed in this report (covering the period from 2015 to the present day) indicates sufficiently strong evidence regarding the biophysical mechanisms, through which woodland characteristics affect recreational visits, and the benefits that visitors obtain from woodlands. However, only limited evidence was found on the recreational value of urban woodlands and no specific study focused on the role of urban trees for recreation.

Table 6. Colour-coded summary table of available evidence on forest recreation: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is a relatively good knowledge of the relationships between site characteristics and recreational visits.	Valuation evidence on the social benefits of recreation in forests is relatively rich.	The Outdoor Recreation Valuation (ORVal) tool synthetises information on the recreational value of greenspace (including woodlands) in England and Wales. Possible improvements for the future include the consideration of tourists, in addition to day visitors.	Among the latest reviewed valuation evidence, relatively scarce attention was paid to urban forests.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

The above colour-coded assessment aligns relatively well with that presented in the Binner et al. (2017)[13] report (see below), except for two aspects. The first difference is that Binner et al. (2017) did

[8] Binner, A., Smith, G., Bateman, I., Day, B., Agarwala, M. and Harwood, A. (2017). *Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales* Forestry Commission Research Report

not include information on the Outdoor Recreation Valuation (ORVal) tool and therefore it reported a downgraded assessment (orange versus green) regarding the availability of decision support tools on recreational values. The second difference is that Binner et al. (2017) provided a more positive assessment (green versus red) of the evidence base on recreational values in urban settings.

Table 7. Colour-coded summary table of available evidence on forest recreation: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Large-scale time-series studies such as Monitoring of Engagement with the Natural Environment (MENE) have provided rich data on the relationship between site characteristics and recreational visits.	Complex valuation methods for analysing recreational behaviour are available; these methods make use of spatially explicit data and are able to account for the availability of substitute sites as well as providing information on use and non-use values.	Research has the potential to substantially improve decision-making in this area. Improved decision-making tools are needed to support urban planning and the management of recreational sites.	The evidence for recreational values from urban trees and woodlands is relatively robust (Brander and Koetse, 2011;[14] Perino et al., 2014[15]); however, none of the urban valuation tools reviewed here currently incorporate recreation into their valuation calculations.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

When we combine the evidence available post-2015 (this report) with that reviewed pre-2015 (Binner et al. 2017), we can then produce a consolidated assessment of research gaps to date (displayed below). This indicates the existence of a relatively strong biophysical and valuation evidence about the role of woodlands for recreation (with minor research gaps), both in rural and urban settings. In addition, ORVal offers a relatively strong decision support tool to better inform decision makers about the recreational value of outdoor greenspace (including woodlands).

[14] Brander, L. M., & Koetse, M. J. (2011). The value of urban open space: Meta-analyses of contingent valuation and hedonic pricing results. *Journal of environmental management,* 92(10), 2763-2773.
[15] Perino, G., Andrews, B., Kontoleon, A., Bateman, I. (2014). The Value of Urban Green Space in Britain: A Methodological Framework for Spatially Referenced Benefit Transfer. *Environmental and Resource Economics* 57: 251-272.

Table 8. Colour-coded summary table showing a consolidated assessment of available evidence on forest recreation, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is a good knowledge of the relationships between site characteristics and recreational visits. This is also thanks to the availability of large-scale time-series studies, such as Monitoring of Engagement with the Natural Environment (MENE)	Valuation evidence on the social benefits of recreation in forests is relatively rich. Complex valuation methods for analysing recreational behaviour are available. These methods make use of spatially explicit data and are able to account for substitute sites and provide information on use and non-use values.	The Outdoor Recreation Valuation (ORVal) tool synthetises information on the recreational value of greenspace (including woodlands) in England and Wales. Possible improvements for the future include the consideration of tourists, in addition to day visitors.	The evidence for recreational values from urban trees and woodlands is relatively robust (Brander and Koetse 2011; Perino et al. 2014); In addition, some evidence on the recreational value of urban woodlands is provided by the Outdoor Recreation Valuation (ORVal) tool.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.2. Air quality

Regarding the role of forests in air quality regulation, 4 recent valuation studies were added to the 14 valuation studies previously identified in Binner et al. (2017), such that 18 valuation studies are currently detailed in the Woodland Valuation Tool.

Review

In the review of the latest evidence on forest benefits, few studies were identified on the biophysical and social values of woodlands, in terms of air filtration and pollutant removal. Forests can significantly reduce (through absorption and deposition) the concentration of particulate matters and other polluting substances in the air, thereby increasing air quality and decreasing the risk of airborne-related negative health effects for people. In this framework, Jones et al. (2017) produced a study for the Office of National Statistics (ONS) in 2017 to summarize, through a natural capital accounting approach, the benefits of UK vegetation (including woodlands) in terms of improved air quality. The report is centred on different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NH_3, NO_2, O_3) and it also provides disaggregated information on air quality in urban areas (urban woodland).

The benefits of improved air quality are identified starting from the calculation of the number of avoided hospital admissions, life years lost or deaths that can be attributed to better air filtration resulting from woodland expansion. To obtain information about the monetary value of such health improvements, published figures of willingness to pay to avoid hospital admissions, death or life years lost were considered. For 2015, UK woodlands, covering a surface of 2 887 500 ha, were reported to have captured 315.5 ktonnes of air pollutants (Jones et al. 2017). The associated social benefits in terms of avoided deaths, avoided life years lost, fewer respiratory hospital admissions and fewer cardiovascular hospital admissions were calculated to be worth GBP 736 360 000. This means a value of GBP 255.02 per ha of woodland.

Some recent UK evidence (Mutch et al. 2017, Moffat et al. 2017, Rogers et al. 2018) specifically focused on the role of urban trees and woodlands in sequestering airborne pollutants. These studies utilised i-Tree Eco[16] to estimate the value of trees in reducing the concentration of different airborne pollutants in different cities (Southampton, Petersfield and Ealing, London); the amounts of pollutants' reductions were then multiplied by the per tonne UK social damage cost value to determine the benefits associated with the achievement of better air quality. Mutch et al. (2017) estimates that urban trees in Southampton remove about 90 tonnes of airborne pollutants per year which is worth GBP 533 720. Moffat et al. (2017) estimate that urban trees in Petersfield capture about 4.4. tonnes of airborne pollutants per year and contribute to improve air quality by creating an annual flow of benefits worth GBP 20 158. Rogers et al. (2018) estimate the annual value of reducing (by 33 tonnes each year) airborne pollutants in London (Ealing) to be GBP 952 000.

Valuation Summary

Below, we provide a summary table of the latest evidence on the values of improved air quality in forests, based on the reviewed studies described in this section.

Table 9. Summary table with some examples of forest-related air quality values reviewed in this report (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Jones et al. (2017)	GBP 736 360 000	Annual value of pollutants captured by UK woodlands in 2015 (315.5 ktonnes of pollutants over a total surface of 2 887 500 ha)	Avoided costs (based on existing valuation literature)	GBP (2004 and 2012)	General public

[16] i-Tree Eco is one of the i-Tree suite applications and i-Tree is a data-driven tool based on the forestry inventory, which estimates tree benefits and management costs. The tool reports annual total and per tree values for, among other things, air quality improvements (SO_2, NO_2, PM_{10} and volatile organic compounds VOCs). For more information on i-Tree and a wider selection of existing reports, please visit www.forestry.gov.uk/fr/itree and for an evaluation of the impact of i-Tree in the UK, please refer to www.forestry.gov.uk/fr/itree-evaluation.

Mutch et al. (2017)	GBP 533 720	Annual value of removing about 90 tonnes of airborne pollutants in Southampton woodlands	i-Tree tool	GBP (2016)	General public
Moffat et al. (2017)	GBP 20 158	Annual value of removing about 4.4 tonnes of airborne pollutants in woodlands in Petersfield.	i-Tree tool	GBP (2016)	General public
Rogers et al. (2018)	GBP 952 000	Annual value of removing about 33 tonnes of airborne pollutants in woodlands in Ealing (London).	i-Tree tool	GBP (2017)	General public

Research gaps

Based on the material reviewed in this report, some recent (post-2015) evidence could be found regarding the role of woodlands in reducing the concentration of air pollutants and the value of improved air quality to people. However, significant research gaps were also identified with respect to the robustness of welfare models to different assumptions, including the assumption that welfare responds linearly to variations in air quality. At the same time, only limited applications were found of existing decision-support tools in urban settings.

Table 10. Colour-coded summary table of available evidence on the role of forests in air quality regulation: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Based on the Jones et al. (2017) natural capital account for air quality, the link between forests/trees and air quality is relatively well understood, even though there is uncertainty regarding the robustness of the results to different model assumptions and data specified at different scales.	The latest available evidence on the values of improved air quality relies on published and peer reviewed literature, but the relationship between the concentration of different pollutants and human welfare is not entirely known.	Only limited applications were found of existing decision-support tools in urban settings.	Some information is available on the biophysical and valuation evidence regarding the role of woodlands to improve air quality specifically in urban settings.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

The above colour-coded assessment should not, however, lead the reader to conclude that the evidence on the importance of woodlands for air purification is generally scarce. As reported in Binner et al. (2017), a wider evidence base is available from the literature reviewed prior to 2015 (see below). In the pre-2015 time period, relatively stronger evidence was found on the biophysical processes through which forests contribute to air filtration and on the values of good air quality in urban settings. Similarly to the post-2015 assessment, Binner et al. (2017) also pointed out significant gaps regarding the valuation of air quality.

Table 11. Colour-coded summary table of available evidence on the role of forests in air quality regulation: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The biophysical pathways through which trees affect air quality are relatively well understood for both rural and urban trees, although debate remains regarding the efficacy of urban forests for improving air quality through pollutant deposition and absorption.	The health impacts caused by air pollution depend upon the number of people being exposed: a tonne of SO_2 in a densely populated area causes more damage than a tonne in a sparsely populated area. The value of pollution absorption by trees should reflect this population exposure.	Although i-Tree and integrated analyses such as the UK NEAFO's TIM provide some assistance, decision support tools which account for the spatially varying impact of air quality improvements are needed.	i-Tree Eco computes the value of removal of air pollutants (NO_2 PM_{10} and SO_2) using a constant value per tonne based on social damage costs for the UK.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Given that the post-2015 evidence does not significantly address the research gaps identified in the pre-2015 review, the combined colour-coding assessment of the literature and research gaps on the effects of trees upon air quality, does not present any improvement with respect to the Binner et al. (2017) report and it can be summarized as follows:

Table 12. Colour-coded summary table showing a consolidated assessment of available evidence on the role of forests in air quality regulation, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The biophysical pathways through which trees affect air quality are relatively well understood for both rural and urban trees, although debate remains regarding the efficacy of urban forests for improving air quality through pollutant disposition and absorption.	The health impacts caused by air pollution depend upon the number of people being exposed; a tonne of SO_2 in a densely populated area causes more damage than a tonne in a sparsely populated area. The value of pollution absorption by trees should reflect this population exposure.	Although i-Tree and integrated analyses such as UK NEAFO's TIM provide some assistance, decision support tools that account for the spatially varying impact of air quality improvements are needed.	i-Tree Eco computes the value of removal of air pollutants (NO_2, PM_{10} and SO_2) using a constant value per tonne, based on social damage costs for the UK. However, human health impacts of air pollution removal are based on US specific models, which are not necessarily applicable in other countries.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.3. Climate

Regarding the role of forests on climate regulation, 12 additional valuation studies were added to the 18 valuation studies previously identified in Binner et al. (2017), for a total of 30 valuation studies currently detailed in the Woodland Valuation Tool.

