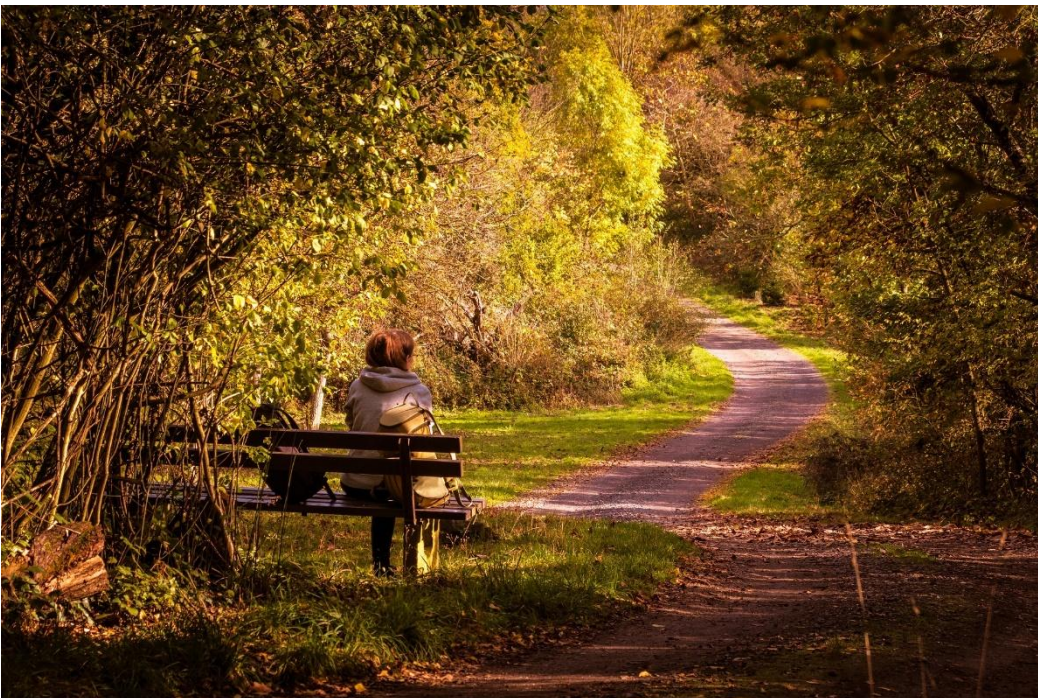


The benefits of trees and woodlands for people, climate and environment: a review of recent evidence

Bethan Stagg, Laura Baker & Emma Hinton

Image by [Thomas](#) from [Pixabay](#)



England's
Community
Forests

The Research Agency of the
Forestry Commission

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research.

The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, data, technical support and consultancy services.

TABLE OF CONTENTS

1	Report summaries.....	4
1.1	Executive summary	4
1.2	Overview: benefits of woodland from the review	5
2	Introduction	7
3	Methodology.....	8
3.1	Review questions	8
3.2	Searches and screening of reviews	8
3.3	Study themes and inclusion criteria	9
3.4	Searches and screening of studies.....	11
3.5	Data coding of studies	12
4	Benefits for Climate and Environment.....	13
4.1	Theme overview	13
4.2	Water resources.....	15
4.3	Soil resources.....	21
4.4	Carbon storage and sequestration	26
4.5	Urban microclimate	32
4.6	Natural resource consumption	37
4.7	Biodiversity	39
5	Benefits for People	43
5.1	Theme overview	43
5.2	Mental health	45
5.3	Physical health	50
5.4	Business / commerce	56
5.5	Farming / food security.....	60
5.6	Society	65
5.7	Culture, heritage and aesthetics.....	69
6	Conclusion	71
7	References	72

1 Report summaries

1.1 Executive summary

This review of recent evidence aims to capture some compelling insights from existing reviews and novel findings from investigative studies about the benefits of trees and woodlands.

The review methodology was developed from a scoping exercise based on the key reviews, which informed the review themes and eligibility criteria for studies. The data sources were the included studies from the most relevant reviews, the England Community Forest's publications bank and Forest Research's publications repository.

The review findings are presented across two themes (climate and environment, people) and twelve intersecting subthemes (e.g. water resources, urban microclimate, mental health, society).

For each subtheme, there is an introduction explaining the issues and relevance of trees to the subtheme, followed by a summary of relevant reviews and the study characteristics and outcomes for the included studies. As part of this work, 45 relevant reviews and 45 eligible studies are also coded (characterised) as a separate interactive dataset.

The review identified a considerable evidence base for the subthemes relating to water resources, carbon storage, urban microclimate and health. There were evidence gaps for soil resources, resource consumption, business and culture.

1.2 Overview: benefits of woodland from the review

Trees reduced the risks of surface water flooding and runoff in urban and rural areas, which helped to prevent flooding and regulated water quality. Trees also benefited aquatic biodiversity by reducing river temperatures.

Tree on farms benefited soil health by reducing soil erosion and compaction and provided substantial carbon sequestration opportunities, in woody biomass and soils. Urban trees outside woodland also sequestered significant amounts of carbon.

Mature woodland and woodland remnants in farms were important for biodiversity. Agroforestry benefited pollinators and natural predators in arable systems and supported livestock welfare by providing shelter in grazing systems.

Trees reduced urban air pollution by absorbing gases, capturing particulates and altering ambient airflow. Trees also mitigated the urban heat island effect, a result of the heat-trapping properties of buildings and energy use. Trees reduced energy consumption for heating and cooling buildings by providing shade and reducing wind exposure and through the cooling effects of water evaporation.

Interactions with trees improved people's mental health, reduced stress levels and promoted wellbeing. Woodland was more beneficial for health than other types of greenspaces, which was believed to be because it provided a barrier to the visual and noise impacts of the built environment, and a complex and diverse natural environment that promoted fascination and distracted from mental discomfort.

Exposure to trees and woodland also benefited physical health. Areas with a high proportion of woodland were associated with lower incidences of mortality, respiratory problems and health costs arising from air pollution. Incidences of obesity and heart failure were also lower in areas with a high proportion of woodland, which was not the case for other types of greenspaces. Trees also reduced harmful exposure to ultraviolet rays and heat-related illnesses.

Trees in urban areas impacted positively on levels of physical activity, particularly for active travel and children's play. Forest school benefited children's cognitive and emotional learning and trees promoted a range of play-based behaviours.

Trees provided beneficial effects for business and commerce. Shopping areas with trees were considered more characterful and attracted more visits and higher customer expenditure. Street trees generally increased property values, with some variation depending on the location, size or structure of trees.

Trees are known to have a range of cultural and aesthetic values. Landowners and citizens considered oak trees to have a particularly high cultural value. Ancient woodlands preserved important archaeological and heritage features and trees outside of woodlands inspired a diversity of artists.

2 Introduction

This review of recent evidence about the benefits of trees and woodlands aims to inform the development of 25-year strategic plans across England's Community Forests and serve as a reference tool for related projects and communications.

The review focuses on recently published international academic literature, grey literature, and evidence from England's Community Forest network. The review aims to capture some compelling insights from existing reviews, as well as novel findings from experimental and observational (cross-sectional) studies. It does not aim to be comprehensive or reproducible but responds to a specific data need within England's Community Forest network.

The benefits are presented across twelve intersecting sub-themes related to people, and climate and environment, for example health and wellbeing, climate mitigation and pressures. As well as capturing evidence about the wide and varied benefits provided by trees and woodlands, the review aims to explain some of the underlying reasons for benefits, as well as any limitations of trees in providing these benefits, trade-offs, and potential negative impacts.

This report is accompanied by two data files about the benefits of trees and woodlands (Appendix A). First, a database of relevant reviews published from 1998 – 2024, which were identified at the scoping stage. Second, a database of recent experimental and observational studies (published 2014 – 2024), which have been characterised according to a suite of relevant variables, including the type and age of woodland and the type of beneficiaries targeted in the study. These data files are designed to be updated over time as required.

3 Methodology

3.1 Review questions

The objective of the review is to answer the following questions:

- What are the benefits of trees and woodlands for people, climate and environment, in contexts relevant to England's Community Forests?
- What are the potential explanatory factors for the identified benefits?
- Are there any limitations of trees in providing the identified benefits, as well as any trade-offs, and potential negative impacts?

3.2 Searches and screening of reviews

The following searches were undertaken on 22/10/2024, which retrieved approximately 150 reviews:

- Searches of study article titles, abstracts and keywords using the academic database Scopus and the search string "benefits AND woodland OR trees" (limited to reviews)
- Searches of full text using Google Scholar and the search string "benefits trees woodland review" (first five pages of retrieved studies)

The authors screened (assessed) titles and abstracts of all reviews for relevance to the review questions and characterised 45 relevant reviews according to theme, relevance level, citation rate and type of review (Appendix A). The types of reviews were systematic, structured or unstructured. Systematic reviews provide the most credible source of evidence as they are based on a highly rigorous, pre-registered protocol. Structured reviews were any type of review with a methods section, explaining how studies were selected, whilst an unstructured review had no methods section. Unstructured reviews are the least objective type of review as we cannot assess whether studies were chosen objectively or were just selected to fit a desired narrative.

3.3 Study themes and inclusion criteria

The 17 highly relevant reviews were used iteratively to refine the thematic framework and the eligibility criteria, in consultation with ECF stakeholders. Findings from the most recent reviews (2014-2024) are also reported in Sections 4 and 5. The thematic framework consisted of two main themes (climate and environment; people), each broken into subthemes and categories (Figure 1). The eligibility criteria are a set of guidelines developed from the review question to determine which studies are included or excluded in the review (Table 1).



Figure 1. Themes, subthemes and examples of categories in the thematic framework

Table 1 Eligibility criteria for studies

Review question element	Inclusion criteria	Exclusion criteria
Phenomena of Interest	Native or food-producing trees or woodland, in urban, peri-urban or rural areas	Trees grown solely for ornamental, pharmacological, timber, bioenergy or biochar purposes
Outcome	Study has produced novel primary data about the benefits or disbenefits of trees or woodland to humans, biodiversity, ecosystems	Study focuses solely on disbenefits of trees or woodland (to humans, biodiversity, ecosystems) Study focuses solely on deadwood e.g. "leaky wood" structures Study is about climate mitigation benefits at the national or global scale Study is about "virtual" interventions (e.g. impact of video of forest on health) Study is about benefits of trees during the previous Covid-19 pandemic
Outcome measure	Any environmental or human variable.	
Study design	Any type of observational or experimental study. Quantitative, qualitative or mixed methods, with or without statistical testing. Modelling, simulations and analyses of existing data sources, if novel data is produced.	Reviews, meta-analyses and opinion papers
Scope	International - but temperate zones only, based on the Köppen climate classification system.	Other climate zones
Study type	Paper in an indexed or non-indexed journal. Thesis or Masters' dissertation. Report by government body or non-governmental organisation with research expertise.	Book / book chapter Undergraduate dissertation Other type of report
Time range	2014 – 2024	Pre-2014

3.4 Searches and screening of studies

The authors independently screened the first sample of 20 studies at each stage in the review as an internal consistency measure, then discussed and resolved any differences in interpretations of the eligibility criteria. Subsequent studies were screened by one author.

The authors screened titles and abstracts of the following studies against the eligibility criteria between 01/11/2024 - 16/12/2024:

- The references cited by the highly relevant reviews (approximately 1,500 studies including duplicates)
- ECF's publications bank and ECF's signposting to a variety of sources (approximately 150 studies including duplicates)
- Forest Research's publications bank for relevant research groups (approximately 200 studies including duplicates)

The resultant 206 studies were screened at full text and assessed by the authors for external validity (relevance to the review questions and context), internal validity (the extent to which the cause-and-effect relationship was supported by the study's experimental design) and volume of evidence (low sample size and/or very limited amount of data collected and analysed). Studies with low external validity, internal validity and/or low volume of evidence were excluded. The remaining 136 studies were characterised by theme, subtheme and category.

A minimum of four studies (where available) were subjectively selected for each subtheme, prioritising studies with highest validity that were representative of the suite of categories listed under each subtheme wherever possible. The authors carried out the following targeted searches in Google Scholar to address the subsequent evidence gaps:

- "Biodiversity benefits woodland"
- "Energy consumption generation trees cities"

- "Functional traits diversity woodland benefits ecosystem services"
- "Riparian woodland temperature water course shading"
- "Soil health benefits woodland"
- "Soil parameters woodland"
- "Tree woodland sense of place"
- "Trees woodland benefits commercial"
- "Woody biomass alternative to fossil fuels "

Google Scholar searches do not have the same reproducibility and transparency as those undertaken in a bibliometric (scholarly) database, but this approach was deemed adequate for this context.

3.5 Data coding of studies

Data coding refers to the process of characterising a study, to provide a set of details about the subjects, outcomes and study design. The coding scheme was developed iteratively in consultation with ECF stakeholders and comprised the following variables: year and country of publication, theme, subtheme, category, summary of main outcome and any secondary outcomes, study context (e.g. public greenspace, farm), woodland type, age and species composition, type of beneficiary (e.g. children, people with disabilities), type of study (experimental or observational), data source (e.g. primary social data, GIS data) and details about any statistical analyses and study design characteristics.

The authors jointly coded a random sample of the first ten studies and discussed and resolved any differences in interpretations of the coding scheme. Subsequent studies were screened by one author. 45 studies were coded in total (Appendix A). PDFs of the reviews and studies are also saved as a separate folder (Appendix B).

4 Benefits for Climate and Environment

4.1 Theme overview

4.1.1 Reviews

There were 11 reviews published from 2014 – 2024 that were of high relevance to this theme, seven of which were structured or systematic reviews (Table 2).

4.1.2 Studies

23 studies were selected for coding in the “climate and environment” theme from the 136 total included studies. The quantity of studies was highest for carbon storage and sequestration, followed by urban microclimate.

There was a lack of studies about the impacts of trees on soil health or natural resource consumption. The few studies focusing on trees and soil health were based in the continental areas of USA rather than temperate areas. Studies on natural resource consumption were mainly about the role of woody biomass as fuel alternative to fossil fuels and located in non-temperate areas in Northern, Southern, Central Europe or Asia.

15 studies about water resources, carbon storage, and urban microclimate were produced using iTree software. Few of these studies involved primary data collection and therefore were not included in the final suite of studies for coding, as per the eligibility criteria.

Table 2 Summary of reviews on the “Climate and Environment” theme
 Review type is categorised as unstructured (UN-STR), structured (STR) or systematic (SYS)

Summary	Water	Soil	Carbon	Urban Microclimate	Biodiversity	Review type	Citation
Benefits of woodlands / trees (UK)	✓		✓	✓	✓	UN-STR	Binner et al. (2018)
Effects of woodland expansion on ecosystem services (UK)	✓		✓		✓	SYS	Burton et al. (2018a)
Ecosystem services of urban forests	✓		✓	✓		UN-STR	(Davies, 2017)
Benefits / disbenefits of trees for grazed dairy systems	✓	✓	✓			STR	England et al. (2020a)
Temperate agroforestry and livestock	✓	✓	✓			SYS	Jordon et al. (2020)
Benefits of urban foraging and food forests			✓			STR	Oncini et al. (2024)
Ecosystem services of street trees				✓		UN-STR	(Salmond et al., 2016)
Economic costs / benefits of urban forests	✓			✓		SYS	Song et al. (2018a)
Hydrological effects of urban tree planting	✓					STR	Baker et al. (2021)
Forested land for natural flood management	✓					UN-STR	Cooper et al. (2021)
Cooling efficacy of urban trees				✓		STR	(Li et al., 2024)

4.2 Water resources

Climate change is expected to lead to severe impacts in the UK resulting from changes in precipitation, with high impact heavy rainfall suggesting more frequent river and surface water flooding¹. Climate change is also contributing to increasing river temperatures, with impacts on freshwater ecosystems including on fish species such as salmonids². Trees, woods and forests can play an important role in reducing these impacts.