Review

Forest ecosystems are important to regulate both the global and the local climate system (Gauthier et al. 2015). Woodlands can contribute to the stabilization of climate by sequestering greenhouse gases and carbon. They are among the largest source of terrestrial carbon storage and play an important role in counteracting climate change, through the uptake of a considerable proportion of anthropogenic CO_2 emissions from the atmosphere (Seidl et al. 2016). Forest carbon is stored above ground within the trees, ground vegetation and litter, and below ground in the roots and soil (Sing et al. 2017). The capacity of woodlands to store carbon is highly variable. It varies naturally depending on the type of tree, the size of the tree and the stage of growth (Sing et al. 2017). However, it can vary greatly also depending on forest management regimes and human-induced disturbances, which can contribute to rapid release of carbon back to the atmosphere (Seidl et al. 2016). For example, forests can store more carbon if they contain deadwood and if trees are grown into maturity, while relatively short rotation lengths for timber production result in lower long-term forest carbon stocks within the forest (Sing et al. 2017). Increasing deforestation alone is responsible for decreasing carbon sequestration and increasing carbon emissions (Sloan and Sayer 2015). However, if felling is coupled with growing new trees, more sequestration could be achieved over the long term relative to leaving trees standing to age, as this latter process tends to reach a point of equilibrium over time, where carbon gains and losses are roughly in balance. Forests managed for greater plant diversity were also observed to have higher carbon sequestration capacity (Verheyen et al. 2016).

In terms of the most recent literature focusing on the values of carbon sequestration, some evidence is available at UK level. By using the UK Government's non-traded carbon price for 2015 (GBP 62), a recent study by Holt and Rouquette (2017) presented the value of carbon sequestration, linked to a project of woodland expansion in Marston Vale (England). The authors reported that the woodland expansion project taking place between 1995 and 2015, and accounting for the creation of 1 141 ha of forests, was responsible for an average sequestration of 4 917 tonnes of carbon dioxide annually (keeping in mind that sequestration is usually very low in the early years and then it increases significantly as trees get bigger). The total value of this carbon sequestration service was calculated to be GBP 304 855, which is equivalent to GBP 267 per ha of woodland created, per year.

Some recent studies (Mutch et al. 2017, Moffat et al. 2017, Rogers et al. 2018) similarly provided evidence of the role of urban trees and woodlands in sequestering and storing carbon in Southampton, Petersfield and Ealing (London). The amount of carbon stored in the trees' biomass and the level of carbon that woodlands contribute to sequester was combined in i-Tree Eco[17] with the price of carbon to obtain the monetized value of carbon sequestered and stored. To monetize the value of carbon sequestered, the non-traded carbon price based on the Department of Energy and Climate Change (DECC) 2015[18] estimations (central scenario) was considered. Mutch et al. (2017) calculated that urban trees in Southampton store about 100 583 tonnes of carbon, worth GBP 23.4 million in 2016, and they remove an estimated 2 684 tonnes of carbon from the atmosphere each year, worth GBP 609 327 (2016 prices). Moffat et al. (2017) similarly estimated that urban trees in Petersfield store about 18 260 tonnes of carbon, which can be valued at GBP 4 220 000, and they capture about 580 tonnes of carbon each year, worth GBP 132 000. Rogers et al. (2018) calculated that urban trees in London

[17] i-Tree Eco is one of the i-Tree suite applications and i-Tree is a data-driven tool based on the forestry inventory, which estimates tree benefits and management costs. The tool reports annual total and per tree values forcarbon sequestration and storage. For more information on i-Tree and a wider selection of existing reports, please visit www.forestry.gov.uk/fr/itree and for an evaluation of the impact of i-Tree in the UK, please refer to www.forestry.gov.uk/fr/itree-evaluation.

[18] DECC 2015. Valuation of energy use and greenhouse gas (GHG) emissions: Background document. DECC, London. 50 pp. [plus] DECC (2015) Data tables 1-20: supporting the toolkit and the guidance. http://www.gov.uk/government/publications/valuation-of-energy-use-andgreenhouse-gas-emissions-for-appraisal

(Ealing) store 76 670 tonnes of carbon each year, generating benefits worth GBP 4 890 000, and they contribute to sequester 2 250 tonnes of carbon annually, worth GBP 527 000.

Outside the UK, Masiero et al. (2016) reported the value of carbon sequestration in forests of different Mediterranean countries to be between EUR 3.51 and EUR 12.61 per ha. By taking into account the carbon emission permit price, Häyhä et al. (2015) reported that the value of carbon sequestration in forests in Trentino (Italy) is EUR 76 per ha, per year. By relying on secondary valuation literature, Felardo and Lippitt (2016) focused on estimating the value of carbon sequestration in Thailand. Their estimates varied with the size of the forest: across a forested surface of 73 050 plots (where each plot is 30 x 30m), the value of carbon sequestration was calculated to be between THB 183 and THB 366 per year; while across a forested area of 62 750 plots, it was estimated to be between THB 366 and THB 550 per year. In the case of China, Zhang et al. (2016) used official statistics on forest volumes and carbon prices to estimate the increase in carbon sequestration in Chinese forests between 2003 and 2008. For the time frame considered, they calculated that carbon stocks increased by 1.88% per year and the total value of forest carbon sinks grew from CNY 26.73 x 10^9 in 2003, to CNY 29.77 x 10^9 in 2008.

In addition to the above approaches, some recent studies also relied on primary valuation to infer information about the general public's preferences for increased carbon sequestration in forests. In a choice experiment on forest ecosystem services in Oregon and Washington States (USA), Roesch-McNally and Rabotyagov (2016) estimated individuals' willingness to pay for a 1% increase in the carbon storage capacity of forests to be between USD 0.76 and USD 1.54 per household, per year (depending on whether a mandatory or voluntary payment vehicle was considered). Similarly, Balderas Torres et al. (2015) studied individuals' willingness to contribute to a carbon offset program in Mexico. For each additional tonne of CO_{2eq} sequestered, the value was estimated to be between USD 5.57 and USD 11.39 (with a one-off payment). By means of a choice experiment in Catalonia (Spain), Varela et al. (2017) estimated that the willingness to pay of the general public for a marginal increase in tonnes of CO_2 sequestered in local woodlands is EUR 0.0005 per person, per year.

Forests affect climate not only through carbon sequestration, but also because they provide shade, which contributes to the protection of people and other living beings from heat and ultraviolet radiation, which are bad for health. In the review of the latest valuation evidence on forest benefits, no study was found that focuses on the value of woodland areas in mitigating heat islands, especially in cities.

Valuation Summary

Below, we provide a summary table with some examples of carbon sequestration value estimates provided by the reviewed studies described in this section.

Table 13. Summary table with some examples of values of carbon emission reduction based on the review presented in this section (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Holt and Rouquette (2017)	GBP 267	Value of carbon sequestration per ha of new woodland created in Marston Vale	Carbon price	GBP (2015)	
Mutch et al. (2017)	GBP 23 400 000	Per year value of carbon storage (about 100 583 tonnes of carbon) in Southampton urban trees	Carbon price	GBP (2016)	General public
Moffat et al. (2017)	GBP 4 220 000	Per year value of carbon storage (about 18 260 tonnes of carbon) in Petersfield urban trees	Carbon price	GBP (2016)	General public
Rogers et al. (2018)	GBP 4 890 000	Per year value of carbon storage (about 76 670 tonnes of carbon) in London (Ealing) urban trees	Carbon price	GBP (2017)	General public
Masiero et al. (2016)	EUR 3.51- EUR 12.61	Per ha value of carbon sequestration in forests in different Mediterranean countries	Price of carbon credits (EUR 4.18 per tonne of CO_2e) and social cost of carbon (EUR 15 per tonne of CO_2e)	EUR (2010)	
Häyhä et al. (2015)	EUR 76	Per ha and year value of carbon sequestration in forests in Trentino (Italy)	Carbon emission permit price	EUR (2010)	
Felardo and Lippitt (2016)	THB 183- THB 366	Per year value of carbon sequestration resulting from forested areas in Thailand	Secondary literature	THB (2005)	
Zhang et al. (2016)	CNY 29.77 x 10^9	Value of 6.913 x 10^9 tC sequestered in 2008 in Chinese forests	Official statistics and carbon price	CNY (2008)	
Roesch-McNally and Rabotyagov (2016)	USD 0.76- USD 1.54	Value of 1% increase in carbon storage capacity of forests per household per year	Choice experiment	USD	General public
Balderas Torres et al. (2015)	USD 5.57- USD 11.39	One-off value of each additional tonne of CO_{2eq} sequestered	Choice experiment	USD (2010-11)	General public
Varela et al. (2017)	EUR 0.0005	Value (per person and year) of a marginal increase in tonnes of CO_2 sequestered	Choice experiment	EUR (2011)	General public

Research gaps:

Based on the material reviewed in this report (covering the period from 2015 to the present day), we can identify some dimensions across which the research literature is incomplete. The biophysical processes underpinning carbon sequestration services provided by trees and the related social values are relatively well understood. This is particularly the case in rural settings, but less so in urban contexts. In addition, the post-2015 review provided little new evidence in terms of decision-support tools to better inform policy-making. Taking these aspects into account, the following research gaps can be identified:

Table 14. Colour-coded summary table of available evidence on the role of forests and trees in climate regulation: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is a good knowledge of the biophysical processes affecting carbon sequestration in forests. Interestingly, the biophysical literature has also started to explore the role of climate change on forest functioning.	Valuation evidence on the social benefits of carbon sequestration is based not only on carbon prices, but increasingly on primary valuation.	In the review of new studies, little new evidence was found on the application of existing decision-support tools (e.g. i-Tree-Eco). No new decision support tool was found on the topic of carbon sequestration in forests.	Among the latest reviewed valuation evidence, little attention was generally paid to the role of urban trees in carbon sequestration and storage.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

With respect to the colour-coded assessment illustrated above, the literature prior to 2015 presented in Binner et al. (2017) and summarized below, provides a relatively better understanding of the role of forests in climate regulation in cities. This is especially true with respect to the role of trees in urban heat island control, even though this evidence relies upon models that were originally developed in the USA and whose applicability to the UK is not entirely clear.

Table 15. Colour-coded summary table of available evidence on the role of forests and trees in climate regulation: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The impact of climate change on the growth and biophysical functioning of trees (e.g. water use) needs to be examined as this will affect the services (dis-services) provided in the future.	Improving estimates of the social cost of carbon/ abatement costs (carbon price is an active area of research, but is unlikely to be resolved in the short or medium term). Employing UK Government carbon prices is a straightforward compromise.	Decision-making tools, which take account of the impact of climate on trees and woodlands and the goods and services provided by them, are needed.	The impact of trees on temperature regulation through shading has been incorporated into i-Tree Eco.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Given the above, when combining the pre-2015 evidence, revised in Binner et al. (2017), with the post-2015 one, reviewed in this report, the consolidated assessment of research gaps to date can be illustrated as follows:

Table 16. Colour-coded summary table showing a consolidated assessment of available evidence on the role of forests and trees in climate regulation, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is good knowledge of the biophysical processes affecting carbon sequestration in forests. Increasingly, the impact of climate change on the growth and biophysical functioning of trees (along with its effects	Valuation evidence on the social benefits of carbon sequestration is expanding. There is increasing research using the social cost of carbon, as well as primary valuation, which has the potential to improve the	Decision making tools, which take account of the impact of climate on trees and woodlands and the goods and services provided by them, are needed.	The impact of trees on temperature regulation through shading has been incorporated into i-Tree Eco. However, because this model was originally developed in the US, there may be limits in terms of its applicability and

on the services and disservices provided by trees) is explored.	knowledge base in this area.		accuracy outside the US.

Key: Strong evidence, with few gaps | Some evidence, but with significant gaps | Major gaps in evidence

6.4. Physical and mental health

On the topic of the physical and mental health benefits of forests, one additional valuation study was added to the 14 valuation studies previously reviewed in Binner et al. (2017), for a total of 15 valuation studies currently detailed in the Woodland Valuation Tool.

Review

Woodlands are increasingly recognized to play an important role in providing opportunities for better physical and mental health. However, there is still scarce understanding of the mechanisms through which individuals' health (particularly mental health) is improved through spending time outdoors in forest ecosystems. In the review of the latest valuation evidence on forest benefits, only one recent publication was found on this topic. At UK level, Holt and Rouquette (2017) reported that the positive effect of an appropriate amount of physical activity in woodlands on human health would be worth (in terms of cost savings to the NHS) GBP 20 000 per year, for each additional quality-adjusted life year (QALY) achieved, namely for each extra life year spent in perfect health.

Valuation Summary

Below, we provide a summary table with some examples of the physical and mental health values linked to forests, based on the review described in this section.

Table 17. Summary table with some examples of values on the physical and mental health benefits provided by forests, based on the review presented in this report (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Holt and Rouquette (2017)	GBP 20 000	Per year value of each additional life year spent in perfect health.	Avoided costs	GBP (2015)	

Research gaps:

Based on the material reviewed in this report, there are several major research gaps that can be identified with respect to the effect of forests on physical and mental health. Only limited knowledge is available on the mechanisms through which woodlands provide improved mental and physical health and the values that improved health provides to people, both in rural and urban settings. Without a sufficient development of this knowledge base, decision support tools cannot be designed to help policy-makers in decision making processes.

Table 18. Colour-coded summary table of available evidence on the physical and mental health benefits provided by forests: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The understanding of the mechanisms through which woodlands provide mental and physical benefits to people is still scarce.	Valuation evidence on the mental and physical health benefits of spending time outdoor in woodlands is very limited and more efforts should be put in place in the future.	In the review of new studies, no new decision support tool was found on the topic of physical and mental health benefits.	Among the latest reviewed valuation evidence, very little attention was paid to the physical and mental health benefits related to urban forests.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Similar conclusions (as summarized below) were also highlighted in the Binner et al. (2017) review, discussing the evidence prior to 2015:

Table 19. Colour-coded summary table of available evidence on the physical and mental health benefits provided by forests: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
A fundamental challenge is the need to establish causality, substitution and response behaviours between trees/woodland (as	There is no commonly applied generic measure for mental health. This makes comparison between biophysical studies difficult and the lack of	The evidence base needs to be developed to facilitate the development of accessible decision support tools that incorporate mental	The key challenge in valuing the physical and mental health benefits provided by urban trees and woodlands lies in developing a clear understanding of the

opposed to other environments) and mental and physical health.	a well-defined and commonly understood mental health good or service poses a challenge for valuation.	health and physical health impacts resulting from activities beyond habitual exercise.	biophysical processes at work and understanding whether these relationships hold, or are augmented, for urban trees.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Hence, the combination of findings presented in Binner et al. (2017), with those summarized in the present report, confirms that substantial efforts are still required to address some important and largely under-researched areas on the topic of the physical and mental health benefits provided by forests. These include the understanding of the causality, substitution and response behaviours between trees/woodland and mental and physical health and the development of appropriate scales (for valuation purposes) to measure the benefits of woodlands on health.

Table 20. Colour-coded summary table showing a consolidated assessment of available evidence on the physical and mental health benefits provided by forests, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The understanding of the mechanisms through which woodlands provide mental and physical benefits to people is still scarce. A fundamental challenge remains to establish causality, substitution and response behaviours between trees/woodland and mental and physical health.	Valuation evidence on the mental and physical health benefits of spending time outdoor in woodlands is very limited and more attention should be given to this in the future. There is no commonly applied generic measure for mental health. This makes the understanding of mental and physical health insufficient and poses considerable challenges to valuation.	The evidence base needs to be progressed to facilitate the development of accessible decision support tools that incorporate mental and health impacts resulting from activities beyond habitual exercise.	The key challenge in valuing the physical and mental health benefits provided by urban trees and woodlands lies in developing a clear understanding of the biophysical processes at work.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.5. Biodiversity

39 additional valuation studies relating to biodiversity (flora, fauna and the environment) were added to the 48 valuation studies previously identified in Binner et al. (2017), for a total of 87 valuation studies currently detailed in the Woodland Valuation Tool. However, the results of only 19 of the post-2015 valuation studies relating to biodiversity have not already been discussed in other parts of this report. In this section, we will only focus on this smaller sub-group of valuation studies.

Review

Forests play an important role in supporting biodiversity. Biodiversity is a measure of an ecosystem's biological complexity and should be distinguished from the constituent forms of life (including flora, fauna and fungi) that exist in that ecosystem. Forests are important to provide habitat for a variety of different species, including both animals and plants, common species as well as native and endemic ones (Alarcon et al. 2015; Petersen et al. 2015). Despite this, biodiversity is often measured in terms of the presence and abundance of specific species in an ecosystem, for example, insects and birds. Alternatively, biodiversity is measured in terms of species richness, which refers to the number of different species, against the total number of species, present in a given environment (Papanastasis et al. 2017). Biodiversity is important for pollination, which supports the production of food including fruit (berries), vegetables, seeds, mushrooms (Lakerveld et al. 2015; Baral et al. 2016) or forage (herbaceous biomass). Beyond food provision, biodiversity also contributes to support the supply of all other ecosystem goods and services.

Forest biodiversity relies upon complex relationships between different trophic levels (Spake et al. 2015) and it is highly susceptible to human-induced pressures. The latest biophysical evidence frequently discusses the effects of different management regimes and other anthropogenic disturbances on forest resilience. For example, agricultural expansion, as well as road construction, are mentioned as important sources of land fragmentation and degradation, which can lead to the loss of forest habitat and species (Sloan and Sayer 2015). Other significant drivers of stress for biodiversity are intensive cattle farming or logging operations (Alarcon et al. 2015).

Regarding the latest valuation evidence, most attention has been given to the non-use benefits that a well-preserved forest biodiversity generates to people. Non-use benefits arise from the knowledge that the environment is preserved, independently of the use or consumption opportunities that the environmental good can provide to people; in addition, non-use values refer to the wellbeing that people experience from knowing that the environment can be passed on to future generations in good condition. In the post-2015 review, evidence on the non-use values of forest biodiversity was gathered starting from international case studies, as no examples were found for the UK.

Through a meta-analysis of forest valuation studies at global level, Ojea et al. (2016) estimated the value of biodiversity conservation in forests to be USD 1 279 per ha, per year. By following a multi-country approach, Bakhtiari et al. (2018) designed a choice experiment exercise and estimated the value placed by the general public in Denmark and Sweden for an increase in forests' natural dynamics (natural decay processes) and species number in different locations. Both forests' natural dynamics and species number were mentioned by sampled respondents as indicators of forest biodiversity. The results showed that, for example, the value of leaving 15 trees per ha to regularly (rather than occasionally) age, die and decay was estimated to range between DKK 190 and DKK 290 per person, per year. The authors also found that willingness to pay for an increase in the number of abundant forest species (from 1000 to 2000) was estimated to be between DKK 400 and DKK 514 per person, per year. Findings also revealed that respondents place a higher value on biodiversity improvements in their own country and region. The sensitivity of biodiversity-related non-use values to the country of provision, can have important implications for setting up international agreements aiming to tackle biodiversity-related problems affecting multiple countries.

Rambonilaza et al. (2016) investigated, through a choice experiment exercise, the value of the general public for forest biodiversity attributes in France. They considered three attributes linked to structural diversity (i.e. stand vertical structure, volume of deadwood, and presence of old-growth forests) and one linked to tree species diversity. They found that people would be willing to pay between EUR 11.11 and EUR 11.79 per household, per year for changing the stand structure and increasing tree age distribution from one height to two heights, or from two heights to mixed heights. People would be willing to pay between EUR 18.34 and EUR 18.38 per household, per year for increasing tree species diversity from lower to higher number of tree species. They would be willing to pay between EUR 2.17 and EUR 7.11 per household, per year for increasing the volume of fallen deadwood from no to little deadwood, or from little to important quantity of deadwood. And they would be willing to pay between EUR 15.06 and EUR 15.40 per household, per year for increasing (from zero to low, or low to high) the density of old-growth trees, which have high ecological value.

Similarly, Bartczak (2015) estimated the value of increasing the naturalness of the Białowieża Forest, with higher levels of naturalness associated with greater richness of species and more complex and diverse ecological structures and functions. She estimated the value of achieving high levels of naturalness in commercial forests to be EUR 20.39 per household, per year and the value of achieving high levels of naturalness in second-growth forests to be EUR 24.81 per household, per year. In a similar study in Poland, Czajkowski et al. (2017) focused on preferences for passive forest protection of the most ecologically valuable forests, which are important to increase forest naturalness. In their choice experiment study, they found that the Polish public would be willing to pay PLN 13.54 per person, per year for a substantial improvement in passive protection of woodlands.

Likewise, Valasiuk et al. (2017a) designed a choice experiment and explored the preferences of the Polish and Belarussian general public for increasing the surface of natural forests in the Białowieża area, which extends over parts of Poland and Belarus. Both the Polish and Belarussian sample of respondents were found to be more supportive towards increasing the protection of the domestic (rather than the non-domestic) portion of the Białowieża forest. For example, the Polish sample would be willing to pay EUR 9.27 per person, per year to extend by an additional 35 km^2 the Polish surface of the Białowieża under passive protection. Similarly, the Belarussian sample would be willing to pay EUR 10.76 per person, per year for the same level of increased protection in the Belarussian portion of the forest. At the same time, both the Polish and the Belarussian sampled respondents would demand some compensation if the increased forest protection measure was implemented in the neighbouring country, rather than within their national boundaries. The authors concluded that WTP is higher the closer the respondent lives to a forest area and the scarcer the forest area around the respondent's place of residence.

Through another choice experiment study, Valasiuk et al. (2017b) explored the preferences of the Swedish and Norwegian public for increasing passive protection in the Fulufjället National Park Area, bordering between Sweden and Norway. The authors found that the Swedish sample would be willing to pay EUR 2.67 per person, per year for an additional 20 km^2 of forest passive protection in the Norwegian portion of the National Park but EUR 12.41 per person, per year if the improvement was in the Swedish part of the protected area. For the same level of change in forest protection, the Norwegian sample would be willing to pay EUR 13.48 per person, per year if the additional portion of protected forest was within the Norwegian borders, but EUR 4.47 per person, per year if the improvement took place in the Swedish portion of the National Park Area. Similar results and conclusions were drawn also when considering different (i.e. larger) levels of passive protection.

Starting from the annual spending on forest restoration in the Czech Republic, Pechanec et al. (2017) estimated that the value of conserving 2 922.89 km^2 of natural forests in the country's protected areas is EUR 76 000 million per year. Similarly, through a contingent valuation exercise, Borzykowski et al. (2018) explored the value of increasing the surface of protected forests in Switzerland from 5% to 10% of total forested cover. They found that members of the general public would be willing to pay between CHF 276.69 and CHF 2 064.38 per person (depending on the parametric distribution considered in the model) for an improvement that took place at national scale. If the same percentage improvement took place at more localised scale (around the city of Geneva), respondents' willingness to pay was found to be between CHF 182.34 and CHF 334.65 per person (depending on the parametric distribution considered in the model).