Trees contribute to reducing surface water runoff and flooding in several ways: by taking up water from soil; by improving water infiltration via their roots, which create voids and channels in the soil; and their canopies intercept rainfall, slowing the rate at which this water reaches the ground and removing a proportion of this via evaporation from the surfaces of the leaves³.

Trees make an important contribution to minimising surface water flooding in both urban and rural areas. Urban areas are typically covered by a high proportion of impermeable surfaces, which increase the risk of surface water flooding and, where trees are present, this risk is reduced. In rural areas, trees slow the flow of runoff and water across floodplains and enhance infiltration rates⁴. Trees can also reduce river temperatures through shading⁵.

Tree condition affects their ability to deliver a range of benefits, including reducing surface water flooding: poor condition may lead to crown dieback or defoliation, which reduces the ability of their canopy to intercept rainfall⁶. It can also reduce their ability to shade river channels and so reduce their ability to reduce river temperatures.

¹ Hanlon et al. (2021)

² Dugdale et al. (2024)

³ Walker et al. (2023)

⁴ Walker et al. (2023)

⁵ Dugdale et al. (2024)

⁶ Walker et al. (2023)

4.2.1 Reviews

A systematic review assessed 160 articles about the effects of woodland expansion on multiple ecosystem services found the evidence base to be dominated by research about conifer plantations.⁷ For deciduous wooded systems, the evidence was strongest for the benefits of woodland expansion in regulating water flow and water quality. However, there were flaws in the approaches authors used for quantifying evidence strength and assessing risk of bias, so evidence should be treated with caution.

Two reviews assessed the impacts of agroforestry (any land management approach combining trees and agriculture) on the ecosystem regulating services of water, soil and carbon. For the other benefits of agroforestry, see Section 5.5.

The first, a systematic review, assessed 83 studies about trees in grazed dairy systems and found that **most relationships reported between on-farm woody systems and ecosystem services were positive**, with few reports of disbenefits for ecosystem services⁸. Causal impact pathways with the strongest evidence base included the **benefits of riparian systems for reducing runoff** and thus water quality. Evidence should be treated with caution due to limitations in the assessment of risk of bias in the assessed studies.

A systematic evidence map (similar to a systematic review but focusing on production of a database of studies) identified 289 relevant studies from 22 temperate countries⁹. A preliminary assessment of studies found **significant positive effects for agroforestry as compared to treeless pasture for: 55% of 22 studies about water quantity and 59% of 27 studies about water quality.**

⁷ Burton et al. (2018)

⁸ England et al. (2020a)

⁹ Jordon et al. (2020)

One structured review focused specifically on the impacts of trees on water resources. This structured review of 55 studies assessed the evidence in relation to the impact of **urban trees on hydrology**¹⁰. The reviewers categorised the evidence into 13 distinct topics: the greatest number of studies assessed focused on runoff (26 studies) and interception (11 studies). The majority of the 55 studies focused on North America (25 studies) with the other main concentrations of studies in East Asia (6 studies), Northwestern Europe (5 studies) or focused on multiple regions (5 studies). **All studies reported a significant benefit from increased tree cover**, but there is a need for more robust studies to increase confidence in these findings.

- In terms of impacts of urban trees on hydrology, **27 studies found that urban trees reduced runoff; 17 found that they increased interception; 7 that they had impacts in terms of evapotranspiration loss; 6 that they increased infiltration; and 3 that they had impacts in terms of canopy interception loss**. However, the review found that most of the studies assessed were not sufficiently robust in terms of frequency and length of monitoring and modelling periods and use of controls.
- 10 studies found differences in terms of tree planting arrangement, location and techniques on outcomes. The **evidence was mixed in terms of identifying an optimal tree density to achieve positive outcomes**.
- 8 of the assessed studies were based on the results of modelling only, whilst 18 combine modelling with measurements. Studies including modelling were mostly focused on investigating the impacts of urban trees on runoff. The results of studies involving modelling are mixed, and the robustness of the evidence is limited: there remains a need for comparing modelled outcomes against empirical observations.

¹⁰ Baker et al. (2021)

- 22 primary studies focused on differences in outcomes relating to tree species. **Tree species and whether trees are coniferous or deciduous is important, but tree characteristics (such as canopy morphology, leaf density, leaf area index, rainfall interception capacity, bark roughness, tree health and tree maturity) are more significant in determining the magnitude of the impact.**

A systematic review assessed 34 studies about the economic benefits and costs of urban forests and extracted and analysed numerical data from studies.¹¹ Results should be treated with caution as there was no assessment of risk of bias in the assessed studies, despite it being described as a systematic review.

- **Of the 26 papers that analysed the benefit-cost ratio, benefits outweighed costs in 22 studies, and the mean annual benefit and cost per tree were \$44.34 and \$37.40, respectively.**
- 19 studies relied on i-Tree software for the valuation and presented a “snapshot” of benefits and costs of established trees for a single year. **The annual volumetric benefit of rainfall interception per tree ranged from 0.28 m³ to 11.3 m³, with annual economic benefit per tree from \$0.28 to \$54.61.**

4.2.2 Coded studies

We assessed six studies that considered the effects of trees and woodland on water resources (Table 3). Three studies investigated the impact of trees and woodlands in terms of avoided runoff, finding a benefit at different scales and locations. Two studies considered the impact of trees on flood risk, with one finding a positive benefit of trees and the other finding no significant effect. One study found that riparian tree planting had a beneficial effect on water temperature in rivers.

¹¹ Song et al. (2018)

Table 3 Summary of coded studies for “water resources” subtheme

Key outcome(s)	Citation
<p>An assessment of trees in Wirral (UK) following the i-Tree Eco methodology estimated that the area supports more than 1 million trees which deliver benefits in terms of 421,000m³ per year in avoided runoff, worth £309,000 per year.</p> <p>The ten tree species that contribute the most to avoided runoff in the Wirral are: Sycamore (<i>Acer pseudoplatanus</i>), Beech (<i>Fagus sylvatica</i>), Black Pine (<i>Pinus nigra</i>), Pedunculate Oak (<i>Quercus robur</i>), Common Lime (<i>Tilia x europaea</i>), Silver Birch (<i>Betula pendula</i>), Scots Pine (<i>Pinus sylvestris</i>), Downy Birch (<i>Betula pubescens</i>), Leyland Cypress (<i>x Cuprocypris leylandii</i>) and Ash (<i>Fraxinus excelsior</i>).</p>	<p>Walker et al. (2023)</p>
<p>Models the impact of riparian tree planting on water temperature in rivers, focusing on modelling the effects of an existing bankside tree planting scheme on the Baddoch Burn in Aberdeenshire, Scotland.</p> <p>Prior to recent planting of ~ 3km total length of around 1m tall native saplings within the 5m riparian buffer zone adjacent to the stream, the area only had an approximately 800m strip of commercially planted conifer woodland in the catchment.</p> <p>When mature, this new tree planting will increase effective shading in the lower reaches of the tributary from 22% to 47%, delivering a ~1.5°C decrease in maximum summer stream temperature in comparison to the present-day baseline.</p> <p>Different spatial configurations of tree planting can have a considerable impact on stream temperature outcomes. Optimal temperature reductions were predicted where effective shade is maximised (due to reduced channel width) and where water volumes and residence times mean that impact of reduced solar radiation is greatest.</p> <p>In general, to optimise stream temperature outcomes, riparian planting should be focused: in upstream reaches, unless temperature reduction in a specific location is the objective; in longer planting zones; in higher numbers of planting zones; and reducing the amount of open area between planting zones.</p>	<p>Dugdale et al. (2024)</p>
<p>A study of street trees in a Chinese Forest City (Dalian) analysed the structural characteristics of Dalian’s 57,699 street trees (28 tree species). Dalian’s street trees intercepted approximately 217,404 m³ rainfall each year. Benefits from stormwater runoff were valued at \$459,457 or \$8 per tree per year, using the i-Tree Streets methodology.</p>	<p>Wang et al. (2018)</p>

Table 3 cont.

Key outcome(s)	Citation
<p>This longitudinal empirical study investigated the impact of different natural flood management interventions on flood risk, focusing on the 69km² Eddleston Water catchment in the Scottish Borders. Interventions across the whole catchment included 207ha tree planting with over 330,000 native trees, alongside other measures. The study analysed data collected over 2 years prior to the installation of these interventions, and for 7 years after their installation.</p> <p>Headwater catchments up to 25.64 km² showed significant delays in flood peak lag time of 2.6–7.3 hours in catchments provided with a combination of leaky wood structures, on-line ponds and riparian planting with fencing. The greatest increases in lag time, of up to 7.3 hours, were found in the smallest catchments, with significant differences extending downstream. The installation of natural flood management interventions in larger catchments did not significantly increase the lag time.</p> <p>There was no evidence that riparian and wetland tree planting alone has a significant effect on lag times. Although the largest increases in lag times occurred in a catchment in which 2ha riparian and wetland tree planting was delivered in addition to the installation of a series of 35 leaky barriers, there was no increase in lag times in a different catchment which had received 7.5ha riparian and wetland tree planting since 2013.</p>	<p>Black et al. (2021)</p>
<p>The UK has approximately three quarters of a million hectares of non-woodland trees (i.e. individual trees, groups of trees less than 0.1ha in extent and small woods 0.1ha-0.5ha, in both rural and urban areas).</p> <p>Using the i-Tree Canopy methodology, the economic value provided by non-woodland trees in the UK in terms of avoided runoff is £337 million per year (2020 prices).</p> <p>Using the Woodland Natural Capital Accounting Benefit Transfer Approach methodology, the economic value provided by non-woodland trees in the UK in terms of flood mitigation is £55 million per year (2020 prices).</p>	<p>Doick et al. (2021)</p>
<p>This study compared soil parameters for newly established native woodland (established on previously grazed land) and for currently grazed adjacent pasture in four upland pastoral headwater catchment sites in Dartmoor National Park, southwest England.</p> <p>The establishment of native woodland improves the hydrological functioning of soils in upland pastoral catchments and the provision of flash-flood mitigation ecosystem services.</p> <p>Saturated hydraulic connectivity, initial infiltration and wetness threshold were significantly higher in establishing woodland than for grazed pasture areas (saturated hydraulic connectivity: 1,052.5cm per hour for woodland, 574.1cm per hour for pasture; infiltration: 1,849.8cm per hour for woodland, 693cm per hour for pasture; wetness threshold: 29.4cm for woodland, 18.8cm for pasture). Whilst the extent of the difference in saturated hydraulic connectivity and initial infiltration depends on catchment site, the difference in wetness threshold is independent of site.</p>	<p>Murphy et al. (2021)</p>

4.3 Soil resources

Soil is complex and variable: it consists of a mixture of mineral particles, organic matter, water, air and living organisms. It is a non-renewable resource which is important for supporting biodiversity and wildlife; integral to a range of ecosystem services including nutrient cycling, water regulation and carbon storage; and is essential for food production.

Soil degradation has been estimated to cost £1.2 billion every year and over 2 million hectares of soil are at risk of erosion in England and Wales¹².

Soil health is an area of growing interest: this can be defined as “the continued capacity of a soil to function as a vital living ecosystem that sustains biological productivity, maintains environmental quality, and promotes plant and animal health”¹³. The UK Government has made a commitment to improving and protecting soil health and monitoring this for a range of habitats¹⁴ and to improving our understanding of appropriate soil management in relation to trees¹⁵.

Soil is an important component of the forest ecosystem. **Sustainably managed forests can have an important role in conserving soil, controlling soil erosion (and so minimising the loss of nutrients and organic matter) and reducing the risk of landslides; and tree planting can be a significant first step towards rehabilitating degraded soils¹⁶.**

Forestry operations can have negative impacts on soils, such as operations associated with ground preparation, planting, thinning, timber harvesting and road construction; but impacts can be reduced in a number of ways such as by planting to minimise erosion risk, using less intensive cultivation methods and including

¹² Environment Agency (2019)

¹³ Shen & Teng (2023)

¹⁴ Defra (2023)

¹⁵ UK Government (2021)

¹⁶ FAO (2009)

uncultivated buffer zones, minimising soil surface disturbance, and encouraging understorey vegetation and a well-developed surface litter layer¹⁷.

The loss of woodland to agricultural expansion is associated with negative impacts on soil¹⁸. Conventional agriculture can lead to increased soil nitrogen levels (e.g. from fertiliser inputs or resulting from ammonia emissions), negatively affecting biodiversity; pesticide usage can also have a negative impact on biodiversity; over-grazing can lead to compaction, increasing runoff risk; and tillage can contribute to soil erosion. **Tree planting can help to manage soil and nutrient loss from agricultural land, reducing soil erosion by stabilising soils.** Integrating trees into arable crops via shelterbelts and along field boundaries can reduce soil erosion¹⁹. Agroforestry is endorsed in the Environmental Improvement Plan as a way of supporting improved soil health²⁰.

4.3.1 Reviews

Two reviews assessed the impacts of agroforestry (any land management approach combining trees and agriculture) on the ecosystem regulating services of water, soil and carbon. For the other benefits of agroforestry, see Section 5.5.

The first, a systematic review, assessed 83 studies about trees in grazed dairy systems and found that **most relationships reported between on-farm woody systems and ecosystem services were positive**, with few reports of disbenefits for ecosystem services²¹. Causal impact pathways with the strongest evidence base included the **stabilising benefits of plantation and scattered trees in**

¹⁷ FAO (2009); Paterson & Mason (1999)

¹⁸ Ashwood et al. (2019)

¹⁹ Environment Agency (2019)

²⁰ Defra (2023)

²¹ England et al. (2020a)

farmland for reducing slope erosion. Evidence should be treated with caution due to limitations in the assessment of risk of bias in the assessed studies.

A systematic evidence map (similar to a systematic review but focusing on production of a database of studies) identified 289 relevant studies from 22 temperate countries²². A preliminary assessment of studies found **significant positive effects for agroforestry as compared to treeless pasture for 71% of 28 studies about soil erosion.**

4.3.2 Coded studies

We assessed five empirical studies that considered soil parameters for trees and woodland (Table 4). Two studies investigated the impact of woodland creation and establishment on soils and three studies focused on the impacts of silvopasture systems on a range of soil health indicators. Positive associations were found between woodland and/or silvopasture for compaction, carbon to nitrogen ratio and potassium. There were mixed results (or no effect) for other soil health indicators.

Table 4 Summary of coded studies for “soil resources” subtheme

Key outcome(s)	Citation
<p>This study compared soil health for newly established native woodland (established on previously grazed land) and for currently grazed adjacent pasture in four upland pastoral headwater catchment sites in Dartmoor National Park, southwest England.</p> <p>Soils were significantly less compacted in the establishing woodland compared to the areas of pasture (surface soil compaction of 52.0 kilopascals for pasture compared to 21.8 kilopascals for woodland; bulk density of 0.80 grams per cubic centimetre for pasture compared to 0.67 grams per cubic centimetre for woodland). The impact of woodland establishment in lowering surface soil compaction was greatest where soil organic matter was higher.</p> <p>No significant differences in soil organic matter and porosity were found between establishing woodland and pasture, due to catchment differences.</p>	<p>Murphy et al. (2021)</p>

²² Jordon et al. (2020)

Table 4 cont.

Key outcome(s)	Citation
<p>A US study compared 25-year-old deciduous hardwood silvopasture with black walnut (<i>Juglans nigra</i>) and honey-locust (<i>Gleditsia triacanthos</i>) to adjacent open pasture at an agroforestry demonstration centre in Virginia.</p> <p>Silvopasture soils were more fertile than open pasture soils, in terms of the mineral potassium (silvopasture soils had greater potassium - 167.3mg per kilogram of soil for black walnut silvopasture and 184.7mg per kilogram for honey locust silvopasture - compared to open pasture, at 133.3mg per kilogram).</p> <p>The silvopastures were superior to open pasture for various indicators of soil health namely carbon to nitrogen ratio and β-glucosidase activity (a soil enzyme) .</p> <p>There were also some differences in soil health indicators between the two types of silvopasture. Soil organic matter was superior in only one of the forms of silvopasture (64g per kilogram for honey locust silvopasture) compared to open pasture (55g per kilogram). Protein content (as glomalin-related soil protein) was only superior in honey locust silvopasture (5.2mg per gram, to 4.3 mg per gram in open pasture), and soil enzymes (measured using urease activity) was superior only in black walnut silvopasture, as compared to open pasture.</p> <p>No significant differences were found between silvopasture and open pasture for the following measures of soil health: soil bulk density (an indicator of soil compaction); pH; phosphorous; magnesium; or nitrogen from ammonia or nitrate.</p>	<p>Poudel et al. (2022)</p>
<p>This US study carried out empirical research on plots at an agroforestry demonstration site in Alabama. It compared soil parameters between silvopasture plots (created from existing woodland in 2014) and young woodland (planted in 2005), both of which were dominated by coniferous tree species (southern pines, specifically loblolly, <i>Pinus taeda</i>; and longleaf, <i>Pinus palustris</i>).</p> <p>Cultural practices and understorey plant communities differed between the woodland plots and the silvopasture plots, but understorey vegetation for both types of plots was managed by rotational grazing from small ruminants (goats and sheep).</p> <p>Soil fertility (in terms of nitrogen) was greater in silvopasture compared to woodland. No differences were detected in soil health in terms of soil bulk density and moisture between silvopasture and woodland grazing systems.</p>	<p>Karki et al. (2022)</p>

Table 4 cont.

Key outcome(s)	Citation
<p>An empirical study investigated the effects of converting agricultural land to woodland in a lowland landscape in England, following their transition from arable or pasture through secondary woodland to ancient woodland. This study collected data on unmanaged, small (2-5 hectares) broadleaved woodlands created on former agricultural land 50-120 years ago in the National Forest.</p> <p>The study investigated key soil health indicators in young secondary woodland aged 50-60 years, mature secondary woodland aged 110-116 years and ancient woodland over 400 years old) and agricultural (arable and pasture) land</p> <p>Despite constant nitrogen input from fertilisers in the agricultural land, soil fertility (nitrogen concentrations) was superior in woodland compared to agricultural when the organic layer was included (the decaying leaves etc at the surface of the soil).</p> <p>There were no significant differences in soil fertility (nitrogen concentrations) at each soil depth when comparing across the three categories of woodland, but this was significantly greater at 0-20cm depth compared to 20-40cm depth for mature secondary woodland soils.</p> <p>Mineral soil carbon to nitrogen ratio at both 0-20cm and 20-40cm depths was significantly greater for woodland soils than for arable. There was no effect of woodland age on this ratio.</p> <p>Woodland restoration reduced soil compaction: woodland soils had significantly lower soil bulk density than on arable land. No significant effect was found for the impact of woodland age, but soil bulk density at 0-20cm depth was significantly greater on arable sites than for young secondary woodland.</p> <p>There were no statistically significant effects of woodland land use, woodland age or soil depth on soil pH.</p>	<p>Ashwood et al. (2019)</p>
<p>This study compared differences in soil parameters between silvopasture and adjacent grassland in a single agricultural holding in Co. Leitrim, north-west Ireland.</p> <p>Mean soil moisture content was lower in silvopasture (75%) than grassland (89%) and soil porosity declined with distance from trees (35.82% at the trunk, 34.72% at 2 metres from the trunk and 31.13% at 4 metres from the trunk, compared to 22.71% in grassland). This suggests that silvopasture has benefits in terms of improved soil drainage. Mean soil pH was less acidic (pH 6.93) than for grassland (pH 6.27) despite all sites sampled having received the same treatments in relation to applications of fertiliser and lime.</p>	<p>Connolly (2020)</p>

4.4 Carbon storage and sequestration

Carbon storage is defined as the pool of carbon within an ecosystem, and carbon sequestration is the process where carbon dioxide is removed from the atmosphere by photosynthesis and stored in a terrestrial system²³.

The Climate Change Act 2008 (as amended) legally requires England to reach net zero greenhouse gas emissions by 2050. To contribute to meeting this target, it has been recommended that around 30,000 hectares or more of broadleaf and conifer woodland should be planted each year to increase UK forestry cover from 13% to at least 17%, to deliver annual emissions sequestration of 14 megatonnes of carbon dioxide equivalent (MtCO_{2e}) from forests and an additional 6MtCO_{2e} from agroforestry up to 2050²⁴.

Trees, woods and forests slow the rate at which carbon dioxide accumulates in the atmosphere, sequestering large amounts of carbon both above and below ground, in woody biomass (capturing carbon dioxide from the atmosphere during photosynthesis and storing it in woody materials) and in soils (where soils beneath trees are enriched through the addition of carbon from leaf litter, branch fall and root death)²⁵. Carbon accounts for around half of the dry weight of a tree's woody biomass and larger trees tend to sequester the most carbon²⁶.

Several factors affect the extent to which trees sequester and retain carbon. There are differences between broadleaved and coniferous trees: coniferous trees tend to be faster growing and initially have a higher (approximately 20% higher) annual sequestration rate; whereas broadleaved trees tend to have a greater wood density and broadleaved woodlands tend to have a longer lifespan than coniferous

²³ Flack et al. (2022)

²⁴ Committee on Climate Change (2020)

²⁵ Pugh et al. (2019); Forestry Commission (2022)

²⁶ Walker et al. (2023)

woodlands and so are better able to sequester carbon over the longer term²⁷. Trees in poor condition may grow more slowly or result in defoliation or crown dieback, reducing their ability to sequester carbon²⁸, and trees release the carbon they have stored when they decompose, or their wood is burnt. To keep sequestered carbon locked up for as long as possible within trees, felled or dead trees should be used (e.g. for timber, seasoned as native hardwood for sale, used in sculptures and carvings or for street and park furniture) or retained as standing deadwood with benefits for biodiversity, instead of chipping or seasoning for firewood²⁹.

4.4.1 Reviews

A structured review assessed 74 studies about “wild food foraging” and urban food forestry, this includes forest gardens where food production occurs in the herbaceous layer as well.³⁰ Five studies produced quantitative data about benefits of food forests, with **estimation of above-ground and below-ground biomass ranging from 3.69 to 39.53 megagrams carbon/hectare.**

A systematic review assessed 34 studies about the economic benefits and costs of urban forests and extracted and analysed numerical data from studies.³¹ Results should be treated with caution as there was no assessment of risk of bias in the assessed studies. 19 studies relied on i-Tree software for the valuation and presented a “snapshot” of benefits and costs of established trees for a single year. **Annual carbon storage per tree ranged from 11 kg to 852 kg, while annual carbon sequestration ranged from 3.5 kg to 96 kg per tree, with an annual economic benefit per tree from \$0.34 to \$13.38.**

²⁷ Flack et al. (2022)

²⁸ Hand & Doick (2019)

²⁹ Walker et al. (2023)

³⁰ Oncini et al. (2024)

³¹ Song et al. (2018)

Two reviews assessed the impacts of agroforestry (any land management approach combining trees and agriculture) on the ecosystem regulating services of water, soil and carbon. For the other benefits of agroforestry, see Section 5.5.

The first, a systematic review, assessed 83 studies about trees in grazed dairy systems and found that **most relationships reported between on-farm woody systems and ecosystem services were positive**, with few reports of disbenefits for ecosystem services³². Causal impact pathways with the strongest evidence base included the **benefits of shelterbelt systems for carbon sequestration**.

4.4.2 Coded studies

We assessed eleven studies that considered the impact of trees, woods and forests on carbon storage and sequestration (Table 5). Three studies examined the effects of existing trees on carbon storage, whilst seven studies focused on recent or new planting schemes. Half the studies compared the impacts of trees / forests for carbon storage and sequestration to other land uses. Three of these studies considered silvopasture, finding that it stored more carbon than woodland. Woodland stored more carbon per hectare than a range of habitats and smaller / more ancient woodlands had greater topsoil carbon storage than other sizes or ages of woodland.

Table 5 Summary of coded studies for “carbon” subtheme

Key outcome(s)	Citation
<p>An assessment of trees in Wirral (UK) following the i-Tree Eco methodology estimated that the area supports more than 1 million trees which deliver 6,942 tonnes per year of net carbon sequestration (valued at £6.3 million per year) and store 338 tonnes of carbon, equivalent to 1.2 million tonnes of carbon dioxide, which has been valued at £307.6 million per year.</p> <p>The ten tree species that store the most carbon in the Wirral are: Sycamore (<i>Acer pseudoplatanus</i>), oaks (<i>Quercus spp.</i>), beeches (<i>Fagus spp.</i>), Leyland Cypress (<i>x Cuprocyparis leylandii</i>), Common Lime (<i>Tilia x europaea</i>), Silver Birch (<i>Betula pendula</i>), Black Pine (<i>Pinus nigra</i>), Scots Pine (<i>Pinus sylvestris</i>), Ash (<i>Fraxinus excelsior</i>) and Wild Cherry (<i>Prunus avium</i>).</p>	<p>Walker et al. (2023)</p>

³² England et al. (2020a)

Table 5 cont.

Key outcome(s)	Citation
<p>This study compared soil bulk density and organic carbon content of woodland, silvopasture and pasture, in a single site in lowland England.</p> <p>Soil organic carbon was measured in pasture, silvopastoral tree, and woodland treatments at six depths (from 0–150 cm). Fourteen years after tree planting, carbon content in the surface soil layer (0–10 cm) was highest in the pasture (6.0g per 100g soil), intermediate in silvopasture (5.3g per 100g soil) and lowest in the woodland (4.6g per 100g soil). In the subsequent soil layer (10–20 cm), there was no significant difference in carbon content for pasture compared to silvopasture, whereas woodland was significantly lower (13% lower than pasture). There were no treatment effects on soil carbon identified at soil depths below 20 cm.</p> <p>Measurements of above ground carbon storage by the trees identified that tree planting had increased total carbon storage, and the authors estimated that silvopasture would store more carbon over time than woodland or pasture.</p>	<p>Upson et al. (2016)</p>
<p>This study investigated the net carbon benefits that urban tree planting could have in China, based on an analysis of existing datasets. If trees were planted in urban areas in China to increase their greenness (specifically, an increased 0.1% Normalised Difference Vegetation Index), these trees could store 247-284 megatonnes of carbon dioxide over 30 years.</p>	<p>Huang et al. (2024)</p>
<p>A study of street trees in a Chinese Forest City (Dalian) analysed the structural characteristics of Dalian’s 57,699 street trees, which include 28 tree species.</p> <p>Dalian’s street trees were estimated to store 29,873 tonnes of carbon dioxide (valued at \$4,478,353) and to sequester 2,317 tonnes of carbon dioxide annually (valued at \$347,358), using the i-Tree Streets methodology.</p> <p>Tree maintenance activities and decomposition were associated with the release of 762 tonnes of carbon dioxide annually.</p> <p>Annual avoided carbon dioxide emissions resulting from the contribution of street trees to the urban microclimate amounted to 4,683 tonnes (valued at \$702,073).</p> <p>Taken together, the amount of carbon dioxide removed by street trees each year was estimated to be 36,111 tonnes, valued at \$935,205 or \$16.2 per tree.</p>	<p>Wang et al. (2018)</p>
<p>A US study compared 25-year-old deciduous hardwood silvopasture with black walnut (<i>Juglans nigra</i>) and honey-locust (<i>Gleditsia triacanthos</i>) to adjacent open pasture at an agroforestry demonstration centre in Virginia.</p> <p>When compared to open pasture, silvopasture soils had a greater carbon to nitrogen ratio and higher soil total carbon and microbial carbon content.</p>	<p>Poudel et al. (2022)</p>

Table 5 cont.

Key outcome(s)	Citation
<p>This study modelled the carbon sequestration potential of three broadleaved woodland planting scenarios on agricultural land in the Loddon Catchment in southeast England, which spans three counties and covers an area of 68,277 hectares.</p> <p>Over a 50-year time horizon, woodland planting on arable land has the greatest sequestration potential (4.02 tonnes of carbon per hectare per year) compared to planting on pasture land (3.75 tonnes of carbon per hectare per year, which is 6.8% lower). This difference is due to initial higher carbon storage in grasslands compared to arable land.</p> <p>At the catchment scale, woodland planting on pasture had the greatest total carbon sequestration potential (668,540 tonnes of carbon for planting on pasture, compared to 77,402 tonnes of carbon for planting on arable land).</p> <p>The largest gains in carbon storage for both arable and pasture land were in aboveground biomass, representing on average 71% of the carbon sequestration achieved by woodland planting.</p> <p>Planting woodland on arable land had a higher market value compared to planting on pasture over a 50-year time horizon: planting on arable was estimated to have a market net present value (i.e. the current value of all future revenue that the company could earn from that asset) of €5,180.64 per hectare, compared to a market net present value of €4,834.08 per hectare for planting on pasture. In contrast, the highest total social net present value (the social costs and benefits of the asset) was in the pasture (€43.48 million per hectare).</p>	<p>Flack et al. (2022)</p>
<p>This study analysed the biodiversity value and provision of selected ecosystem services, including carbon storage, for patches of lowland heathland in Dorset, considering a range of habitat types to inform landscape-scale management decisions.</p> <p>Carbon storage was directly assessed on a random sample of ten heathland sites by measuring the amount of carbon in five carbon pools: vegetation; soil (to 30cm depth); roots; humus; and dead organic matter.</p> <p>Woodland was found to store 244 tonnes of carbon per hectare. This was greater than scrub (181 tonnes of carbon per hectare), dry heath (159 tonnes of carbon per hectare), mire (138 tonnes of carbon per hectare), grassland (137 tonnes of carbon per hectare) and humid/wet heath (125 tonnes of carbon per hectare).</p>	<p>Cordingley et al. (2016)</p>
<p>The UK has approximately three quarters of a million hectares of non-woodland trees (i.e. individual trees, groups of trees less than 0.1 hectares in extent and small woods 0.1-0.5 hectares, in both rural and urban areas).</p> <p>The economic value provided by non-woodland trees in the UK in terms of carbon sequestration is £2.092 billion per year (using the i-tree Canopy methodology) and £946 million per year (using the Woodland Natural Capital Accounting Benefit Transfer Approach)</p>	<p>Doick et al. (2021)</p>

Table 5 cont.