Ahlheim et al. (2015) focused on the preferences of the urban population in the South-West of China for the reforestation of a rubber plantation area. In their contingent valuation exercise, the authors found that people would be willing to pay CNY 163.84 per household, per year for the proposed improvement. Similarly, Oviedo and Caparrós (2015) explored the preferences of the general public for afforestation in the Southwest of Spain. By using both a contingent valuation and a choice experiment study, they found that people would be willing to pay for interventions aimed at planting stone pines, a native species in Spain, in areas currently covered with shrubs and eucalyptus. Depending on the method considered, willingness to pay for 40 ha of shrub removal was found to be between EUR 31.65 and EUR 39.20 per person; similarly, willingness to pay for 40 ha of eucalyptus removal was estimated to be between EUR 33.92 and EUR 38.15 per person. Values for removing double the surface of shrub or eucalyptus were estimated to be only slightly higher (up to EUR 43.89 per person). In a similar setting, Varela et al. (2017) designed a choice experiment exercise and found that the general public in Catalonia (Spain) would be willing to pay EUR 7.14 per person, per year for each extra tree species present in Aleppo pine forests in the region.

Apart from considering the non-use values associated with flora and fauna species in forests, some studies also focused on the role of forest wildlife for food production and subsistence. In 2015/16, the woods and forests on land managed by Forest Enterprise England were estimated to sustain the production of 15 767 000 trees, being worth GBP 3 774 000, and 12 000 wild game carcasses, being worth GBP 40,000 (Forest Enterprise England 2016). A few other recent studies focused on the value of food products in other European countries outside the UK. Masiero et al. (2016) found that in Mediterranean regions, the value of forest non-timber products (e.g. nuts, cork, animals, etc.) accounted for EUR 11.96 per ha in 2010, based on market prices. In the case of forests in the Trentino region (Italy), Häyhä et al. (2015) reported the market value of hunted animals (game) to be EUR 5 per ha and year, the value of mushrooms to be EUR 14 per ha and year and the value of berries to be EUR 2 per ha and year.

A slightly higher number of research works focusing on the value of forest food products could be found outside Europe and especially in developing countries. Ojea et al. (2016) estimated the value of food and fibre provided by forests to be USD 1 268 per ha, per year, using a global-scale meta-analysis. Through a contingent valuation study in Ethiopia, Gelo and Koch (2015) estimated the value placed by the general public upon the establishment of a community forest plantation, for sustainable grazing and fuel wood collection. This value was estimated to be ETB 80.52 per person. Using secondary valuation information, Felardo and Lippitt (2016) found that non-timber forest products (e.g. mushrooms, herbs, larvae, etc.) in Thailand are worth between THB 0.016 and THB 0.96 per year. Rai and Scarborough (2015) designed a choice experiment exercise in rural Vietnam to estimate the preferences of the general population for increasing the provision of subsistence products in forest ecosystems. They found that each person would be willing to pay NPR 695.61 for reducing, by one hour, the time needed to collect subsistence products in nearby forests.

Only one reference study in the review was found to focus on the value of plants for pharmaceutical uses. Through a contingent valuation study in Iran, Amiri et al. (2015) estimated that the value attached by the general public to the preservation of the myrtle plant for medicinal purposes is IRR 26 820 per household, per month.

Valuation Summary

Below, we provide a summary table with some examples of biodiversity-related values, based on the review described in this section.

Table 21. Summary table of some examples of biodiversity-related non-use values reviewed in this report (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Ojea et al. (2016)	USD 1 279	Per ha and year value of biodiversity conservation in forests around the world	Meta-analysis of international studies	USD (2008)	
Bakhtiari et al. (2018)	DKK 190- DKK 270	Per person and year value of regularly (rather than occasionally) leaving 15 trees/ha to age, die and decay	choice experiment	DKK (2012)	General public
Rambonilaza et al. (2016)	EUR 18.34- EUR 18.38	Per household and year value of increasing species diversity in French forests (from low to high number of tree species)	choice experiment	EUR (2012)	General public
Bartczak (2015)	EUR 20.39	Per household and year value of high levels of naturalness in commercial forests in the Białowieża Forest (Poland)	choice experiment	EUR (2011)	General public
Czajkowski et al. (2017)	PLN 13.54	Per person and year value of substantially increasing passive protection of Polish forests	choice experiment	PLN (2010)	General public
Valasiuk et al. (2017a)	EUR 9.27- EUR 10.76	Per person and year value of 35 extra km^2 of passive protection of the Białowieża Forest area, extending over Poland and Belarus	choice experiment	EUR (2015)	General public
Valasiuk et al. (2017b)	EUR 2.67- EUR 13.48	Per person and year value of 20 extra km^2 of passive protection of the Fulufjället National Park Area, extending over Sweden and Norway	choice experiment	EUR (2015)	General public

Pechanec et al. (2017)	EUR 76 000 000 000	Per year value of conserving 2 922.89 km^2 of natural forests within protected areas in the Czech Republic	Annual spending on restoration	EUR (2015)	
Borzykowski et al. (2018)	CHF 276.69- CHF 2064.38	Per person (one-off) value of increasing the surface of protected forests in Switzerland (from 5% to 10%)	Contingent valuation	CHF (2014)	General public
Ahlheim et al. (2015)	CNY 163.84	Per household and year value of the reforestation of a rubber plantation area in South-West China	Contingent Valuation	CNY (2009)	General public
Oviedo and Caparrós (2015)	EUR 31.65- EUR 39.20	Per person (one-off) value of 40ha of shrub removal to allow for stone pine reforestation in Spain	Choice experiment and contingent valuation	EUR (2010-11)	General public
Varela et al. (2017)	EUR 7.14	Per person and year value of each extra tree species present in Aleppo pine forests in Catalonia (Spain)	Choice experiment	EUR (2011)	General public

Table 22. Summary table with some examples of reviewed studies focusing on the value of forest biodiversity in supporting the production of food and pharmaceutical products (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Forest Enterprise England (2016)	GBP 40,000	Value of wild game (12 000) hunted in woods and forests managed by Forest Enterprise England in 2015-16	Market value	GBP (2015-16)	
Masiero et al. (2016)	EUR 11.96	Per ha average value of non-timber products (e.g. nuts, cork animals, etc.) across different Mediterranean forests	Market value	EUR (2010)	
Häyhä et al. (2015)	EUR 14	Per ha and year value of mushroom products supplied by forests in the Trentino region (Italy)	Market value	EUR (2010)	

Ojea et al. (2016)	USD 1 268	Per ha and year value of food and fibre products supplied by forests (international)	Meta-analysis	USD (2008)	
Gelo and Koch (2015)	ETB 80.52	Per person value linked to the establishment of a community forest plantation aimed to provide sustainable grazing and fuel wood in Ethiopia	Contingent valuation	ETB	General public
Felardo and Lippitt (2016)	THB 0.016-THB 0.96	Per year value of non-timber forest products (e.g. mushrooms, herbs, larvae, etc.) in Thailand	Secondary valuation literature	THB (2012)	General public
Rai and Scarborough (2015)	NPR 695.61	Per person value of increasing Nepalese forests' capacity to provide subsistence products and decrease (by one hour) forest product collection time.	Choice experiment	NPR (2010?)	General public
Amiri et al. (2015)	IRR 26 820	Per household and month value of preserving the myrtle plant for medicinal purposes in the Lorestan Province (Iran)	Contingent valuation	IRR	General public

Research gaps:

Based on the material reviewed in this report, we can identify several dimensions across which the literature on forest biodiversity is incomplete. Some biophysical evidence is available on the role of specific species. However, more comprehensive indicators to measure woodland biodiversity should be developed, beyond the consideration of single species. The lack of an appropriate biodiversity indicator also represents a limiting factor for the economic valuation literature. More biophysical and valuation evidence is needed before decision-support tools can be developed to better inform decision-making. Major research gaps were also identified with respect to understanding the benefits provided by biodiversity in urban woodlands.

Table 23. Colour-coded summary table of available evidence on the role of forests and trees for biodiversity: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Biodiversity knowledge is limited to the consideration of specific species and it does not rely on the existence of a standardised indicator.	There is some evidence available on the benefits of biodiversity and increasingly this evidence is spatially explicit. However, the lack of well–developed biodiversity indicators and the consideration of specific biodiversity aspects, limits the possibilities of valuing biodiversity as a whole.	In the review of new studies, no new decision support tool was identified on the topic of forest biodiversity.	In general, very few of the reviewed valuation studies have focused on the benefits of biodiversity in urban settings.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Similar conclusions were also drawn in Binner et al. (2017), which revised the literature prior to 2015, as summarized below:

Table 24. Colour-coded summary table of available evidence on the role of forests and trees for biodiversity: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The need for improvements in the economic valuation of biodiversity needs to be matched by better data and natural science understanding of the physical impacts of afforestation upon measures of biodiversity and human health.	A particular problem arises regarding estimation of the non-use benefits of biodiversity where the lack of behavioural action precludes the use of revealed preference methods.	The measurement of biodiversity, biophysical evidence base and robust valuation methods need to be established before meaningful decision support tools that incorporate biodiversity can be developed.	While there is evidence to suggest that urban woodlands and domestic gardens promote biodiversity in towns, the biodiversity related benefits provided by urban trees are not well understood and do not form part of the values reported by tools such as i-Tree Eco.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

When combining the evidence reviewed in this report with that reviewed in Binner et al. (2017), we can produce a consolidated assessment of research gaps to date, which can be summarized as follows:

Table 25. Colour-coded summary table showing a consolidated assessment of available evidence on the role of forests and trees for biodiversity, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Need for better data and natural science understanding of the impacts of afforestation upon biodiversity and human health. Biodiversity knowledge is limited to the consideration of specific species and it does not rely on the existence of a standardised and comprehensive indicator.	There is some evidence available on the benefits of biodiversity and increasingly, on the related non-use values. However, the lack of well-developed biodiversity indicators represents a major challenge in the valuation of biodiversity as a whole.	The measurement of biodiversity, biophysical evidence base and robust valuation methods need to be established before decision support tools that incorporate biodiversity can be developed.	While there is some evidence to suggest that urban woodlands and domestic gardens promote biodiversity, the related benefits and values are not well understood.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.6. Plant (tree) health

Two additional valuation studies on forest plant health were added to the only valuation study previously included on this topic in the Woodland Valuation Tool, resulting in a total of 3 valuation studies.

Review

The topic of forest plant health is largely under-investigated, but it is attracting increasing attention. Forest health is frequently associated with the absence of pests and diseases that damage the structure, growth rate and functionality of woodlands (Baral et al. 2016). Plant health is often linked to greater forest resilience, namely the capacity of woodland ecosystems to withstand pressures arising from human-induced degradation and still provide the same level of ecosystem services (Asner et al. 2015; Ghazoul et al. 2015). Macpherson et al. (2016) found that the presence of pests and diseases can affect optimal forest management decisions, particularly with respect to the timing of harvesting. Pests and tree diseases can reduce tree growth, increase the susceptibility to secondary infection and increase the proportion of trees that are dead and subject to tree decay.