Key outcome(s)	Citation
<p>This study collected data from 224 deciduous woodlands across 7 regions in temperate Europe, comparing small (both recent and ancient) and larger woodlands or forest patches in agricultural landscapes. The study compared two 5 km² landscapes in each region with contrasting connectivity levels.</p> <p>Data was collected on the supply potential of six ecosystem (dis)services, including topsoil carbon storage. Smaller woodlands and more ancient woodlands had a higher topsoil carbon storage capacity. Biodiversity was not found to affect topsoil carbon storage capacity. Soil nutrient availability decreased topsoil carbon storage.</p>	<p>Valdés et al. (2020)</p>
<p>This study investigated the effects of converting agricultural land to woodland in a lowland landscape in England, following their transition from arable or pasture through secondary woodland to ancient woodland. This study collected data on unmanaged, small (2-5 hectare) broadleaved woodlands created on former agricultural land 50-120 years ago in the National Forest.</p> <p>Broadleaved woodland restoration led to significantly greater soil organic carbon stocks compared to arable land.</p> <p>Soil organic carbon (including mineral soil organic carbon stock; concentration at 0-20cm depth; and concentration to a depth of 40cm) was significantly greater under ancient woodland compared to arable land.</p> <p>Soil organic carbon stocks in secondary broadleaved woodlands (50–110 years) were comparable to those found in long-term ancient woodlands (>400 years).</p> <p>0-20cm depth of soil in secondary woodland contained significantly greater soil organic carbon than 20-40cm depth.</p>	<p>Ashwood et al. (2019)</p>
<p>This study modelled the impact of bioenergy on reducing carbon emissions using US forest parameters. It focused on a lifecycle analysis of wood produced in south-central US oak-hickory forests if used for bioenergy production in power plants, simulating the impact of substituting this for coal on carbon emissions.</p> <p>The immediate impact of substituting wood for coal is an increase in atmospheric carbon dioxide relative to coal. The payback time for this carbon debt ranges from 44–104 years after clearcut, depending on forest type—assuming the land remains forest.</p> <p>Replanting oak-hickory hardwood forests with fast-growing pine plantations raises the carbon dioxide impact of the wood when used for bioenergy production, because the equilibrium carbon density of plantations is lower than natural forests.</p> <p>Growth in wood harvest for bioenergy causes a steady increase in atmospheric carbon dioxide: as long as bioenergy generates an initial carbon debt, increasing harvests mean more is 'borrowed' every year than is paid back. Any carbon savings are only achieved if forests are allowed to regrow to pre-harvest levels following harvesting for bioenergy production.</p>	<p>Sterman et al. (2018)</p>

4.5 Urban microclimate

Trees can make a range of positive contributions to urban microclimates³³, and the England Trees Action Plan recognises their role in cooling urban areas and improving air quality³⁴.

The woodland natural capital accounts³⁵ estimated that in **2022, UK woodlands delivered urban heat regulating benefits valued at £753 million**. Exposure to high temperatures is related to increased morbidity and mortality rates³⁶, and the urban heat island effect can expose urban residents to increased risks from heatwaves³⁷. Trees can contribute to localised cooling through providing shade as well as through transpiration, helping to mitigate against the urban heat island effect³⁸. Higher tree canopy coverage has been linked to reduced rates of heat-related morbidity in urban areas³⁹. Compared to other vegetation, trees have a greater cooling effect due to their deep roots, which deliver more evapotranspiration, and the amount of shade they cast⁴⁰. The ability of trees to reduce urban temperatures depends on several factors including the number of trees and for individual trees, leaf density and crown shape⁴¹.

Trees can also deliver important benefits in relation to air pollution mitigation: they exchange gases with the atmosphere and capture particulates⁴². Trees can reduce people's exposure to air pollutants harmful to human health through dispersion (disrupting airflow and creating turbulence) and deposition (absorbing pollutants including gases (e.g. nitrogen dioxide, ozone and sulphur dioxide) and particles

³³ Petri et al. (2019)

³⁴ UK Government (2021)

³⁵ Office for National Statistics (2024a)

³⁶ Matthews et al. (2017)

³⁷ Heaviside et al. (2017)

³⁸ Walker et al. (2023)

³⁹ Petri et al. (2019)

⁴⁰ Wang et al. (2023)

⁴¹ Tamaskani Esfehankalateh et al. (2021)

⁴² Dwyer et al. (1992)

(e.g. PM₁₀) onto leaf surfaces)⁴³. Conifers can be especially beneficial in air pollution removal: evergreen species that retain their leaves year-round provide air-cleaning benefits all year, and finely divided leaves are particularly effective at intercepting air pollution⁴⁴. The location of trees in relation to pollution sources affects the extent to which trees can limit people's exposure to air pollution: tree canopies may trap pollution at the source, such as over a busy road, increasing risk of exposure there but reducing it away from the pollution source and that closed canopy⁴⁵. Reducing local temperatures can also reduce the rate at which some pollutants, such as ozone, are formed⁴⁶. However, some trees can contribute to air pollution: some species emit biogenic volatile organic compounds (BVOCs) that can combine with oxides of nitrogen (NO_x) to contribute to the production of other pollutants such as ozone⁴⁷.

Finally, trees can help to mitigate against noise pollution, which can have a range of negative impacts on human health, by absorbing high frequency sound energy in their soft, green vegetation and redirecting and scattering sound waves via their woody structures, aiding further sound absorption by the atmosphere and the ground⁴⁸. They can also help reduce the perception of noise.

4.5.1 Reviews

A structured review and meta-analysis (an examination of the numerical data from included studies) assessed 182 studies on the cooling effects of urban trees across 17 climates in 110 global cities or regions⁴⁹. Studies included both field

⁴³ Akbari (2002); Walker et al. (2023)

⁴⁴ Walker et al. (2023)

⁴⁵ Defra (2018); Walker et al. (2023)

⁴⁶ Jacob & Winner (2009)

⁴⁷ Walker et al. (2023)

⁴⁸ Fletcher et al. (2022)

⁴⁹ Li et al. (2024)

measurements and simulations (i.e. data produced using a computer model). 73 of the studies were located in temperate regions. Planting trees reduced the peak monthly temperatures to below 26 °C in 83% of the cities.

For studies in temperate regions, **the change in pedestrian-level air temperature resulting from the addition of trees ranged from –6.00°C (cooling) to +1.50°C (warming). Only 7 of the 73 temperate studies reported warming effects of trees, with all seven results based on nighttime temperatures.** Growing deciduous and evergreen trees together generally resulted in 0.5°C higher cooling compared to studies using single species, for tropical, temperate, and continental climates.

A systematic review assessed 34 studies about the economic benefits and costs of urban forests and extracted and analysed numerical data from studies.⁵⁰ Results should be treated with caution as there was no assessment of risk of bias in the assessed studies. 19 studies relied on i-Tree software for the valuation and presented a “snapshot” of benefits and costs of established trees for a single year. **Net annual air quality benefits per tree ranged from –0.003 kg to 1.81 kg, with annual economic benefit per tree from –\$0.68 to \$21.28.**

4.5.2 Coded studies

We assessed eight empirical studies that considered the impact of trees on urban microclimates (Table 6). Most studies considered the effects of trees on air pollution, finding that trees have a positive impact on a range of pollutants. Only one study also considered negative impacts, specifically around emissions of biogenic volatile organic compounds. Two studies investigated the effect of trees on temperature, finding a positive impact for urban cooling. One study considered noise pollution and found positive benefits associated with woodland planting.

⁵⁰ Song et al. (2018)

Table 6 Summary of coded studies for “urban microclimate” subtheme

Key outcome(s)	Citation
<p>An assessment of trees in the Wirral (UK) following the i-Tree Eco methodology estimated that the area supports more than 1 million trees which deliver benefits in terms of the removal of 244 tonnes per year of a range of pollutants (nitrogen dioxide, ozone, sulphur dioxide, carbon monoxide, particulate matter), valued at £773.7 million per year.</p> <p>The ten species that deliver the greatest amount of pollution removal via deposition in the Wirral are: Sycamore (<i>Acer pseudoplatanus</i>), Beech (<i>Fagus sylvatica</i>), Black Pine (<i>Pinus nigra</i>), Pedunculate Oak (<i>Quercus robur</i>), Common Lime (<i>Tilia x europaea</i>), Silver Birch (<i>Betula pendula</i>), Scots Pine (<i>Pinus sylvestris</i>), Downy Birch (<i>Betula pubescens</i>), Leyland Cypress (<i>x Cuprocyparis leylandii</i>) and Ash (<i>Fraxinus excelsior</i>).</p>	<p>Walker et al. (2023)</p>
<p>This study combined field measurements with numerical modelling to explore the summer cooling effect of sixteen different combinations of tree percentages and tree leaf area densities for an urban area – a hot spot street canyon in the residential area of Seongnam – in South Korea.</p> <p>By changing the characteristics of the vegetated base area from 4% trees to 60% trees, and from a low leaf area density to a high one, the daily average and daily maximum temperatures were reduced by approximately 3°C and 5.23°C, respectively. In contrast, adjusting leaf area density alone was only associated with a temperature difference of approximately 0.5°C.</p> <p>The magnitude of cooling delivered by trees via evapotranspiration depends on a range of factors including the type, amount and size of the trees and their canopies. For the study area, the cooling effect provided by trees is reduced during the evening, between 5 pm-8 pm.</p>	<p>Tamaskani Esfehankalateh et al. (2021)</p>
<p>This study modelled the noise mitigation that could result from five potential woodland planting scenarios within the administrative area covered by Birmingham City Council (UK).</p> <p>Noise mitigation from woodland is highest in deeper stands, with mitigation decreasing with distance from the woodland. New woodland should be targeted in areas of greatest noise mitigation opportunity, which for Birmingham occurs where residential buildings lie alongside the noisiest roads.</p> <p>More than 177,000 Birmingham residents benefit from noise mitigation from woodland, estimated to be valued at £3.83 million every year.</p>	<p>Fletcher et al. (2022)</p>
<p>This study investigated the relationship between land surface temperature and tree canopy cover in Leeds (UK), based on an analysis of high-resolution remote sensing data.</p> <p>There is a strong relationship between land surface temperature and canopy cover: greenspace types with lower tree canopy coverage had higher land surface temperature. Land surface temperature decreased by 1.4°C for every 10% increase in canopy coverage. This modelling study suggests that doubling canopy coverage across the city could reduce the mean land surface temperature by around 2.5°C during the warmest summer months.</p>	<p>Wang et al. (2023)</p>

Table 6 cont.

Key outcome(s)	Citation
<p>A study of street trees in a Chinese Forest City (Dalian) analysed the structural characteristics of Dalian’s 57,699 street trees, which include 28 tree species.</p> <p>Dalian’s street trees absorbed or intercepted 16.3 tonnes of air pollutants (specifically, nitrogen dioxide, ozone, sulphur dioxide and PM₁₀) each year, valued at \$193,972.</p> <p>Street trees also delivered benefits in terms of indirectly avoided emissions of air pollutants by reducing energy consumption: this amounted to 21.9 tonnes each year, valued at \$209,855.</p> <p>These trees were also responsible for releasing a total of 4.5 tonnes of biogenic volatile organic compounds, at a cost of \$22,740.</p> <p>The net benefits of Dalian’s street trees in terms of air pollutant removal were valued at \$381,088 or \$7 per tree, using the i-Tree Streets methodology.</p>	<p>Wang et al. (2018)</p>
<p>The UK has approximately three quarters of a million hectares of non-woodland trees (i.e. individual trees, groups of trees less than 0.1ha in extent and small woods 0.1ha-0.5ha, in both rural and urban areas).</p> <p>The economic value provided by non-woodland trees in the UK in terms of carbon sequestration is UK in terms of air pollution removal is £1.404 billion per year (using the i-tree Canopy methodology) and £273 million per year (using the Woodland Natural Capital Accounting Benefit Transfer Approach)</p>	<p>Doick et al. (2021)</p>
<p>This study modelled the impacts of existing urban trees on residential energy use and emissions for the US, using secondary data.</p> <p>By reducing residential energy demand for air conditioning, urban trees in the US avoid thousands of tonnes of pollution emissions from power plants, which are valued as saving \$3.899 billion per year in terms of the emission-related costs avoided. Specifically, the US urban forest is estimated to avoid the emission of 39,172 metric tonnes of NO_x (valued at \$368,657,000); 112,538t SO₂ (valued at \$1,004,7393,000); 493t CH₄ (valued at \$484,000); 17,467t CO (valued at \$27,928,000); 4,529t PM_{2.5} (valued at \$638,322,000); 1,860t PM₁₀ (valued at \$104,799,000) and 1,194t VOC (valued at \$1,441,000).</p>	<p>Nowak et al. (2017)</p>
<p>Using a computer model based on nitrogen dioxide measured at 144 sites in Portland, Oregon (USA), and after taking roads, railways and elevation into account, it was estimated that every 10 hectares of tree canopy within 400 metres of a site was associated with 0.57 parts per billion decrease in nitrogen dioxide. Using BenMAP (a GIS dataset produced by the US Environmental Protection Agency) and a 200-metre resolution nitrogen dioxide model, it was estimated that this nitrogen dioxide reduction could result in significantly fewer incidences of respiratory problems (e.g. asthma-related A&E visits), providing a \$7 million USD benefit annually.</p>	<p>Rao et al. (2014a)</p>

4.6 Natural resource consumption

A large proportion of greenhouse gas emissions are related to energy use: in 2022, households and the energy sector were responsible for 41% of total UK greenhouse gas emissions⁵¹.

Trees can contribute to reducing energy consumption for heating and cooling in several ways: by providing shade; by reducing windspeed or blocking cold winds; and by cooling the air via evapotranspiration⁵². However, in cold climates, shade from trees can increase energy demand for heating⁵³. Tree size, species (evergreen vs. deciduous), and tree distance and direction from the building all affect building energy use⁵⁴.

The ability of trees to mitigate air pollution can also contribute to a reduction in energy consumption, providing supportive conditions for people to manage cooling by opening windows or spending more time outdoors⁵⁵.

In addition, places with trees may be more attractive for some recreational activities, and so incorporating more trees into urban areas can potentially reduce fuel consumption for travel in order to access those recreational benefits⁵⁶.

4.6.1 Reviews

A systematic review assessed 34 studies about the economic benefits and costs of urban forests.⁵⁷ Results should be treated with caution as there was no assessment of risk of bias in the assessed studies. 19 studies relied on i-Tree software for the valuation and presented a “snapshot” of benefits and costs of established trees for

⁵¹ Office for National Statistics (2024b)

⁵² Akbari (2002); Akbari & Taha (1992); Akbari et al. (1997); Donovan & Butry (2009); Nowak et al. (2017); Stone & Norman (2006); Wang et al. (2018)

⁵³ McPherson et al. (1988)

⁵⁴ Nowak et al. (2017)

⁵⁵ Salvo (2020)

⁵⁶ Dwyer et al. (1992)

⁵⁷ Song et al. (2018)

a single year. **Annual cooling savings per tree ranged from 23 kWh to 288 kWh while heating savings ranged from –3.06 kWh to 842 kWh.**

4.6.2 Coded studies

We assessed three empirical studies that considered the impact of trees on energy consumption (Table 7). The three studies found that urban trees have a positive effect on energy consumption, with concomitant benefits in terms of substantial financial savings.

Table 7 Summary of coded studies for “consumption” subtheme

Key outcome(s)	Citation
<p>This study investigated the net carbon benefits that urban tree planting could have in China, based on an analysis of existing datasets.</p> <p>It explored the relationship between monthly residential electricity consumption for 10,000 households representative of all of China, with greenness measured in terms of a Normalised Difference Vegetation Index.</p> <p>For every 0.1% increase in greenness, per capita residential electricity consumption decreases by 1.76%.</p>	Huang et al. (2024)
<p>A study of street trees in a Chinese Forest City (Dalian) analysed the structural characteristics of Dalian’s 57,699 street trees, which include 28 tree species. Benefits from energy savings were valued at \$1.7 million or \$29.2 per tree, using the i-Tree Streets methodology. Annual electricity savings were valued as 12,339 gigajoules per year (\$248,176), whilst savings in natural gas consumption were valued as 141,011 gigajoules per year (\$1,436,228). Large stature trees provided the greatest benefits, whereas small stature trees with less leaf area and canopy cover provided the least.</p>	Wang et al. (2018)
<p>This study modelled the impacts of existing urban trees on residential energy use and emissions for the US, using secondary data.</p> <p>Overall, the US urban/community forest is estimated to save \$11.7 billion each year. \$7.8 billion of this saving is from energy costs. Existing urban trees reduce US residential energy use by 7.2%: \$4.7 billion of this is from reduced electricity use (a reduction of 38.8 million megawatt hours) and \$3.1 billion is from reduced heating use (a reduction of 246 million MMBtus, where 1 MMBtus is 1 million British Thermal Units). Reduced emissions from power plants deliver an additional saving of \$3.9 billion per year.</p> <p>On average, the value of energy savings per hectare of tree cover in urban forests in the US is \$455 per year, with an additional \$228 per year from avoided emissions.</p> <p>The US urban forest was estimated to avoid 43.8 million tonnes of CO₂ from power plants, valued at \$1.752 billion.</p>	Nowak et al. (2017)

4.7 Biodiversity

Biodiversity brings many benefits, including increased ecosystem functionality and the delivery of multiple ecosystem services⁵⁸. However, the UK is one of the most nature-depleted countries in the world: nearly 1 in 6 UK species are threatened with extinction and nature continues to be in serious decline driven by centuries of habitat loss, development and persecution⁵⁹.

Woods and forests support a diverse range of species, providing food and shelter. Native woodland is associated with significant biodiversity benefits and fragments of ancient woodland can provide refugia for biodiversity within the landscape⁶⁰.

However, the UK is also one of the least forested countries in Europe⁶¹ resulting from a long history of woodland clearance, most recently driven by development pressures and agricultural expansion. As set out in the England Trees Action Plan⁶², investment in increased tree planting in combination with protecting and improving existing woodlands is an important element of responding to biodiversity loss and will form a core part of the Nature Recovery Network.

A significant increase in the amount of non-native, commercial conifer plantation is anticipated to be catalysed by the UK's recent ambitious tree planting targets, much of which is likely to be on land of low agricultural value, but which may host habitats with their own significant biodiversity value such as unenclosed upland heathland, bog and grassland⁶³. The biodiversity benefits of woodland should be considered alongside the biodiversity benefits of other habitats, whereby landscape-scale management necessitates making ecological trade-offs⁶⁴. There are established concerns about the potential ecological impacts of afforesting with non-

⁵⁸ Valdés et al. (2020)

⁵⁹ Burns et al. (2023)

⁶⁰ Valdés et al. (2020)

⁶¹ Forest Research (2022)

⁶² UK Government (2021)

⁶³ Douglas et al. (2020)

⁶⁴ Cordingley et al. (2016)

native conifers, especially following controversial large-scale afforestation on peatlands⁶⁵. Even where tree planting seeks to reforest with native, deciduous tree species, it takes a long time for biodiversity to recover with reforestation, underlining the importance of well-managed ancient woodlands⁶⁶.

4.7.1 Reviews

Two reviews assessed the impacts of agroforestry (any land management approach combining trees and agriculture) on the ecosystem regulating services of water, soil and carbon. For the other benefits of agroforestry, see Section 5.5.

The first, a systematic review, assessed 83 studies about trees in grazed dairy systems and found that **most relationships reported between on-farm woody systems and ecosystem services were positive**, with few reports of disbenefits for ecosystem services⁶⁷. Causal impact pathways with the strongest evidence base included the **biodiversity benefits of native vegetation in woody systems**. Evidence should be treated with caution due to limitations in the assessment of risk of bias in the assessed studies.

4.7.2 Coded studies

We assessed seven empirical studies that considered the biodiversity impacts of trees and woodland (Table 8). Three studies focused on understanding the impacts of reforestation whilst one focused on understanding the implications of retaining trees within a mosaic of habitats. Two studies considered multiple taxonomic groups whereas one focused on breeding birds, two on earthworms, one on fish and aquatic invertebrates and one on soil microorganisms.

⁶⁵ Shah et al. (2021)

⁶⁶ Valdés et al. (2020)

⁶⁷ England et al. (2020a)

Table 8 Summary of coded studies for “biodiversity” subtheme

Key outcome(s)	Citation
<p>Biodiversity value was assessed for a range of habitats associated with lowland heathland mosaics in Dorset. Here, biodiversity value is the mean number of species (mammals, birds, butterflies, reptiles, amphibians, vascular plants and bryophytes) listed in the UK Biodiversity Action Plan found per 4-hectare survey square. The biodiversity value of woodlands (1.95) was higher than for mire (1.67) but lower than for grassland (2.76), scrub (2.52), dry heath (2.50) and humid/wet heath (2.42).</p>	<p>Cordingley et al. (2016)</p>
<p>This study compared breeding bird species richness and abundance in existing plantations of native-dominated woodland of varying ages (8-24 years) and sizes with adjacent moorland and farmland in a representative UK upland landscape (700 km² in Highland Perthshire, Scotland).</p> <p>Bird species richness increased with increasing woodland cover, height and age, suggesting a positive association with woodland maturation, and declined with increasing elevation. Abundance of most bird species, including many species of conservation concern, was generally higher in native woodland than moorland, except for Meadow Pipit which was more abundant on moorland. Native reforestation of open ground offers net gains in bird species richness but could disbenefit open-ground birds. Modelling predicts that creating 54.9 km² native woodland in Scotland between 2017-2018 had a negative impact on Meadow Pipit (a loss of 6,214 individuals or 0.13% of the current UK population) but a positive impact on Willow Warbler (an increase of 6,040 individuals or 0.13% of the current UK population).</p>	<p>Douglas et al. (2020)</p>
<p>This empirical study collected data from 224 deciduous woodlands across 7 regions in temperate Europe, comparing small (both recent and ancient) and larger woodlands/forest patches in agricultural landscapes. The study compared two 5 km² landscapes in each region with contrasting connectivity levels.</p> <p>Species richness was surveyed for six taxonomic groups (understorey herbs, mushrooms, ground beetles, spiders, woodlice, millipedes) which were selected because they are assumed to influence the potential delivery of six ecosystem (dis)services (abundance of usable plants, pest control potential, tick-borne disease risk, game production potential, topsoil carbon storage, stemwood volume). A ‘multidiversity’ index representing the mean species richness across these taxonomic groups was calculated for each patch.</p> <p>Tree species diversity was associated with greater structural diversity and increased with the age of the patch. Multidiversity was higher in larger and more ancient patches. Multidiversity had a significant positive impact on the abundance of usable plants, pest control potential and game production potential. Neither macroclimatic conditions nor amount of forest cover around each woodland affected multidiversity.</p>	<p>Valdés et al. (2020)</p>
<p>This study compared differences in earthworm populations between silvopasture and adjacent grassland in a single agricultural holding in Co. Leitrim, north-west Ireland.</p> <p>This found a statistically significant difference in earthworm abundance, with greater mean abundance of earthworms in silvopasture sites (36 earthworms per square metre) compared to grassland (18 earthworms per square metre).</p>	<p>Connolly (2020)</p>

Table 8 cont.

Key outcome(s)	Citation
<p>This long-term empirical study focused on assessing the impacts of afforestation with conifers on the sensitive peaty headwaters of the River Halladale in an internationally important area of blanket bog in Northern Scotland in 1996.</p> <p>Data from surveys of fish and aquatic benthic invertebrates showed that forestry operations and forest growth to age 24 years had no adverse impact on population diversity or abundance, with no evidence of deterioration in freshwater ecology. Overall, salmonid and invertebrate numbers and diversity were typical of good quality streams/rivers in North Scotland. With the exception of salmon numbers in one stream, salmonid and benthic macroinvertebrate populations have remained stable or improved. This demonstrates that conifer afforestation delivered in line with the UK Forestry Standard can be compatible with sustaining healthy fish and macroinvertebrate populations in sensitive peaty catchments.</p>	<p>Shah et al. (2021)</p>
<p>An empirical study investigated the effects of converting agricultural land to woodland in a lowland landscape in England, following their transition from arable or pasture through secondary woodland to ancient woodland. This study collected data on unmanaged, small (2-5 hectares) broadleaved woodlands created on former agricultural land 50-120 years ago in the National Forest.</p> <p>Earthworms have an important ecological role: they are 'ecosystem engineers', associated with soil chemical, physical and biological quality and they provide a range of ecosystem services.</p> <p>Restoring broadleaved woodland on agricultural land improves earthworm diversity and within the first 50-60 years following restoration, these woodlands support an increased diversity of earthworm species than older woodlands or agricultural land.</p> <p>However, earthworm abundance is lower in woodland (121.1 individuals per square metre in young woodland, 119.7 in mature woodland and 96.6 in ancient woodland) compared to agricultural land (349.7 individuals per square metre in pasture, 162.5 in arable). No significant differences were found in earthworm species richness between woodland and agricultural land.</p> <p>Compared to agricultural land, woodlands had 4% more surface-living species of earthworms and a greater proportion of deep-burrowing earthworms, but 18% fewer shallow-burrowing earthworm species.</p>	<p>Ashwood et al. (2019)</p>
<p>A US study compared 25-year-old deciduous hardwood silvopasture with black walnut (<i>Juglans nigra</i>) and honey-locust (<i>Gleditsia triacanthos</i>) to adjacent open pasture at an agroforestry demonstration centre in Virginia.</p> <p>This study found that each system had diverse and distinctive ecological niches for soil microbial communities. Silvopasture had less phospholipid fatty acid and less actinomycetes abundance compared to open pasture. Black walnut silvopasture had less arbuscular mycorrhizal fungi than open pasture.</p> <p>No significant differences were found for bacteria (either gram-positive or gram-negative) or total bacterial abundance, nor for total fungi abundance.</p>	<p>Poudel et al. (2022)</p>

5 Benefits for People

5.1 Theme overview

5.1.1 Reviews

There were 13 reviews published from 2014 – 2024 that were of high relevance to this theme, ten of which were structured reviews (Table 9).

5.1.2 Studies

There were 26 studies selected for coding in the “people” theme from the 136 total included studies. The quantity of studies was highest for mental health, physical health and society, with many of the studies encompassing all three of these subthemes. There was a lack of studies about business / commerce, farming / food security or culture, heritage and aesthetics. Many of the studies about business / commerce focused on property values and were based in non-temperate zones in the Americas. Studies about the cultural, heritage and aesthetic values of trees tended to be opinion or reflective articles, with no data collection.

Table 9 Summary of reviews on the “People” theme

Review type is unstructured (UN-STR), structured (STR) or systematic (SYS)

Summary	Mental health	Physical health	Business	Farming / food	Society	Culture	Review type	Citation
Impacts of forest school on children					✓		STR	Dabaja (2022b)
Ecosystem services of urban forests	✓		✓	✓	✓	✓	UN-STR	(Davies, 2017)
Silvo-pastoral systems and dairy cows				✓			STR	Deniz et al. (2023)
Benefits / disbenefits of trees for dairy systems			✓	✓			STR	England et al. (2020a)
Social / cultural values of trees at risk from pests and diseases	✓	✓	✓		✓	✓	STR	Hall et al. (2020a)
Tree benefits (National Forest Wales)	✓	✓			✓		STR	Hall et al. (2021)
Temperate agroforestry and livestock				✓			SYS	Jordon et al. (2020)
Benefits of urban foraging / food forests				✓			STR	Oncini et al. (2024)
Ecosystem services of street trees						✓	UN-STR	(Salmond et al., 2016)
Economic costs & benefits of urban forests			✓				SYS	Song et al. (2018a)
Tree cover and property values (US)			✓				SYS	Siriwardena et al. (2016a)
The impact of agroforestry on pest control and pollination				✓			STR	Staton et al. (2019)
Urban trees and human health	✓	✓					STR	Wolf et al. (2020)

5.2 Mental health

Mental health problems are steadily increasing in the global population. A key contributor is the rise of urban living⁶⁸. Challenges to mental health in urban areas include pollution, social isolation, lack of green space, violence and high crime rates. There is growing recognition about the benefits of exposure to natural environments for urban dwellers' mental health⁶⁹. Natural environments benefit mental health first by lessening the negative impacts of the socially dense, polluted and noisy urban environment and second, due to the restorative qualities of sensory interactions with living and non-living elements in nature⁷⁰.

Trees and woodland are believed to be particularly restorative for mental health, with various reasons proposed for their unique beneficial effects. Most importantly, trees and shrubs provide a more effective barrier to the visual and noise impacts of the built environment than other types of vegetation.⁷¹ Woodlands tend to be diverse and structurally complex, characteristics that tend to **promote a sense of fascination and distraction from mental discomfort**.⁷² Woodlands have a high degree of perceived "naturalness", another factor that promotes these mental states. Seasonal foliage changes are also an aspect of trees that provide restorative properties.⁷³ The immersive nature of woodland vegetation may also create a sense of escape from everyday concerns. For small urban parks, **the quantity of trees and bushes in the park was positively associated with participants' subjective sense of being away from everyday concerns** for 52 adults surveyed in Sweden, based on photographs of 74 parks⁷⁴.

⁶⁸ (Srivastava, 2009)

⁶⁹ (Lackey et al., 2021)

⁷⁰ (Engemann et al., 2019)

⁷¹ (Hauru et al., 2012)

⁷² (Van den Berg et al., 2014)

⁷³ (Paddle & Gilliland, 2016)

⁷⁴ (Nordh et al., 2009)

But not all individuals find the immersive qualities of woodland therapeutic and the lack of sight lines and potential for concealment can induce stress and fear.⁷⁵ Freestanding trees also provide unique mental health benefits. **Having a tree adjacent to the house was recently found to be positively associated with self-reported wellbeing.**⁷⁶ **The rate of antidepressant prescriptions decreased with increasing density of street trees in London, independently of socioeconomic factors.**⁷⁷

5.2.1 Reviews

A scoping review about benefits and disbenefits of urban trees for human health assessed 63 studies about mental health (a scoping review maps the existing literature on a broad topic).⁷⁸ **Most of the reviewed studies found that exposure to trees or woodland improved mental health, anxiety or mood,** but few studies used comparative treatments in the study design, apart from some studies that compared trees to a built environment e.g. carpark.