Climate change can contribute to outbreaks of woodland pests and diseases. For example, insect outbreaks have started to spread to higher latitudes and altitudes, as a result of reduced thermal constraints. The positive effect of warming on insect population dynamics, including reproductive rates and reducing winter mortality, has led to increasing damage in some forests. Concurrently, climate extremes, such as longer and more intensive droughts, are increasing the susceptibility of trees to insect attacks by weakening secondary defence reactions to, for instance, bark beetle (Seidl et al. 2016).

In addition, plant health and resilience can also be influenced by different forest management regimes. Some studies have argued, that forests managed for greater plant diversity are more resilient to insect outbreaks (Verheyen et al. 2016). This means that planted forests tend to have a lower regulatory capacity against diseases, predators or parasites with respect to natural forests (Baral et al. 2016).

Within the valuation literature, very scarce attention was given to the social values and benefits of forest plant health. However, a couple of recent contributions are worth mentioning. Sheremet et al. (2017) focused on control measures for invasive tree species in the UK. By means of a choice experiment exercise, they found that people would be willing to pay GBP 6.4 per household per year for a management measure that prevents pest and diseases, especially when the outbreak had negative effects on biodiversity (rather than on other forest services, including carbon storage, timber production, recreation and scenic beauty). Respondents were also found to be willing to pay GBP 8.46 per household per year for a change in forest management to control for invasive species, especially when the forest is on charity- and/or national government-owned land (rather than business-owned or local authority land). The authors additionally identified a demand for monetary compensation of between GBP 6.20 and GBP 7.30 if clear felling or biocides (rather than a combination of measures, including thinning) are adopted as tree disease control measures.

Similarly, Meldrum (2015) investigated the general public's preferences for the management of invasive, non-native pathogens causing lethal diseases in forests in Western US. In his contingent valuation study, the author found that people would be willing to pay USD 241.26 per household for the implementation of invasive species control measures.

Valuation Summary

Below, we provide a summary table with some examples of values linked to forest tree health presented in the reviewed studies, as described in this section.

Table 26. Summary table with some examples of forest plant health values reviewed in this report (full details given in the Woodland Valuation Tool).

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Sheremet et al. (2017)	GBP 6.4	Per household and year value of a management program to prevent pest and diseases and avoid negative effects of outbreaks on biodiversity in UK forests	Choice experiment	GBP	General public
Meldrum (2015)	USD 241.26	Per household (one-off) value of a program to manage invasive, non-native pathogens causing lethal diseases in forests in Western US.	Contingent valuation	USD (2010)	General public

Research gaps

Based on the material reviewed in this report, literature seems to be particularly incomplete with respect to the understanding of the benefits of forest plant health. There is limited understanding of the concept of 'plant health' and little knowledge of the biophysical mechanisms that encourage or prevent the spread of pests and diseases in forests. As a result, little evidence is available on the economic value of forest plant health, both in rural and urban settings. Given the scarcity of literature focusing on this topic, no support tool was found to help planning and decision-making. Based on the above points, the following research gaps can be identified:

Table 27. Colour-coded summary table of available evidence on plant (tree) health: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is limited understanding around the concept of plant health and scarce knowledge regarding the mechanisms through which plant health can be affected.	There is very scarce valuation research on plant health, with only few examples focusing on pest and disease control. More efforts are needed in the future in this field of study.	In the review of new studies, no new decision support tool was found on the topic of forest plant health.	None of the reviewed studies so far have focused on plant health in forest urban settings. Given the value of urban greenspace for people, this area deserves future attention.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

The above conclusions match with those outlined in the review of the literature on forest plant health prior to 2015, discussed in the Binner et al. (2017) report. Although the latter does not provide any colour-coded assessment for plant health, we have instead relied upon the conclusions and research gaps identified in the text of the report to evaluate the strength of the available evidence.

By combining the pre and post-2015 reviews, the resulting consolidated assessment of research gaps to date can be summarized as follows:

Table 28. Colour-coded summary table showing a consolidated assessment of available evidence on plant (tree) health, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is limited understanding around the concept of plant health and limited knowledge of the counterfactual (i.e. situation without pest/disease outbreak).	There is very scarce valuation research on plant health, with only few examples focusing on pest and disease control. More efforts are needed in the future in this field of study.	More research is needed regarding the biophysical processes and the values linked to plant health before decision support tools can be developed.	There is insufficient understanding of the mechanisms and drivers of pests and diseases in urban settings. Given the value of urban greenspace for people, this area deserves future attention.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.7. Water quality

One additional valuation study on the benefits of forests in terms of water quality was added to the 18 valuation studies previously identified on this topic in Binner et al. (2017), for a total of 19 valuation studies currently detailed in the Woodland Valuation Tool.

Review

Some recent studies have explored the link between trees and water quality. Pérez-Silos (2017) summarized the effect of woodland creation on reducing the concentration of various diffuse pollutants in water (including suspended solids/sediments, nitrates, ammonium, phosphate, atrazine [pesticide]). Papanastasis et al. (2017) discuss the role of forests in supporting soil functionality, which positively contributes to good water quality. In particular, they argue that forest plant cover encourages soil stability, which allows for water filtration without sediment runoff and hence, leads to high water quality. Similarly, Baral et al. (2016) also point out the role of woodlands in the filtration, retention and storage of freshwater available for human consumption and industrial use.

Despite all of the above studies recognizing the beneficial effect of woodlands on water quality, they also acknowledge that this effect varies substantially depending on the forest management regime. For example, Seidl et al. (2016) concludes that increasing disturbances can lead to increased soil erosion and to leaching of nitrates, which reduce water quality. Based on this, forest plantations are sometimes less effective than natural forests in regulating water and sediment fluxes. This is, though, not the case in the UK, where the UK Forestry Standard (https://www.forestry.gov.uk/ukfs) is specifically designed to prevent such negative impacts from forest plantations.

Within the literature reviewed in this report, only one study has focused on valuing the benefits that forests provide in terms of water quality. By considering the volume of fresh water consumed and the market price of domestic water, Häyhä et al. (2015) estimated that the value of water filtration services provided by forests in the Trentino region (Italy) is EUR 75 per ha per year.

Valuation Summary

Below, we provide a summary table of the values of improved water quality in forested areas, based on the literature reviewed in this report.

Table 29. Summary table with some examples of forest-related water quality values, based on the review presented in this report (full details given in the Woodland Valuation Tool).

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Häyhä et al. (2015)	EUR 75	Per ha and year value of water filtration services provided by forests in the Trentino region (Italy)	market price	EUR (valuation year not available)	

Research gaps

Based on the material reviewed in this report, we can identify a number of dimensions across which the research literature on the benefits of forests on water quality, is incomplete (summarized below). Overall, some recent research has improved the understanding of the biophysical mechanisms through which woodland creation can boost water quality. However, little is still known about the corresponding economic value to people, both in rural and urban areas. Because of the scarcity of research on this topic, no decision-support tool is available to help policy-making. More efforts would be desirable in this area in the future.

Table 30. Colour-coded summary table of available evidence on the role of forests and trees on water quality: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Some studies have explored the link between woodlands and water quality. Although the knowledge base has improved, some research gaps still exist, for example, with respect to the role of site hydrology, soil type, forest design and woodland management.	There is very scarce research on the non-market benefits of water quality linked to forests. More research is also needed to understand the appropriate geographical scale at which the impacts of forests on water quality should be studied (i.e. small scale versus catchment scale).	In the review of new forest studies, no decision support tool was found on the topic of water quality.	None of the post-2015 reviewed studies have focused on water quality in urban forest areas. Special attention needs to be deserved to the consideration of upstream versus downstream impacts, given that urban centres are often located downstream.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

These conclusions largely coincide with those drawn in the review of the literature prior to 2015 (presented in Binner et al. 2017 and summarized below). The main difference is related to the available evidence focusing on the biophysical processes, through which forests affect water quality. In the report focusing on the evidence prior to 2015, major gaps were identified in this area, while in the post-2015 literature reviewed in the present report, only some gaps were detected.

Table 31. Colour-coded summary table of available evidence on the role of forests and trees on water quality: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Many studies fail to link water quality outcomes to woodland management or planting actions. This makes it difficult to establish causality and limits the usefulness of	There is a need to extend the valuation of different pollutants and their removal from waterways. This needs to be flexible in terms of the scale of analyses embracing both	The evidence base needs to be developed to facilitate the development of accessible decision support tools that incorporate water quality.	There is limited existing information on the relationships between urban trees and water quality (e.g. their role in reducing sewage treatment costs and

existing studies for investment appraisal when the objective is to achieve specific improvements in water quality.	catchment and national levels.		improving urban recreation).

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

When we combine the evidence gaps identified in the present report with those highlighted in Binner et al. (2017), it is possible to produce a consolidated assessment of research gaps to date which can be summarized as follows:

Table 32. Colour-coded summary table showing a consolidated assessment of available evidence on the role of forests and trees on water quality, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Many studies fail to link water quality outcomes to woodland management or planting actions, but some evidence is starting to be produced on this area of study. There are still research gaps concerning the relationship between forested areas and better water quality and the factors affecting or mediating this relationship.	There is relatively scarce research on the non-market benefits of water quality linked to forests. More research is also needed to understand the appropriate geographical scale at which forest impacts on water quality should be studied (i.e. small scale versus catchment scale). More should be explored on the valuation of different pollutants and their removal from waterways.	More biophysical and valuation evidence needs to be produced to facilitate the development of accessible support tools that incorporate water quality.	There is limited existing information on the relationship between urban trees and water quality (e.g. their role in reducing sewage treatment costs and improving urban recreation). Special consideration is required for upstream versus downstream impacts, given that urban centres are often located downstream.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.8. Water quantity (and flood alleviation)

5 additional valuation studies on the effect of forests on flood alleviation were added to the 12 valuation studies previously identified in Binner et al (2017), resulting in a total of 17 valuation studies currently detailed in the Woodland Valuation Tool.

Review

In the published biophysical literature reviewed in this report, some attention was dedicated to the influence of trees on water quantity (Balthazar et al. 2015; Baral et al. 2016). Forests play a role in intercepting rainfall and they also contribute to accumulating water content underground, hereby impacting on flow discharge. Because of this, forests supply an important service to society by providing a natural infrastructure against hazards, such as flooding and snow avalanches. Generally, management practices that interfere with forests' natural processes are acknowledged to contribute to reduce woodlands' capacity to provide a buffering effect on water run-off (Seidl et al. 2016).

In the UK, a recent study for the Forestry Commission (Dixon and Pettit 2017) investigated the impact of woodland creation on catchment hydrological processes in Southwell (England). To estimate the hydraulic models, both above-ground and below-ground processes were considered. Woodland expansion was found to reduce flood risks by: increasing infiltration of water into the soil profile through maintaining soil macroporosity; increasing rain interception before it reaches the land surface; and reducing (through the presence of tree trunks and woody material) the speed at which the flow travels through wooded areas. In the study, flood risk reduction, measured as the decrease in the number of properties removed from flood risk due to woodland creation, was found to be significant, particularly in the presence of medium and larger flood events, rather than lower order events. Interestingly, for the case study area considered, flood risk rate was found not to be statistically related to the type of woodland cover (i.e. conifer versus broadleaf).