A frequent topic in studies about stress was “forest bathing”, a therapeutic practice from Japan. **“Forest bathing” was associated with a decrease in depression in two studies and promoted stress recovery in six studies.**

A structured review (albeit with only brief methods section) assessed approximately 200 studies about health and social capital and concluded that there was **high consensus in the evidence for the benefits of community woodland to mental health, physical health and social capital,** but conflicting evidence

⁷⁵ (Milligan & Bingley, 2007)

⁷⁶ (Ordóñez et al., 2024)

⁷⁷ (Taylor et al., 2015)

⁷⁸ (Wolf et al., 2020)

about the benefits of urban trees for these three factors. There was no explanation in the review about how evidence agreement was measured.⁷⁹

5.2.2 Coded studies

We assessed ten empirical studies that considered the mental health benefits of trees or woodland (Table 9). In three studies, residents reported mental health benefits of living in areas with trees or woodland. Frequent forest visitors had lower stress levels compared infrequent visitors, and a forest therapy programme relieved some stress factors in the infrequent visitors. The main benefits of an “active forest” programme were related to wellbeing and stress relief. Two studies focused on adolescents: exposure to woodland promoted self-care for mental wellbeing in the first study and was associated with improved cognitive development and mental health in the second study. A study focusing on children found that forest school helped overcome children’s fear of woodlands. **Three studies found that trees or woodlands were more beneficial for mental health than other types of outdoor space**, for example grassland and other low-lying vegetation.

⁷⁹ Hall et al. (2021)

Table 10 Summary of coded studies for “mental health” subtheme

Key outcome(s)	Citation
Residents reported lower psychological distress (but not depression or anxiety) in areas with a high level of tree canopy cover (30%) compared to areas with low cover canopy (0-9%), which was not the case for areas with grass or other low-lying vegetation.	(Astell-Burt & Feng, 2019)
Respondents in areas with more forests reported fewer days of mental health complaints compared to other types of green spaces, independently of other factors (e.g. age, sex, ethnicity, income, education level)	(Akpinar et al., 2016)
32 urban-dwelling adults in focus groups mentioned benefits of urban trees, with an emphasis on benefits of trees for mental health and urban biodiversity. Urban trees in all settings were appreciated, but those in urban parks and similar settings were seen as the most beneficial.	(Ambrose-Oji et al., 2021)
This study looks at the impacts of forest school participation on primary-aged children through observations of 71 children and interviews with 20 forest school practitioners. 17 of the 20 UK forest school practitioners believed that the regular forest school activities helped to overcome 5-11-year-old children’s fears of woodlands.	(Harris, 2021)
(1) 120 frequent users of the forest environment exhibited lower levels of physiological and psychosocial stress compared to 91 low frequency users, for some (but not all) of the factors measured in the study. (2) A forest therapy program relieved low frequency users’ psychosocial stress for some of the factors measured in the study. The participants were healthcare workers, an industry with high emotional burden and subsequent stress levels. The experimental group comprised infrequent users of the forest environment that participated in a five-day forest therapy program (based on walking, exercising, and meditation/sensory engagement in the forest location). The control group comprised frequent users of the forest environment that did not participate in the forest therapy programme.	(Jung et al., 2015)
The street tree density per km of street ranged from 15.7/km to 81.7/km, with mean (Standard Deviation) of 40.2 (14.0) trees/km, across the 31 boroughs and primary care trusts in the study. Antidepressant prescribing rate varied from 357.9 to 577.8 prescriptions per 1000 population Simple regression analysis indicated that a greater tree density (one additional tree per km of street) was associated with 1.38 fewer prescriptions for antidepressants (95% CI 0.03 to 2.72) per 1000 population. This effect remained after controlling for some of the potential confounders (mean income, deprivation index, employability status, mean age, percentage smokers).	(Taylor et al., 2015)

Table 10 cont.

Key outcome(s)	Citation
<p>Higher daily exposure rates to natural space and particularly woodland was associated with enhanced cognitive development and mental health, for 3,568 adolescents in London.</p> <p>Daily exposure rates were measured as the proportion of natural environment within 250m around the adolescent’s home and school. Cognitive development was measured using EF score. EF stands for executive function, a set of mental processes that help with the planning, monitoring and carrying out tasks. Mental health was measured using the SDQ total difficulties score. SDQ stands for the Strengths and Difficulties Questionnaire, which comprises a series of questions about emotional and behavioural problems. Overall wellbeing was measured using the HRQoL score, which stands for Questionnaire Health-Related Quality of Life.</p> <p>When comparing the adolescents exposed to the highest level of woodland (~38%) to those exposed to the lowest level of woodland (0%), the estimated percentage change in cognitive development was 6.83% (95% CI: 3.41, 9.11) using the EF score and the percentage change in the risk of emotional and behavioural problems was –16.36% (95% CI: –27.49, –3.50) using the SDQ total difficulties score. There was no improvement of adolescents’ cognitive development and mental health for a higher daily exposure to grassland with the exception of the outcome for overall well-being using the HRQoL score.</p>	(Maes et al., 2021)
<p>A multi-visit nature-based intervention in Westonbirt Arboretum (UK) providing three types of immersive engagement (social, woodland craft, creative / sensory) helped to reduce stress and improve wellbeing, for participants (26 young people with autism and 24 adults with diverse mental health problems).</p>	(O’Brien, 2018)
<p>The study focuses on 120 adults participating in the Active Forests programme at nine forest sites (UK), a programme aiming to encourage, support and sustain or change physical activity.</p> <p>One of the eight dominant themes in the interview data was the mental health benefits of being physically active in forests, with participants mentioning stress relief from being active, the forest as a calming place and the enjoyment associated with being active in a forest.</p>	(O’Brien, 2019)
<p>304 adult participants in the Wirral (UK) expressed high agreement (based on median score) with a statement about trees being “good for mental wellbeing”, in a survey comprising 19 statements on the social and cultural values of trees and woods.</p>	(Walker et al., 2023)

5.3 Physical health

The rise in urban living poses a variety of physical health risks, including air and water pollution, rapid disease transmission due to close proximity of people and the reduction in physical activity due to the shift to sedentary jobs and lifestyles.⁸⁰

Localised air pollution produced by motorised traffic, domestic fuel burning and industrial activities, is a significant problem in many cities. It contributes to a range of diseases (particularly respiratory and cardiovascular) and is responsible for more than 4 million premature deaths worldwide.⁸¹

Nearly a third (1.8 billion) of the global adult population did not meet the recommended levels of physical activity in 2022, a trend that has been increasing steadily for the last 20 years.⁸² Insufficient physical activity increases the risk of non-communicable diseases (e.g. heart disease, Type II diabetes) and is responsible for more than 5 million premature deaths worldwide.⁸³

Urban planning and design can have a significant impact on both air quality and levels of physical activity in a number of ways. First, through the provision of safe, accessible routes that promote active travel (modes of travel that involve physical activity e.g. walking, cycling) instead of motorised transport.⁸⁴ Second, through greenspace provision, which encourages engagement in physical recreational activities. Third, because vegetation helps to reduce or divert air pollution.

However, the relationship between greenspace density and active travel can be complex. Some studies identified a negative relationship between greenspace density and rates of commuter-related cycling and walking, because of the additional distance required for their commute⁸⁵. High population density in cities

⁸⁰ (Moore et al., 2003)

⁸¹ (Cohen et al., 2017)

⁸² (Guthold et al., 2018)

⁸³ (Lee et al., 2012)

⁸⁴ (World Health Organization, 2023)

⁸⁵ (Fan et al., 2014)

was found to be associated with lower air pollution emissions, because less travel is required between destinations making this easier by public transport or active travel.⁸⁶

Studies have found that **woodland promotes outdoor recreation to a greater extent than other habitat types** (see 5.3.3), which the authors proposed was because woodland offered more protection from the weather and more appealing vegetation,⁸⁷ or because woodland promoted moderate, regular exercise and relieved stress more than the other habitat types.⁸⁸ These proposals are supported by a study in China, which found that **adults preferred three different types of woodland to amenity grassland**, either because the woodland alleviated heat discomfort to a greater extent or was more interesting or aesthetically pleasing.⁸⁹ In contrast, one study found that large herbaceous areas (i.e. grassland and other low-lying vegetation) had higher rates of physical activity than areas with large woodlands or shrublands. The study did not consider habitat mosaics.⁹⁰

Studies have found that **trees produce a reduction in air pollution and related health problems** (see 5.3.3). Vegetation can reduce air pollution through three main mechanisms: dispersal (causing the gas or particle-based pollutants to spread over a wider area), deposition (the pollutants stick to the plant surface) or modification (the plant absorbs the pollutants and breaks them down).⁹¹ **Trees have the potential to reduce air pollution more than other vegetation types because taller vegetation traps particles through deposition more efficiently than short vegetation.**⁹² However, in some contexts rows of trees can

⁸⁶ (Castells-Quintana et al., 2021)

⁸⁷ (Ghimire et al., 2017b)

⁸⁸ (Wu et al., 2018b)

⁸⁹ (Duan & Li, 2022)

⁹⁰ (Tsai et al., 2016)

⁹¹ (Diener & Mudu, 2021)

⁹² (Fowler et al., 2004)

exacerbate localised air pollution by reducing the wind movement and airflow that helps to dilute pollutants.⁹³

Urban and peri-urban forests have been shown to serve a particularly valuable role in addressing health inequalities in the UK, particularly related to low levels of physical activity and lifestyle-related diseases and in forest areas that are close to where people live and work.⁹⁴ The review highlighted the value of qualitative studies for capturing complexity, particularly around safety issues and user conflicts in some urban woodlands.

5.3.1 Reviews

The scoping review about benefits and disbenefits of urban trees for human health referred to in the previous section also assessed 95 studies relating to physical health.⁹⁵ The following results refer to separate studies (i.e. there is no repetition of studies between bullet points) identified in the scoping review.

- **Eight modelling studies identified positive effects of urban trees in reducing the mortality, respiratory problems and health costs associated with air pollution.**
- **Three studies based on data collection also found positive effects, specifically lower prevalence of lung cancer and asthma in areas with high tree cover, especially when ambient air pollution was high.** By contrast, three studies found neutral effects of trees on asthma prevalence and one study found a negative effect. Authors attributed the negative effect to allergies triggered by exposure to pollen and volatile organic compounds (VOCs) emitted by certain tree species (VOCs are chemicals that evaporate easily).

⁹³ (Vos et al., 2013)

⁹⁴ (O'Brien, 2010)

⁹⁵ (Wolf et al., 2020)

- 40 studies assessed health impacts of pollen and VOCs, with most studies finding that certain tree species exacerbated allergic symptoms, particularly for older people and in hot or humid conditions.
- **Five studies found that trees reduced harmful exposure to ultraviolet rays, particularly in school grounds, and where there were large trees with dense foliage.** Three additional studies found that trees reduced heat-related mortality or illness.
- **19 studies assessed impacts of trees on physical activity, of which 18 found positive associations, including walking for recreational or commuting purposes, commuting-related cycling and children's play.** Three studies also found negative or neutral effects, which authors attributed to impacts of trees on perceived neighbourhood safety or walkability (the accessibility of urban amenities by foot).
- **Eight studies found positive associations between tree exposure, proximity or density and likelihood of not being obese** (usually measured using Body Mass Index).
- 16 studies assessed the relationship between trees and cardiovascular health. **Seven studies found that "forest bathing" improved cardiovascular function in healthy adults. Three studies found that forest exposure reduced symptoms relating to cardiovascular disease in older adults,** whilst another study found that forest exposure had no impact on disease.

A structured review (albeit with only brief methods section) assessed approximately 200 studies about health and social capital and concluded that there was **high consensus in the evidence for the benefits of community woodland to mental health, physical health and social capital**, but conflicting evidence

about the benefits of urban trees for these three factors. There was no explanation in the review about how evidence agreement was measured.⁹⁶

5.3.2 Coded studies

We assessed six empirical studies that considered the physical health benefits of trees or woodland (Table 10). Two studies (referred to in 5.3) found that **incidences of obesity and sudden (cardiac) death were lower in areas with a high amount of forest, which was not the case for other types of greenspaces, e.g. grassland and shrubland**. Two studies (referred to in 5.3.1) found that **tree density and canopy area respectively were associated with a reduction in respiratory disease-related health problems**. One study found that a forest exercise intervention had no impact on levels of physical activity, whilst another study found that people agreed that trees contributed to physical wellbeing.

Table 11 Summary of coded studies for “physical health” subtheme

Key outcome(s)	Citation
660,505 asthma emergency hospitalisations from 1997-2012 were assessed to understand the effects of tree cover and air pollution in urban areas (NO ₂ , SO ₂ and PM _{2.5}) on emergency hospitalisations due to asthma. Tree density was associated with reduced asthma hospitalisation when pollutant exposures were higher but had no significant association when pollutant exposures were lower. This effect is likely to be due to the role of trees in pollutant removal and disposition.	(Alcock et al., 2017)
304 adult participants in the Wirral (UK) expressed high agreement with a statement about trees being “contribute to physical wellbeing” (based on media score), in a survey about values of trees and woods.	(Walker et al., 2023)

⁹⁶ Hall et al. (2021)

Table 11 cont.

Key outcome(s)	Citation
<p>Using a computer model based on NO₂ measured at 144 sites in Portland, Oregon (USA), and after taking roads, railways and elevation into account, it was estimated that every 10 hectares of tree canopy within 400 metres of a site was associated with a 0.57 ppb (parts per billion) reduction in nitrogen dioxide. Using BenMAP (a GIS dataset produced by the US EPA) and a 200-metre resolution NO₂ model, it was estimated that this NO₂ reduction could result in significantly fewer incidences of respiratory problems (e.g. asthma-related A&E visits), providing a 7 million USD benefit annually.</p>	(Rao et al., 2014b)
<p>The study focuses on 120 adults in Active Forests, a programme supporting physical activity, at nine forest sites (UK). 2/8 themes in interview data related to physical health benefits of participation. There was evidence of sustained change in physical activity levels following participation, although it was not possible to attribute this to the programme directly. Those less active before (<2.5 hours activity per week) were significantly more likely to be active at a 3 month follow up. Those who were more active before (>2.5 hours activity per week) increased physical activity by 46%.</p>	(O'Brien, 2019)
<p>The probability of adults being overweight /obese was significantly lower in U.S. counties with a high per-capita forestland, compared to those with a low per-capita forestland, which was not the case for other types of green space i.e. rangeland (native grassland / shrubland), pasture and cropland, for 198 U.S. counties. The authors controlled for socioeconomic and demographic characteristics at individual and county levels that previous studies had linked to body weight, as well as spatial variables such as proximity to public recreation lands, outdoor recreation resources, and environmental / natural amenities that could be correlated with forestland and have an independent effect on body weight. It was estimated that a one-acre increase in per-capita forestland, which is associated with a decline in BMI by 0.0005, would lower U.S. public medical expenditures by \$3.0 million per year.</p>	(Ghimire et al., 2017a)
<p>Sudden unexpected death, commonly caused by cardiac arrest, was negatively associated with greenway (recreational cycle / walking track) density and the percentage of forest by total land area. There was no relationship between sudden expected death and the percentage of non-forest greenspace types (e.g. shrubland, grassland) and measures of tree canopy (i.e. street trees) also did not influence the rate of sudden unexpected death. This was for 396 adult cases of sudden unexpected death in North Caroline, U.S. These results suggest that increasing the length of greenways density by 1 km in every km² of land area produced a decrease in sudden unexpected death risk of 18%. Increasing forest area by 10%, produced a decrease in sudden unexpected death risk of 10%. The authors controlled for various demographic and socioeconomic factors.</p>	(Wu et al., 2018a)

5.4 Business / commerce

There is an urgent need for nations to transition to 'green' economies, economic models that prioritise environmental stability at least as highly as the financial value of goods and services, to mitigate the global crises of climate change and rapid biodiversity loss. Current production and consumption patterns are having devastating impacts on the natural environment.

Furthermore, biodiversity and wealth generation are inextricably linked, and the World Economic Forum estimates that half of the world's total Gross Domestic Product (\$44 trillion) is dependent on nature, for example through resource extraction or ecosystem services such as clean air and healthy soils.⁹⁷ Reducing the nature-related risks of operations, supply chains, and markets in turn helps to stabilise financial systems.

Trees and forests have an important role to play in mitigating nature-related economic risks and enabling the transition to 'green' economies. Intact forests provide a range of valuable commodities and ecosystem services, whereas their destruction has led to significant costs related to disease, air pollution, drought, civil unrest and the breakdown of trade agreements.⁹⁸ Trees can contribute to 'green' economies in various ways, through their benefits for retail, tourism, employment and employability, property value and investment.

Street trees provide an economic benefit to shopping districts. **Residents surveyed in 26 US cities perceived retail areas with trees as having a significantly more positive place character and superior products and shopkeepers, compared to retail areas without trees.**⁹⁹ Place character included qualities such as attractiveness, atmosphere and positive image. There

⁹⁷ (World Economic Forum, 2020a)

⁹⁸ (World Economic Forum, 2020a)

⁹⁹ (Wolf, 2005)

was also a significant positive effect of trees on variables related to residents' likely travel time and distance, duration and frequency of visit, expenditure and acceptable parking fees. **Respondents mean (average) willingness-to-pay value for shopping was 69.42 USD in the retail areas without trees, compared to 92.22 USD in the areas with trees.** In other words, people are willing to pay more for the same items in areas with trees. Trees were also favoured as positive features by visitors to shopping malls in Malaysia.¹⁰⁰

Retail data from 1,116 retail streets across five commercial districts in China showed that consumers spend more time in shopping areas with an intermediate canopy size of street trees but spend less time in shopping areas with either extremely sparse or substantial tree canopies.¹⁰¹ The authors suggested that a large tree canopy could impede retail by shading shop fronts or affecting shop visibility to customers.

Street trees also provide an economic benefit to the historic and cultural districts of cities. In a survey of 383 residents in Germany, based on photographs of ten different squares, there were **positive effects of trees on the perceived attractiveness of urban squares, likely frequency of visit and length of stay and acceptable price level in adjacent restaurants.**¹⁰²

Trees and forests provide an economic benefit in tourism. In 2009, **332 million tourists (mainly domestic) visited forest parks in China, generating 300 million USD in park fees.**¹⁰³ In 2011, **tourists' willingness-to-pay value for visiting an urban forest in Georgia, USA, had a mean value of 11.25 USD per person per visit,** representing a total potential revenue of between 81 and 167 million USD.¹⁰⁴ The nature reserves adjacent to five Polish cities were assessed and authors concluded that large forest reserves with good infrastructure and

¹⁰⁰ (Hami et al., 2018)

¹⁰¹ (Liu et al., 2024)

¹⁰² (Rašković & Decker, 2015)

¹⁰³ (Chen & Nakama, 2013)

¹⁰⁴ (Majumdar et al., 2011)

accessibility could be used as attractive ecotourism products to relieve tourist pressures on the historic city centres¹⁰⁵. Urban agroforestry and horticulture enterprises in Tanzania contributed significantly to creating a more attractive urban environment and increasing cities' ecotourism value. 47% of the 114 enterprises regularly received tourists, with tree species with high cultural or medicinal value proving a particularly important attraction¹⁰⁶.

Evidence suggests that the value of trees is perceived differently, according to whether the trees are on public or private properties. Whilst the reviews and coded studies in Sections 5.4.1 and 5.4.2 show public support for trees on private properties, other studies suggest trees in public places are perceived as having higher value. For example, a study in Perth, Australia that found that street trees increased housing premiums, whilst tree cover on the property itself had no effect.

A 10% increase in street tree cover over the median (average) cover of 19.66% increases median house price (AU\$ 765,000) by approximately AU\$ 3,250.¹⁰⁷ A survey-based study found that residents' negative attitudes toward trees were significantly associated with the size of tree canopy in their front gardens, in other words people with large canopied trees / a large number of trees in their front gardens have more negative attitudes to trees than those without, in the USA.¹⁰⁸

5.4.1 Reviews

A structured review and meta-analysis calculated the impact of tree canopy cover on the value of residential properties, using 15 hedonic property value studies in the USA (hedonic values take the property's environmental characteristics into account, not just the house value).¹⁰⁹ The meta-analysis suggested that **property-level tree cover of about 30% and county-level tree cover of about 38%**

¹⁰⁵ (Gonia & Jeziarska-Thöle, 2022)

¹⁰⁶ (Busungu, 2022)

¹⁰⁷ (Ram Pandit, 2012)

¹⁰⁸ (Coleman et al., 2023)

¹⁰⁹ (Siriwardena et al., 2016b)

maximized the property value. County- level refers to an administrative similar to a local authority. These levels of tree cover reflect the balance of trees for optimising shade versus sunlight and privacy versus views, as well as disbenefits from trees relating to leaf litter, for example.

There were no reviews or studies identified about hedonic property values and trees for the UK.

5.4.2 Coded studies

There were only three eligible studies identified for this theme, despite extensive searching (Table 11). Two studies evaluated the financial impact of street trees on property values, whilst the other study investigated the impact of woodland context on timber production.

Table 12 Summary of coded studies for “business” subtheme

Key outcome(s)	Citation
<p>This study collected data from 224 deciduous woodlands across 7 regions in temperate Europe, comparing small (both recent and ancient) and larger woodlands / forest patches in agricultural landscapes. The study compared two 5 km² landscapes in each region with contrasting connectivity levels.</p> <p>Stemwood volume (ie for timber production) was unaffected by biodiversity levels of the woodland, decreased in acidic soils and with tree species diversity and increased with woodland structural diversity. Game production potential was higher for smaller woodlands and increased with biodiversity levels, more acidic soils, tree diversity and decreased with soil fertility.</p>	(Valdés et al., 2020)
<p>This property analysis was based on 1026 single-family properties in Baltimore, Maryland. On average, the amount of tree canopy in the 100–400m zone around a single-family property was positively associated with home price. A 10% increase in surrounding canopy was associated with a marginal increase in property value of 11,467 USD. The extent of price increase varied according to the socioeconomic and physical context of the neighbourhood, with willingness to pay for urban tree canopy increasing for larger properties and proximity to city centre.</p>	(Sachs et al., 2023)
<p>A study of street trees in a Chinese Forest City (Dalian) analysed the structural characteristics of Dalian’s 57,699 street trees, which include 28 tree species.</p> <p>Dalian’s street trees contributed \$1.5 million (\$25/tree) to the total estimated property value for that area.</p>	(Wang et al., 2018)

5.5 Farming / food security

Agriculture currently uses 70% of the land area in the UK¹¹⁰ and produces 62% of all its domestic food consumption by economic value, part of which is exported¹¹¹. There are 209,000 farms in the UK, employing 462,000 people and contributing £13.7 billion (0.6% of GDP). 27% of the 17 million hectares used for agriculture is dedicated to crop production, 64.5% to grassland and 8.5% for other uses (including woodland).¹¹² 22% of the total output value comes from dairy and eggs, 40% from meat, 14% from cereals, 17% from flowers, fruit and vegetables and 7% from other crops (e.g. biofuels).¹¹³

Agriculture is responsible for 12% of greenhouse gases in the UK, including 70% nitrous oxide emissions, 49% methane and 2% carbon dioxide. Agriculture also produces most of the UK's ammonia emissions, which negatively impact on air quality and human health.¹¹⁴ Most nitrous oxide emissions originate from the application of manure and nitrogen fertilisers on farmland, whilst ruminant livestock (mainly cows and sheep) are responsible for most of the methane and ammonia emissions.¹¹⁵

Intensive agriculture has a number of other environmental impacts. Pesticides, used mainly for crop production, are shown to be harmful to terrestrial and aquatic biodiversity.¹¹⁶ Synthetic fertilisers, used for grass and crop production, have negative impacts on water quality, air quality and climate change. UK arable soils have lost at least 40% organic carbon and contributes to soil compaction and erosion.¹¹⁷

¹¹⁰ (Defra, 2024b)

¹¹¹ (Defra, 2024d)

¹¹² (Defra, 2024b)

¹¹³ (Defra, 2024c)

¹¹⁴ (Department for Energy Security and Net Zero, 2025)

¹¹⁵ (Defra, 2024a)

¹¹⁶ (Defra, 2024b; FERA, 2023)

¹¹⁷ (Environment Agency, 2019)

Designing global food systems that ensure food security whilst reducing environmental degradation is a major challenge facing humanity. Food system data analyses suggest that a global dietary shift from ruminant livestock towards plant-based foods is one effective solution.¹¹⁸ Trees and forests could also play a significant role in addressing these challenges.

Natural and planted forests provide a range of ecosystem regulating services in agricultural landscapes¹¹⁹ and even small woodland patches were shown to be highly beneficial to food production in temperate areas by two studies.¹²⁰ Remote sensing data (data collected by satellite) identified that 2010, the total **global tree cover on agricultural land sequestered 36.29 PgC (petagrams of carbon) per year**, which was steadily increasing year on year.¹²¹ To put this in perspective, it is useful to know that all global terrestrial vegetation sequesters 112–169 PgC each year. However, it is important to also highlight that the authors did not factor in the carbon lost due to forest clearing for agricultural expansion.

Agroforestry, describing any land management approach combining trees and agriculture, yields a variety of benefits, from the production of food and wood products to the ecosystem services discussed in Section 4, which include soil health, water quality and carbon storage. The UK Committee on Climate Change **recommended agroforestry as a strategy for farms to reduce carbon emissions** and prepare for climate change and expressed concern at the low take-up of incentives for agroforestry in the UK.¹²² **Agroforestry was also endorsed in the Environmental Improvement Plan** for the potential benefits to soil health, water quality and climate resilience and net zero targets.¹²³ **Silvoarable systems were also one of the management practices recommended in the State of**

¹¹⁸ (Clark & Tilman, 2017; Poore & Nemecek, 2018; Symonds, 2021)

¹¹⁹ (Brockhoff et al., 2017)

¹²⁰ (Decocq et al., 2016; Valdés et al., 2020)

¹²¹ (Zomer et al., 2016)

¹²² (Committee on Climate Change, 2018)

¹²³ (Defra, 2023)

the Environment Report for reducing soil erosion whilst maintaining productivity.¹²⁴

The reviews and studies in the following sections (5.5.1 and 5.5.2) focus on the direct benefits of trees to the farm enterprise, for example impacts on net productivity, livestock welfare, and pest control, since broader environmental benefits are covered elsewhere (mainly Section 4.1.1).

5.5.1 Reviews

Three reviews about the impacts of agroforestry found evidence that trees were beneficial for livestock welfare.

A systematic review assessed 19 articles that compared the effects of silvopastoral system and treeless pasture on thermal comfort in dairy cows.¹²⁵ There was **strong evidence for the beneficial effects of silvopasture on the localised climate**, in terms of air temperature (derived from 6 studies), wind speed (derived from 5 studies) and “black globe” temperature, which measures how hot it feels in direct sunlight (based on 4 studies). There was also **strong evidence for the beneficial effect of silvopasture on two common measures of thermal comfort**, known as “black globe” humidity index (5 studies) and radiant thermal load (3 studies). The effects on cows’ behaviour and bodily functions were less clear.

A systematic review (also discussed in Section 4.1.1) assessed 83 studies about trees in grazed dairy systems and found a **strong evidence base for the shade benefits of shelterbelt and mixed silvopasture systems for reducing heat stress in livestock**.¹²⁶

¹²⁴ (Environment Agency, 2019)

¹²⁵ (Deniz et al., 2023)

¹²⁶ (England et al., 2020b)

A systematic evidence map¹²⁷ (also discussed in Section 4.1.1) found that **the shade or shelter produced by trees had a positive effect on livestock heat stress, cold stress or mortality in 13/14 studies.**

A structured review assessed 19 studies investigating the impact of temperate silvoarable systems on pest control and pollination.¹²⁸ For the 12 studies included in a meta-analysis, **the abundance of arthropod herbivores (i.e. insect pests) was significantly lower in the silvoarable compared to the arable systems** ($z = -2.005$, $p\text{-value} = .045$), with a mean effect size of 0.75. Effect size is a measure of the magnitude of a statistical relationship. Two studies measured slug abundance, which was higher in the silvoarable than arable systems, with effect sizes of 1.12 to 1.53 across the two studies. Three studies measured **the abundance of pollinating insects, which was higher in the silvoarable system compared to the arable control.** Effect sizes ranged from 1.17 to 2.55. This outcome should be treated with caution as study replication was low.

5.5.2 Coded studies

Five eligible studies were identified for this theme (Table 12). Two studies found that natural woodland patches and agroforestry respectively had a positive impact on the pest control potential for agriculture. Another study found agroforestry was beneficial for reducing the risk of heat stress in lambs, compared to treeless pasture. Two studies explored agroforestry's impacts on productivity and environmental benefits, with one study finding that tree crop productivity was not affected by addition of crops or livestock and the other finding that productivity in agroforestry systems was lower than equivalent non-agroforestry systems. Agroforestry provided environmental benefits in both studies.