Regarding the value of flow control services provided by forests, only little evidence was provided by the recent literature reviewed for this report. One study is Holt and Rouquette (2017), who focused on a specific catchment area in Marston Vale (England) to explore the economic value of flood alleviation linked to woodland creation. The value of the flow control services provided by woodlands is estimated starting from information on avoided costs. Data on the relationship between woodland cover and peak flow reduction, as well as data on the decrease in annual fluvial flood expenditure, were taken from Smithers et al. (2016)[19]. The average reduction in annual fluvial flood expenditure per hectare of woodland created was reported to be GBP 24.30. With respect to this figure, several

[19] Smithers, R., Korkeala, O., Whiteley, G., Brace, S. & Holmes, B. (2016) Valuing flood regulation services for inclusion in the UK ecosystem accounts. Ricardo Energy & Environment for UK Office for National Statistics.

caveats need to be acknowledged. Information on flood expenditure comes only from one study, which focused on an upland area, in a specific part of the country. Based on this, reported values could be very different for different settings, as acknowledged by Smithers et al. (2016) and Holt and Rouquette (2017). In addition, focusing only on savings in flood-related investment costs is likely to under-estimate the social value of reduced flood risks. For example, such an approach overlooks a substantial amount of flood-related costs, including the negative impacts of flooding on people's health or the costs of flooding to private households and commercial activities, in terms of lost properties and missed income opportunities.

A similar problem is also found in Dixon and Pettit (2017). This study, prepared for the Forestry Commission, focuses on the benefits of reduced flood damages achievable through woodland creation in the Southwell area (England). Starting from a detailed hydraulic model estimating the effect of woodland expansion on flood risk reduction, the authors relied on data available from published literature to estimate the monetary value of reduced flood-related damages. For example, the authors report the value of avoiding health and wellbeing impacts linked to fluvial flooding to be GBP 286 per household, per year. This value includes the benefits of avoiding the stress of flooding and of preventing other flood-related general health impacts. There is some disagreement regarding the accuracy and reliability of this figure, though. In fact, it doesn't consider the risk to life which, whilst rare, has a significant impact on the calculation of the full benefits for health and wellbeing of reduced flood risk. Other examples of figures reported in Dixon and Pettit (2017) include the value of avoiding indirect dry-out costs (GBP 774.80 per property) and the value of avoiding the costs of vehicle losses (GBP 3 100 per property).

Regarding the role of trees in providing flood alleviation services specifically in urban settings, some recent UK studies (Mutch et al. 2017, Moffat et al. 2017, Rogers et al. 2018) are worth mentioning. These studies first estimate the total amount of water interception attributed to urban trees, by using the i-Tree Eco survey[20], and then multiply this amount by the rate charged by the local water company for sewerage. This way, the authors provide information on the valuation of avoided surface water runoff which is attributable to the presence of urban trees. Based on this, Mutch et al. (2017) estimates that urban trees in Southampton intercept about 95 million litres of water every year and the value of the associated avoided water runoff is GBP 142 894. Moffat et al. (2017) estimate that urban trees in Petersfield intercept about 12 800 000 litres of water every year, which provides benefits worth GBP 17 200. Rogers et al. (2018) estimate that urban trees in London (Ealing) intercept about 74,435 m^3 of water per year and the value of the associated avoided water runoff is calculated to be GBP 113 000.

[20] i-Tree Eco is one of the i-Tree suite applications and i-Tree is a data-driven tool based on the forestry inventory, which estimates tree benefits and management costs. The tool reports annual total and per tree values for, among other things, avoided surface water runoff. For more information on i-Tree and a wider selection of existing reports, please visit www.forestry.gov.uk/fr/itree and for an evaluation of the impact of i-Tree in the UK, please refer to www.forestry.gov.uk/fr/itree-evaluation.

Valuation Summary

Below, we provide a summary table of the evidence reviewed in this section on the values linked to flow control in forested areas.

Table 33. Summary table with some examples of forest-related flow control values, based on the review presented in this report (full details given in the Woodland Valuation Tool).

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Holt and Rouquette (2017)	GBP 24.3	Per ha (of woodland created) and year value of a reduction in annual flood expenditure resulting from the establishment of a new woodland area in Marston Vale (England)	Secondary literature	GBP (2015)	
Dixon and Pettit (2017)	GBP 286	Per household and year value of avoiding health and wellbeing impacts of fluvial flooding in Southwell, Nottinghamshire (England)	Avoided costs (secondary literature)	GBP (2005 or 2013, depending on the item considered)	Residential property owners
Mutch et al. (2017)	GBP 142 894	Annual value of intercepting about 95 000 000 litres of water every year and avoiding associated water runoff in Southampton	i-Tree-Eco	GBP (2016)	General public
Moffat et al. (2017)	GBP 17 200	Annual value of intercepting about 12 800 000 litres of water every year and avoiding associated water runoff in Petersfield.	i-Tree-Eco	GBP (2016)	General public
Rogers et al. (2018)	GBP 113 000	Annual value of intercepting about 74,435 m^3 of water per year and avoiding associated water runoff in London (Ealing)	i-Tree-Eco	GBP (2017)	General public

Research gaps

Based on the material reviewed in this report, some recent research was found focusing on the effect of woodlands on water storage, flow control and the value of this service for society. However, such research is limited, both in terms of the number of available studies and in terms of the geographical scale considered. Only little evidence was found regarding applications of existing decision support tools (i.e. i-Tree Eco) to better understand the role of woodlands in flood control. It is possible to conclude that the dimensions across which the post-2015 reviewed literature is incomplete are as follows:

Table 34. Colour-coded summary table of available evidence on the role of forests and trees on water quantity regulation: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Relatively few studies have explored the link between woodlands and water quantity and the mechanisms through which forests provide water flow control services. Some examples of sophisticated hydrological models are available at local scale, but less is known about the role of forests on hydrological dynamics at regional scale.	There is some research on the non-market benefits of forests in terms of flow control. However, significant gaps remain regarding the understanding of the relationship (linear or non-linear) between changes in flood risk and welfare. As for water quality, more research is also needed to understand the appropriate geographical scale to be considered when studying the impacts of woodlands on flood risk reduction.	In the review of new forest studies, only limited evidence was found regarding the application of existing decision support tools (e.g. i-Tree Eco) to aid policy-making in the field of flood regulation.	Only little recent evidence is available on the benefits of forests on flood risk reduction in urban areas, particularly in relation to flood risk upstream versus downstream. Given that flooding can potentially affect a high number of people in urban centres downstream, this issue deserves more attention.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Binner et al. (2017), discussing the available evidence and gaps relative to the literature published prior to 2015, drew similar conclusions. However, their colour-coded assessment (summarized below) presents one main difference: it signalled the existence of more significant research gaps, with respect to the biophysical evidence on the impacts of forests on flood regulation.

Table 35. Colour-coded summary table of available evidence on the role of forests and trees on water quantity regulation: reviewed studies covering the period prior to 2015, based on Binner et al. (2017)

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Data are needed to validate models, (e.g. at catchment scale). Robust biophysical evidence quantifying the relationship between local woodland management, location and forest design, and changes in the quantity of water available is needed to support reliable valuation and decision-making. The impact of climate change and rising CO_2 levels on the water use of trees needs to be examined as this will affect the services (dis-services) provided in the future.	Key business interests such as manufacturing and industrial production, agriculture and the energy sector are all potential beneficiaries for whom values associated with water quantity are not robustly known.	There is a clear need to integrate the variety of values associated with water resources and the role that woodlands can play in enhancing these.	i-Tree Eco includes a module which uses hydrological models developed for the USA to compute the quantity of storm water capture. The value of avoided runoff is based on estimated or user-defined local values. As the local values include the cost of treating the water as part of a combined sewage system the lower, national average externality value for the USA is utilised and converted to local currency with user-defined exchange rates.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Given the above, when combining the available evidence on the importance of woodlands for flow control, the consolidated assessment shows an upgrade (with respect to Binner et al. 2017) in the colour coding used to evaluate the biophysical evidence available (from red to orange). The consolidated assessment can be summarized as follows:

Table 36. Colour-coded summary table showing a consolidated assessment of available evidence on the role of forests and trees on water quantity regulation, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
Some studies have explored the link between woodlands and water quantity and the mechanisms through which services of water flow control are provided by forests. However, data are needed to validate models. Robust biophysical evidence is also needed on the quantification of the relationship between local woodland management, location and forest design and changes in the water quantity available. The impacts of climate change will also need to be better understood.	There is some research on the non-market benefits of water quantity linked to forests. However, as for water quality, more research is also needed to understand the appropriate geographical scale at which forests affect water quantity. The benefits of water quantity regulation for potential beneficiaries such as agriculture, the energy sector, the manufacturing and industry sectors are not robustly known.	There is a clear need to integrate the variety of values associated with water resources and the role that woodlands can play in enhancing these.	Some evidence is available on the benefits of water quantity regulation supplied by urban forests. Given that flooding can potentially affect a high number of people in urban centres downstream, more attention should be deserved to the role of forests on water flow regulation upstream and downstream.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

6.9. Urban trees

11 additional valuation studies focusing on urban trees were added to the 21 valuation studies previously identified in Binner et al. (2017), for a total of 32 valuation studies currently detailed in the Woodland Valuation Tool.

Review

Trees in urban areas support the provision of the same ecosystem services and goods provided by trees in non-urban areas. However, the major difference is that urban woodlands often extend over small patches of land and are located in close proximity to where a lot of people live, which makes them particularly valuable. Despite the importance of urban trees and forests, relatively little attention was paid to this topic by the literature reviewed in this report.

In our review of the latest evidence on forest biophysical studies, only one article discussed the role of forests in urban and peri-urban areas (Lwasa et al. 2015). By means of a meta-analysis, Lwasa et al. (2015) highlighted the role of urban trees particularly in climate regulation. In addition to stabilising global climate through carbon sequestration, urban trees are also important for local climate by contributing to the reduction of urban heat islands.

Evidence on the economic value of urban forests equally was found to be scarce. Indeed, only few valuation studies were explicitly conducted at urban/city scale and/or focused on ecosystem services provided by forests in urban areas.

At UK level, Holt and Rouquette (2017) found that vicinity to a woodland can contribute to an increase in house prices by GBP 734 per household per year. Dixon and Pettit (2017) discussed the value of reduced flood damages linked to the existence of forests in Southwell (England). They reported the value of avoiding health and wellbeing impacts related to fluvial flooding to be GBP 286 per household and year, the value of avoiding indirect dry-out costs to be GBP 774.80 per property, and the value of avoiding costs in terms of flood-related vehicle losses to be GBP 3 100 per property. Some evidence was also found at UK level on the value of single trees in urban areas: Mutch et al. (2017), Moffat et al. (2017) and Rogers et al. (2018) focused on several ecosystem services provided by urban trees in Southampton, Petersfield and London (Ealing), respectively. By means of the i-Tree Eco Tool, these studies particularly estimated the value provided by urban trees in terms of carbon storage and sequestration, air purification services (reduction in the concentration of airborne pollutants) and avoidance of surface water runoff. For example, Mutch et al. (2017) estimated that the annual value of urban trees in Southampton, contributing to intercepting about 95 000 000 litres of water every year and reducing the risk of flooding, is GBP 142 894; Moffat et al. (2017) estimated that the per year value of Petersfield urban trees in terms of carbon storage (about 18 260 tonnes of carbon annually) is GBP 4 220 000; Rogers et al. (2018) estimated that the value of urban trees in Ealing (London), which contribute to the removal of airborne pollutants (about 33 tonnes of carbon per year), is about GBP 952 000 annually.

Outside the UK, Chen et al. (2015) investigated urban residents' preferences for increasing the surface of woodland acreage in town. Based on their choice experiment results, they found that people would be willing to pay between USD 7.73 and USD 9.26 per household for each extra acre of forest preserved close to home. Through a contingent valuation exercise, Borzykowski et al. (2018) explored the value of increasing the surface of protected forests around the city of Geneva (Switzerland) from 5% to 10% of the total forested cover. They found that members of the general public would be willing to pay between CHF 182.34 and CHF 334.65 per person (depending on the parametric distribution considered in the model) for an increase in the forest area close to the place of residence. Ahlheim et al. (2015) estimated the preferences of the urban population in the South-west of China for the reforestation of a rubber plantation area. In their contingent valuation exercise, they found that people would be willing to pay CNY 163.84 per household, per year for the proposed environmental improvement. By using a contingent valuation approach, Dare et al. (2015) estimated the benefits of tree management in an urban area in Nigeria. The authors estimated the value of urban trees, providing good scents and nice scenery to local residents, to be NGN 365.69 per individual, per month. Escobedo et al. (2015) estimated the value of additional trees and the effect of urban tree structure on property prices in the US. By using a hedonic price approach, they found that the home price premium associated with each additional tree close to the property is USD 1 586 per home. In addition, they found that the home price premium linked to each extra unit of increase in the Leaf Area Index (an indicator used to measure the proportion of leaf area over ground area) is USD 9 348 per home.

Among the studies reviewed in this report, only a limited number also focused on the recreational benefits of forests in urban areas. For example, Calleja et al. (2017), by means of a contingent valuation study conducted in the Retiro Park in Madrid (Spain), found that visitors would be willing to pay EUR 6.36 per person for a reduction in the amount of noise and more tranquillity in the park. Similarly, Lupp et al. (2016) focused on estimating the preferences of visitors for two woodland parks in the metropolitan area of Munich (Germany).

Valuation Summary

Table 37 (below) provides a summary with examples of values linked to urban forest benefits, based on the review of studies described in this section.

Table 37. Summary table with some examples of values supplied by urban forests, based on the review presented in this report (full details given in the Woodland Valuation Tool)

Source	Value	What it refers to	Method	Currency (and valuation year)	Sample
Holt and Rouquette (2017)	GBP 734	Per household and year home price premium if the property has a woodland view on the urban fringe.	Hedonic price method	GBP (2015)	Property owners
Dixon and Pettit (2017)	GBP 286	Per household and year value of avoiding health and wellbeing impacts of fluvial flooding in Southwell, Nottinghamshire (England)	Avoided costs (secondary literature)	GBP (2005 or 2013, depending on the item considered)	Residential property owners

Mutch et al. (2017)	GBP 142 894	Annual value of intercepting about 95 000 000 litres of water every year and avoiding associated water runoff in Southampton	i-Tree-Eco	GBP (2016)	General public
Moffat et al. (2017)	GBP 4 220 000	Per year value of carbon storage services (about 18 260 tonnes of carbon) provided by Petersfield urban trees	Carbon price	GBP (2016)	General public
Rogers et al. (2018)	GBP 952 000	Annual value of removing about 33 tonnes of airborne pollutants in woodlands in Ealing (London).	i-Tree tool	GBP (2017)	General public
Chen et al. (2015)	USD 7.73- USD 9.26	Per household value of each extra acre of forest preserved close to home in selected urbanizations in Rhode Island (US)	Choice experiment	USD (2015)	General public
Borzykowski et al. (2018)	CHF 182.34- CHF 334.65	Per person (one-off) value of increasing the surface of protected forests in the Geneva area (from 5% to 10%)	Contingent valuation	CHF (2014)	General public
Ahlheim et al. (2015)	CNY 163.84	Per household and year value of the reforestation of a rubber plantation area in South-West China	Contingent Valuation	CNY (2009)	General public
Dare et al. (2015)	NGN 365.69	Per person and month value of urban forest management, providing ecosystem services to residents in terms of scent and scenery, in urban areas in Nigeria	Contingent valuation	NGN	Urban residents
Escobedo et al. (2015)	USD 1 586	Per home price premium for each extra tree close to the property in a study in the US.	Hedonic price method	USD (2008-09)	Urban residents
Calleja et al. (2017)	EUR 6.36	Per visitor (one-off) value of tranquillity (noise reduction) in the Retiro Park (Madrid, Spain)	Contingent valuation	EUR (2015)	Visitors
Lupp et al. (2016)	EUR 2 913.57 and EUR 15 440	Per ha and year value of two urban woodlands in the Munich metropolitan area (Germany)	Miscellaneous	EUR (2016)	Visitors

Research gaps

Based on the material reviewed in this report, we can identify a number of dimensions across which the research literature on the benefits of urban forests is incomplete. Since the Binner et al. (2017) report, some additional evidence was found on the role of urban trees in climate regulation. Some recent studies also focused on the amenity value that urban trees provide to residents. However, little has been done in terms of applying existing decision support tools or developing new ones to help policy-makers and planners to take better decisions regarding urban tree management. The research gaps identified based on the material reviewed in this report can be summarized as follows:

Table 38. Colour-coded summary table of available evidence on the role of urban trees: reviewed studies covering the period 2015 to the present day

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
There is a relatively good understanding of the biophysical processes through which urban trees contribute to climate regulation, but major gaps exist with respect to other services.	Some valuation evidence is available regarding the impact of urban trees on house prices or recreation values but more efforts should be put in place in the future to better understand the effect on other types of values.	In the review of new studies, only limited evidence was found of the application of existing decision support tools in urban setting.	Among the latest reviewed valuation evidence, relatively scarce attention was paid to the benefits provided by urban trees.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

Although Binner et al. (2017) do not provide a formal colour-coded assessment of research gaps regarding the role of urban trees, we relied upon the conclusions drawn in the text of their report to identify the available evidence and incomplete knowledge areas for the period prior to 2015. Based on this, no significant differences could be identified, in terms of research gaps, relative to the material reviewed in this report. In both reports, biophysical and valuation evidence on urban trees emerged to be patchy and generally scarce.

Taking the above into account, the combination of the recommendations presented in Binner et al. (2017) with the conclusions identified in the present report, allows to produce a consolidated assessment of research gaps to date, which can be illustrated as follows:

Table 39. Colour-coded summary table showing a consolidated assessment of available evidence on the role of urban trees, based on reviewed studies prior to, as well as posterior to, 2015

Biophysical evidence	Valuation evidence	Decision support tools	Urban tree literature
The understanding of the mechanisms through which urban woodlands provide benefits to people is relatively good for some ecosystem services (i.e. recreation), but not for others (i.e. air quality, water quality and quantity, physical and mental health).	Some valuation evidence is available on urban forests. There seems to be significant research on the climate-related benefits of urban forests, but major gaps remain with respect to the other ecosystem services.	Some tools are available, bringing together the existing evidence on the benefits of urban forests (e.g. i-Tree, CAVAT, Helliwell), but decision supporting tools would benefit from refined knowledge on the biophysical and valuation evidence.	Overall, there are some areas or topics where knowledge is relatively consolidated, but more efforts are still required to fill in the existing research gaps regarding urban woodland values.

Key: Strong evidence, with few gaps; Some evidence, but with significant gaps; Major gaps in evidence

7. Conclusions

Based on the literature review carried out for this report, and focusing on the biophysical and economic valuation evidence on forest benefits from 2015 to the present date, several main conclusions can be drawn, as we will discuss in this section.

Results of our review suggest that there is mixed understanding regarding: 1) forest-related biophysical processes, through which woodlands supply environmental goods and services that are of relevance to people, and 2) the economic values that people derive from the appreciation of such goods and services. While there is a relatively good biophysical understanding of some of the benefits provided by forests (i.e. recreation or carbon sequestration), this is far less so in the case of other ecosystem goods and services. Based on our review, priority areas include the development of a sets of appropriate biophysical indicators to measure environmental change especially in relation to biodiversity, physical and mental health, plant health etc. Within the economic valuation literature, more evidence will need to be produced on the monetized benefits of plant health, physical and mental health, but also water quality and quantity related to forest ecosystems. Given the importance of these under-researched ecosystem services for human wellbeing, more efforts are encouraged within the biophysical and valuation literatures in this area in the future.

For valuation estimates to be meaningful and policy relevant, two aspects are particularly important and deserve more attention in the future: 1) research in the natural science and in economic valuation should be progressed in an integrated and coordinated way, provided that valuation evidence should be grounded on a robust biophysical evidence; 2) more interaction and collaboration should be sought between researchers and policy-makers to identify and discuss priorities. In this light, it is expected that the development of decision support tools, integrating knowledge on the biophysical and valuation evidence and tailored to address specific policy-relevant issues, will become of paramount importance to guide decision-making around forest management.

Based on our review, some recent evidence is available on the values of forest benefits at UK level. However, while it is true that the wider international research literature is growing, more efforts should be encouraged within the UK, given that transferring values from one location to another (especially across countries) is prone to errors. In our review of recent literature, we have incorporated examples of studies also from outside the UK to collect the latest available evidence on methods used and issues raised in forest valuation. However, we have strong reservations about using the reported non-UK values in a UK context. Values are formed in specific settings and it is likely that differences in preferences, environmental conditions, income levels, etc. exist across different countries and can drive differences in willingness to pay. For some of these factors, adjustments could be easily introduced in willingness to pay values. For instance, values can be weighted by the purchase power parity (PPP) index to account for differences in income and consumers' purchasing power across countries. However, it is more difficult to adjust willingness to pay values to account for other aspects, including differences in preferences across individuals and groups or differences in available substitute sites across countries. Our recommendation is that, without appropriate adjustments, the values obtained from international studies should not be used in a UK context. More information is provided in Annex 1 regarding available methods for value adjustment and value function transfer. In any case, it is worth noting that even after adjustments in willingness to pay are introduced, transferring values from one site to another is still subject to some error. Exploring the likelihood of making an error when transferring values across different case study areas would be helpful to better inform decision-makers regarding the appropriateness of using international valuation studies in a UK context.

Given the relatively broad geographical scale considered by most of the reviewed studies (e.g. either national or regional), it seems important to progress research on forest benefits also at a finer scale. For example, to better understand the impacts of forests on water quantity and quality, the design of catchment-wide scale studies, as well as the consideration of upstream and downstream impacts, are expected to be particularly useful to inform decision-making processes. In addition, although some of the reviewed studies have accounted for spatial patterns in the analysis of preferences (e.g. transboundary or nation-wide valuation studies), this area of research is still in its infancy. Some studies have provided evidence of distance-decay also in the presence of non-use values, where theoretically the location of the improvement (with respect to the respondent) should not matter.

However, beyond distance-decay effects, other spatial patterns of preferences for forest benefits could also be worth considering.

Our review has highlighted a particularly high number of studies using stated preference methods to estimate the benefits provided by forests. Although these techniques are robustly grounded on welfare theories and sometimes they are the only option available when the objective is to evaluate preferences for hypothetical scenarios, they can also be subject to some bias if respondents are not familiar with the valuation scenario or behave in a strategic (untruthful) way. In such circumstances, the existing valuation evidence can be enriched by the use of revealed preference methods. This is because revealed preference techniques, based on people's observed decisions and actions rather than declared intentions, have the potential to provide more realistic behavioural insights on individuals' preferences.

The reviewed literature has shown high heterogeneity both in terms of the attributes valued as well as in terms of the estimated willingness to pay. In this sense, it seems necessary to better understand the drivers and causes of such heterogeneity in values. This includes the consideration of socio-demographic and context-specific variables, which are only rarely controlled for in the studies revised in the present report.

8. Next steps and research priorities

This report presents the latest evidence on the economic values of forests benefits, alongside an assessment of valuation research gaps. Addressing these gaps remains both a priority and a substantial research challenge and in the meantime reviews such as that presented here play a useful part in bringing together what remains a somewhat organically evolving literature. To that end the Woodland Valuation Tool in its present format summarizes a considerable amount of information on forest values. However, at the moment, comparing economic values is not easy. This is because the values currently reported in the Tool refer to a mixture of different environmental changes and are reported sometimes as aggregate values and sometimes as unit values. In addition, values are recorded in different currencies and valuation years. In order to make the valuation evidence comparable, more efforts should be made to calculate marginal values, that is unit rather than aggregate values. At the same time, the estimated willingness to pay values should be reported using a standardized currency (often USD) and by considering one homogeneous year of reference for the valuation. Once these steps are taken, the estimated values across studies can be meaningfully compared.

Starting from such standardized marginal values, a meta-analysis of forest values could then be performed. This would allow us to regress forest values for given environmental goods and services as a function of selected determinants, to better understand the drivers of values and attempt to explain the variability across studies. Possible determinants that can explain differences in values include: the country where the valuation evidence was collected, the payment vehicle used, the final environmental good and service considered and the magnitude of the change, the valuation method employed, the geographical scale and average distance of respondents to the improvement site etc. However, to perform a meta-analysis the reviewed studies should be carefully selected and only those focusing on similar settings and public goods should be screened for consideration. This will likely reduce the number of possible observations suitable for meta-analysis, which is not ideal for statistical exploitation.

To overcome this potential problem, extra evidence, particularly at UK level to minimise transferability issues, could be added to the Woodland Valuation Tool database. In this sense, additional evidence can be incorporated by considering smaller or larger scale studies. Although there is a need for both, the consideration of larger scale studies offers particularly good opportunities if the objective is to collect nation-wide evidence. By relying on single-design and big valuation studies there is the potential to develop more accurate and robust and hence policy-relevant analyses. UK scale valuation exercises, for instance, exist for recreation values and results are summarized in the Outdoor Recreation Valuation Tool – ORVal (based on the UK survey "Monitor of Engagement with the Natural Environment"). Beyond recreation, other UK-scale biophysical and valuation evidence on food production, water quality and quantity, greenhouse gas storage and biodiversity are currently being integrated into the NEVO (Natural Environment Valuation Online) Tool. This tool is currently being developed by the Land, Environment and Economics and Policy (LEEP) Institute at the University of Exeter and it will aim to integrate existing biophysical models into existing valuation models, through a value transfer approach, to explore how the characteristics of the environment and alternative uses can affect benefits and alter trade-offs. Where secondary valuation evidence is not available, information should be collected through primary valuation exercises.

A.1. Annex 1 Methods for valuing non-market goods and services.

Prices and values are often not the same thing. The proof of this difference is commonplace. For example, some of the most valuable recreation sites in the world are free to enter. This zero entrance price in no way equates to the value of these resources and any decision maker who ignores this difference is likely to make poor decisions. Economic research has sought to provide the value evidence required for good decision making by developing the following methods:

- *Production Function Methods:* Many ecosystem services provide valuable but unpriced inputs to the production of market goods, e.g. rainwater and crop pollination are vital for food production. One widely applicable strategy for valuing these services is to examine the change in value of production generated by nature's services (Barbier 2007, Hanley and Barbier 2009). Fezzi et al. (2014) undertake such a 'production function' analysis to examine the consequences of future climate change on agriculture. They estimate the effect of rainfall and temperature on food output.
- *Revealed Preference Methods:* The value of many non-market, unpriced ecosystem services can be revealed by examining people's behaviour. For example, while many outdoor recreation sites are free to access, visiting them often imposes travel and time costs on individuals, thereby introducing a trade-off between those costs and the wellbeing individuals experience from visits from which values can be assessed (Bateman et al., 2016). Those studies following such an approach employ a method called the travel cost method. Similarly, such 'revealed preference' methods have used people's house purchase decisions to value reduced levels of road, rail and air noise (Day et al., 2007) and better air quality (Chay and Greenstone, 2005), following an approach called 'hedonic price' method. Other studies of safety equipment purchases (Jenkins et al. 2001) and wage rates across risky jobs (Arnould and Nichols, 1983) have been used to estimate values for health risk reduction.
- *Stated Preference Methods:* the methods described above rely on behaviour observed directly or indirectly in existing markets. However, decision makers may be interested in assessing the value of changes that have not yet occurred. While one option is to extrapolate from existing revealed preference data, an alternative approach is to use surveys or experiments in which subjects are presented with choices regarding proposed changes in non-market goods such as environmental quality (Bateman et al. 2002). Methods falling under this category include the choice experiment and the contingent valuation approach. For example, Chalak et al., 2012 asked consumers a series of questions concerning the amount they would be prepared to pay, in higher bills, for their utility providers to adopt low carbon technologies. Such stated preference (SP) techniques have been used widely in the valuation of environmental goods and services as they directly tap in to the views of the individual. Studies can examine either the willingness to pay for environmental improvements or the value of avoiding some defined chance of environmental decrements. Stated preference techniques are in some cases the only available valuation method and are more suitable in situations where those providing valuations are familiar with the good in question,

understand the consequences of change and have strong incentives to answering questions in an unbiased manner (Day et al. 2012).

- *Value transfer methods:* The methods outlined above can require considerable investments of time and resources to implement robustly. Consequently researchers have developed techniques to transfer values from previous studies to obtain lower cost, rapid valuations which can be adapted to the conditions of a given decision making situation (Plummer 2009, Bateman et al. 2011, Brander et al. 2012, Richardson et al. 2015). Three main alternative approaches are available for value transfer: 1) transfer of unadjusted or somehow adjusted point estimates; 2) meta-analyses; and 3) transfer of value functions.
  - The first approach assumes that values for a similar change and good, available from the literature, can be applied to a different but similar site and population without the need for further adjustments or by introducing minimal adjustments (e.g. to account for income differences across the sampled population).
  - The second approach (meta-analysis) relies on synthesising evidence on a particular empirical outcome based on different prior primary studies in similar but different contexts (Bateman and Jones 2003). When used for value transfer purposes, meta-analyses are most often applied to identify and test systematic influences of valuation methods, study, economic, and resource attributes on WTP, characterize results of the literature addressing certain types of nonmarket values, and so on. Meta-analyses usually rely on relatively smaller sample size because it is not easy to find primary studies with similar focus and, in most of cases, the only information that can be controlled for across all studies is related to methodological variables.
  - The third approach for benefit transfer relies on the consideration of the value function transfer approach (Bateman et al. 2011). This method requires the consideration of multiple studies with identical design or one single study based on a considerable number of observations. By keeping the design constant, value function transfer approaches do not require to control for methodological variables (as in the case of meta-analyses). They rather allow to explore the role of more (theoretically) interesting variables explaining differences in values, such as the quantity or quality of the good being valued, the characteristics of individuals or populations (e.g., income, education), or other site characteristics such as the price, quality or availability of substitutes.

Regardless of the value transfer approach considered, it is always good practice to measure the degree of error that one would make when transferring values from one (similar but different) setting to another one of interest. Literature suggests that the value function transfers are usually associated with a lower transfer error (a smaller difference between the true and transferred value). Mixed results are available regarding the potential for meta-analysis to achieve more robust and accurate value transfers relative to alternative methods (Johnston et al. 2015).

- *Cost-based (non-valuation) methods:* While values are the ideal inputs to decision making, in some circumstances cost estimates provide sufficient information for a decision to be made. For example, Heal (2000) discusses the case of whether or not to take the valleys supplying water to New York out of polluting agricultural production. Here the cost of building a water purification plant far outstripped the cost of paying farmers to change to methods which avoided pollution. This does not provide a value for all of the ecosystem services that would be provided by an unpolluted watershed (including better habitats for wild species, improved recreational quality, etc.) but it does provide a lower boundary on that value, fully justifying taking the watershed out of polluting agriculture (a decision which was subsequently implemented). Similarly the avoidance of damage costs have been widely used to provide useful information to decisions concerning flood assessments (Barbier 2007, Barbier et al. 2013). Care has to be taken with cost based methods though. The costs of attaining desired improvements for biodiversity can be calculated (UK-NEA 2011, Bateman et al. 2013) but these must not be taken as indicators of the value of such conservation.

A.1.1. References

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A.2. Annex 2. List of biophysical and valuation references considered in the post-2015 review (incorporated in the updated Woodland Valuation Tool)

A.2.1. Biophysical literature

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A.3. Annex 3 Definition of the final environmental goods and services and production functions categories considered in the review (taken from Binner et al. 2017)

Final environmental goods and services categories	Description
Water quality	The condition of water in terms of its chemical, physical, biological, radiological and/or aesthetic characteristics
Water quantity	The volume and flow of water
Air quality	The condition of the air including chemical composition (e.g. NO_X, SO_2 and scent)
Climate	Temperature, rainfall and greenhouse gas concentrations
Flora, fauna and fungi	Plant and animal life
Environmental amenity	Characteristics of the surroundings and/or conditions in which a beneficiary lives, works or recreates
Sound and scent	Sources of sounds and scents as well as the magnitude of the emission
Views	Visible characteristics in which a beneficiary lives, works or recreates
Soil	Measures of the condition of the soil including soil type (e.g. clay, loam, sand), acidity (pH), moisture
Timber and fibre	Measures of the direct timber and fibre produced by trees and woodlands

Production function	Description
Timber products	The physical timber and fibrous material. This includes timber for extraction (e.g. wood for construction, fuel) and timber used for subsistence (e.g. wood for construction, fuel).
Food (agriculture and subsistence)	The edible substances as well as indirect benefits (e.g. pollination). This includes the extraction of edible substances from trees or woodlands both commercially and for subsistence (e.g. mushrooms, fruits, nuts) and indirect benefits, such as habitat for healthy populations of pollinators or trees providing shelter for crops.
Industrial production	The benefits trees provide to commercial and industrial businesses. This includes the impact on water and the atmosphere, for example providing industry with the opportunity to discharge waste.
Pharmaceuticals	The medicinal products and inputs. This includes the extracted wood, bark, roots, leaves, flowers, fruits or seeds used in medicines.
Hydropower	The benefits trees provide through the impact on the water environment for hydroelectric power producers.
Drinking water	The benefits trees provide through the impact on the water environment for water suppliers.
Transportation	The benefits trees provide through the water environment for the transporters of goods or people.
Flood alleviation	The benefits trees provide through the water environment for the alleviation of floods.
Urban heat island	The benefits trees provide in terms of shade, temperature regulation and energy savings.
Carbon sequestration	Carbon storage and sequestration, and greenhouse gas emissions.
Housing	The benefits trees provide to residential households. This includes the benefits through the impact on water and the atmosphere (including health benefits), opportunities for recreation and amenity value.
Physical health	The benefits trees provide to the physical health of the population through improvements in air quality, water quality, opportunities for exercise and so on.
Mental health	The benefits trees provide to the mental health of the population.
Recreation	Opportunities for recreation activities. This includes nature viewing (e.g. bird watching), hiking, and the opportunities to experience views, sounds and scents.
Artistic	Opportunities for amateur and professional artists. This includes the use of the environment to produce art such as the opportunities to experience views, sounds and scents.
Learning	Opportunities for educators, students and researchers to learn from and experience the environment.
Spiritual and cultural	The benefits trees provide for spiritual, ceremonial or celebratory purposes.
Non-use value	The benefits trees provide for people who care about existence value of the environment (those who think it is important to preserve the environment for moral/ethical connection or fear of unintended consequences) or bequest values (those who think it is important to preserve the environment for future generations).