¹²⁷ (Jordon et al., 2020)

¹²⁸ (Staton et al., 2019)

Table 13 Summary of coded studies for “farming” subtheme

Key outcome(s)	Citation
<p>This empirical study collected data from 224 deciduous woodlands across 7 regions in temperate Europe, comparing small (both recent and ancient) and larger woodlands / forest patches in agricultural landscapes. The study compared two 5 km² landscapes in each region with contrasting connectivity levels. Species richness (of understorey herbs, mushrooms, ground beetles, spiders, woodlice, millipedes) had a significant positive impact on the pest control potential of the woodland.</p>	<p>(Valdés et al., 2020)</p>
<p>The study measured spider abundance, taxonomic and functional diversity (as proxies of pest control potential) in temperate alley-cropping agroforestry systems as compared to open croplands in four locations in northern Germany.</p> <p>Hunting spiders were significantly more abundant in the agroforestry systems compared to the open cropland controls. The highest abundance was found at 1 metre from the tree row edges. Tree row proximity generally benefited the taxonomic and functional diversity of the overall spider communities as well, particularly adjacent to tree rows.</p>	<p>(Matevski et al., 2024)</p>
<p>This study examined ten case studies about the integration of crops and/or livestock within high value tree systems (e.g. apple orchards, walnut plantations). The case studies identified production, environmental or economic benefits of crops and livestock that did not compromise the value of the tree products, for example legume crops and grazing sheep.</p>	<p>(Pantera et al., 2018)</p>
<p>The study investigated the impact of shade on the body temperatures of ewe lambs (young sheep) in two hardwood silvoarable systems (black walnut, <i>Juglans nigra</i>, and honeylocust, <i>Gleditsia triacanthos</i>) compared to treeless pasture in Virginia, US.</p> <p>Ewe lambs had lower body temperatures in the black walnut silvopasture during the hottest part of the day (1200–1900 h) compared to treeless pasture and lower body temperatures in the honeylocust silvopasture at 1500h compared to pasture. Ewe lambs in pasture experienced more fluctuation in day to nighttime core temperature change compared to silvoarable systems.</p>	<p>(Pent et al., 2021)</p>
<p>This study undertook a cost evaluation for eleven case study regions in Europe, three of which were wet temperate (UK – arable with hedgerows, northern France – mosaic of hedgerows, woodland, pasture and arable production, northern Spain – sweet chestnut groves with pasture and arable)</p> <p>Total value of the harvest was lower for the agroforestry system compared to the non-agroforestry system for the three temperate case study areas (32.3 and 42.7 Euros per hectare per year respectively).</p> <p>Estimated cost of environmental impacts was lower for the agroforestry compared to the non-agroforestry systems for the three temperate case study areas (25.4 and 54.8 Euros per hectare per year respectively).</p>	<p>(Kay et al., 2019)</p>

5.6 Society

Fewer and fewer people have regular contact with nature, whether it be walking in a protected landscape, listening to birdsong in the park, or noticing the insects in an urban garden.¹²⁹ Reasons for this decline include the increase in sedentary lifestyles and digital media use, a lack of access to greenspaces rich in local flora or fauna, perceived safety of outdoor spaces, and shifts in families' habitual behaviours.¹³⁰

The diminishing experience of nature is a trend with multiple consequences for individuals and society. Interactions with nature foster individuals' mental and physical health and development.¹³¹ Nature connectedness (a person's self-perceived affinity with nature) is positively associated with pro-environmental social behaviours, for example waste reduction and energy saving, as well as specific pro-nature behaviours, for example, conservation volunteering and behaving responsibly in protected areas.¹³² Specifically considering trees, nature connectedness was strongly associated with tree planting behaviours.¹³³

Trees and woodland have specific characteristics that could help to promote contact with nature and to foster nature connectedness. Qualities of trees that have been shown to appeal to adults are discussed in Sections 5.2 and 5.3. Yet the potential role of trees for developing connections with nature is an under-explored area. In a structured review of 48 studies about the relationship between nature connectedness and pro-environmental behaviour, only 40% of studies considered trees or forests at all, with only 6% of studies investigating the impact of forest experience on environmental behaviours.¹³⁴

¹²⁹ (Soga & Gaston, 2016)

¹³⁰ (Soga et al., 2018)

¹³¹ (Keniger et al., 2013)

¹³² (Martin et al., 2020)

¹³³ (Whitburn et al., 2019)

¹³⁴ (Häyrinen & Pynnönen, 2020)

A key area to consider is the unique properties of trees for childhood play, since childhood nature experiences are frequently associated with adult environmental attitudes and behaviours.¹³⁵ A three-year study based on observations of 130 children (7- 12 years) in Finland found that **trees provided 25 distinctly different types of opportunities for children’s creative play**. Many opportunities were based around the role of trees as three-dimensional spaces and structures for play scenarios and climbing, as well as producers of loose materials for creative play, for example, sticks, seeds and cones as tools and props in make-believe scenarios, and branches for construction of dens and other structures.¹³⁶ A researcher in a dual role as playworker observed eight children (3–15 years) over one year in a woodland area, as part of the “Exploring Nature Play” programme (UK), and found that all eight children derived similarly rich play opportunities from the woodland.¹³⁷

The reviews and studies in the following sections (5.6.1 and 5.6.2) are derived from searches about societal benefits of trees for social capital, quality of life, education/learning and crime reduction, as well as play and nature connectedness.

5.6.1 Reviews

A structured review about Forest School, a woodland based outdoor learning model, assessed 28 studies, of which 21 were conducted in the UK.¹³⁸ The review found that **participation in forest school improved children’s capabilities in the following domains (numbers of studies in brackets): learning and cognitive skills (17); environmental awareness (14); social and cooperative skills (13); physical skills (8); self-confidence and self-esteem (6), risk management (6).**

¹³⁵ (Broom, 2017; Wells & Lekies, 2006)

¹³⁶ (Laaksoharju & Rappe, 2017)

¹³⁷ (Goodenough et al., 2021)

¹³⁸ (Dabaja, 2022b, 2022a)

A scoping review referred to under “health” (Sections 5.1 and 5.2) also assessed six studies about trees and crime.¹³⁹ Generally, **trees had a positive impact on crime levels**, for example tree cover presence was associated with lower crime levels, but some studies found mixed effects and it is unclear to what extent studies controlled for confounding factors such as the demographic characteristics of areas.

A structured review (albeit with only brief methods section) assessed 160 studies relating to the sociocultural benefits of trees and woodlands at risk from pests and disease.¹⁴⁰ The authors identified monetary valuation data for woodlands and trees in terms of recreation and landscape aesthetics but found no such data for health, heritage, spiritual or place values.

A structured review (albeit with only brief methods section) assessed approximately 200 studies about health and social capital and concluded that there was **high consensus in the evidence for the benefits of community woodland to mental health, physical health and social capital**, but conflicting evidence about the benefits of urban trees for these three factors. There was no explanation in the review about how evidence agreement was measured.¹⁴¹

5.6.2 Coded studies

Six eligible studies were identified for this theme (Table 13). Four studies produced qualitative evidence of the learning and socialising benefits provided by the experiences with woodlands. One study identified benefits in terms of neighbourhood social capital from urban trees. Two studies assessed the amenity value of trees in different contexts.

¹³⁹ (Wolf et al., 2020)

¹⁴⁰ Hall et al. (2020b)

¹⁴¹ Hall et al. (2021)

Table 14 Summary of coded studies for “society” subtheme

Key outcome(s)	Citation
An assessment of trees in Wirral (UK) following the full CAVAT methodology estimated that the 1 million trees have a public amenity asset value of £22.6 billion. This method considers the size, condition, public visibility and life expectancy of trees. Sycamore (<i>Acer pseudoplatanus</i>) contributed 21% of this estimated amenity value.	(Walker et al., 2023)
A multi-visit nature-based intervention in Westonbirt Arboretum (UK) contributed to participants’ social connections and skills learning (26 young people with autism and 24 adults with diverse mental health problems).	(O’Brien, 2018)
The study focuses on 120 adults participating in the Active Forests programme at nine forest sites (UK), a programme aiming to encourage, support and sustain or change physical activity. Two of the eight dominant themes in the interview data related to societal benefits of participation, namely the opportunities for socialising and the learning and skills development.	(O’Brien, 2019)
This study looks at the impacts of forest school participation on primary-aged children through observations of 71 children and interviews with 20 forest school practitioners. Practitioners believed that forest school participation increased children’s connections with nature and place and environmental knowledge.	(Harris, 2021)
This study examines the relationship between tree canopy coverage (GIS data) and neighbourhood social capital (based on a survey of 361 residents) in Baltimore, Maryland. Social capital is defined as mutually beneficial interactions between people in a neighbourhood. There was a significant positive relationship between the density of urban tree canopy in neighbourhood blocks and the amount of self-reported social capital . Authors controlled for various sociodemographic factors.	(Holtan et al., 2015)
This study was based on 4 focus groups (UK) about people’s perceptions of woodlands. Participants mentioned multiple societal benefits derived from urban trees, including the educational and play benefits for children.	(Ambrose-Oji et al., 2021)

5.7 Culture, heritage and aesthetics

Trees and woodlands have a range of cultural values relating to perceived spiritual, aesthetic, symbolic and historical qualities.¹⁴² Ancient woodlands in the UK often preserve important archaeological and heritage features, but woodland managers have poor awareness of these and there is limited guidance about their conservation.¹⁴³ Preserving cultural heritage could add to the economic value derived from trees and woodlands, particularly non-commercial woodlands that have a significant role for tourism and recreation.¹⁴⁴

Ancient and other noteworthy trees, for example the largest or tallest for a particular species, or those with connections to historical events, often have particularly high ecological and cultural value.¹⁴⁵ There are nearly **170,000 ancient and noteworthy trees recorded for the UK**, although actual numbers could be higher.

Trees outside of woodlands also have a significant cultural impact and were shown to have inspired a diversity of artists in the UK.¹⁴⁶ Childhood experiences, emotional connections and a sense of the interconnectedness of humans and nature were the main sources of inspiration for these artists' creative expressions about trees. Protection for such trees is limited in the UK and charities like the Woodland Trust are campaigning to improve their protection.¹⁴⁷

5.7.1 Reviews

There were no relevant reviews for this subtheme, apart from those already discussed in Section 5.1.

¹⁴² (O'Brien, 2005; O'Brien et al., 2024)

¹⁴³ (Rotherham, 2022)

¹⁴⁴ (Agnoletti, 2008)

¹⁴⁵ (Nolan et al., 2020)

¹⁴⁶ (Lestari, 2023)

¹⁴⁷ <https://www.woodlandtrust.org.uk/protecting-trees-and-woods/campaign-with-us/tree-protection-campaign/>

5.7.2 Coded studies

Five eligible studies were identified for this theme (Table 14). Two studies examined land managers’ perceptions of oak trees (*Quercus robur*), whilst another considered the cultural value of historically important young trees. The other two studies considered aesthetic values of woodland and general perceptions of woodland respectively.

Table 15 Summary of coded studies for “culture” subtheme

Key outcome(s)	Citation
This study analysed the biodiversity value and provision of selected ecosystem services (carbon storage, recreation, aesthetic and timber value) for patches of lowland heathland in Dorset, considering a range of habitat types to inform landscape-scale management decisions. Trade-offs between ecosystem services and biodiversity were studied. Perceived aesthetic values were significantly highest in woodland compared to dry and humid heath.	Cordingley et al. (2016)
This study was based on 4 focus groups (UK) about people’s perceptions of woodlands. The cultural and historical values associated with trees was not a strong theme in the data, but participants did place value on trees associated with personal memories and anecdotes and connected with British traditions and sayings.	Ambrose-Oji et al. (2021)
A field mapping and citizen science survey in Prague (Czech Republic) identified 40 culturally significant young trees (or tree groups). These are defined as trees with DBH ≤80 cm, ≤ 100 years old and with documented cultural significance, for example links to locally / regionally significant historical / cultural events.	Rudl et al. (2019)
The study was based on 15 land manager interviews (London, UK). Interviewees perceived oak to be a highly valued tree for its cultural and historical importance. The value was thought to be more significant where oak trees were scarce, in urban areas, streets or gardens.	Marzano et al. (2020)
The study was based on survey responses from 606 private woodland owners, UK. Most managers (82%) considered ancient and veteran oaks to be particularly culturally significant and 74% thought oaks had greater cultural importance than other native British trees. 27% thought oaks in all locations had equal cultural significance, whilst 38% and 27% thought oaks in parklands and hedgerows respectively were the most culturally significant. The most important types of cultural significance to respondents: oaks’ iconic beauty in the landscape, value as a building material, symbolic qualities of strength and stability.	L. O’Brien et al. (2024)

6 Conclusion

This review identified a range of benefits provided by trees and woodland across a suite of themes relating to climate, environment and people. The review also highlighted potential causal factors for many of these benefits, as well as the considerations or limitations associated with these benefits. Many of the stated benefits were supported by quantitative data outcomes, particularly for the themes of water resources, carbon storage, urban microclimate and physical health.

The empirical evidence was strongest for the role of trees and woodland in flood mitigation, the role of trees in below-ground carbon storage, the impacts of trees on localised air pollution, species diversity measures in woodlands and the restorative effects of woodlands for wellbeing and stress reduction. The subthemes relating to society were mainly supported by qualitative evidence.

There were no eligible studies identified for some of the original categories included in the subthemes, for example the impact of trees on active travel, tourism, employment and employability, spiritual and artistic values. These evidence gaps highlight some valuable areas for future work.

7 References

- A Maes, M. J., Pirani, M., Booth, E. R., Shen, C., Jones, K. E., & Toledano, M. B. (2021). Benefit of natural environments particularly woodland on adolescent's cognition and mental health. *Nature Sustainability*, 4(10), 851–858.
- Agnoletti, M. (2008). The Introduction of Historical and Cultural Values in the Sustainable Management of European Forests. *Global Environment*, 1(2), 172–199. <https://doi.org/10.3197/ge.2008.010207>
- Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution*, 116, S119–S126. [https://doi.org/10.1016/S0269-7491\(01\)00264-0](https://doi.org/10.1016/S0269-7491(01)00264-0)
- Akbari, H., Kurn, D. M., Bretz, S. E., & Hanford, J. W. (1997). Peak power and cooling energy savings of shade trees. *Energy and Buildings*, 25(2), 139–148. [https://doi.org/10.1016/S0378-7788\(96\)01003-1](https://doi.org/10.1016/S0378-7788(96)01003-1)
- Akbari, H., & Taha, H. (1992). The impact of trees and white surfaces on residential heating and cooling energy use in four Canadian cities. *Energy*, 17(2), 141–149. [https://doi.org/10.1016/0360-5442\(92\)90063-6](https://doi.org/10.1016/0360-5442(92)90063-6)
- Akpinar, A., Barbosa-Leiker, C., & Brooks, K. R. (2016). Does green space matter? Exploring relationships between green space type and health indicators. *Urban Forestry and Urban Greening*, 20, 407–418. <https://doi.org/10.1016/j.ufug.2016.10.013>
- Alcock, I., White, M., Cherrie, M., Wheeler, B., Taylor, J., McInnes, R., Otte im Kampe, E., Vardoulakis, S., Sarran, C., Soyiri, I., & Fleming, L. (2017). Land cover and air pollution are associated with asthma hospitalisations: A cross-sectional study. *Environment International*, 109, 29–41. <https://doi.org/10.1016/j.envint.2017.08.009>
- Ambrose-Oji, B., Scott, E., Moffat, A., Doick, K., Paterson, A., & Bye, R. (2021). *Public Perceptions of Urban Trees Results of Focus Group Discussions in England, Scotland and Wales*.
- Ashwood, F., Watts, K., Park, K., Fuentes-Montemayor, E., Benham, S., & Vanguelova, E. I. (2019). Woodland restoration on agricultural land: long-term impacts on soil quality. *Restoration Ecology*, 27(6), 1381–1392. <https://doi.org/10.1111/rec.13003>
- Astell-Burt, T., & Feng, X. (2019). Association of Urban Green Space with Mental Health and General Health among Adults in Australia. *JAMA Network Open*, 2(7). <https://doi.org/10.1001/jamanetworkopen.2019.8209>
- Baker, H. J., Hutchins, M. G., & Miller, J. D. (2021). How robust is the evidence for beneficial hydrological effects of urban tree planting? *Hydrological Sciences Journal*, 66(8), 1306–1320. <https://doi.org/10.1080/02626667.2021.1922692>
- Binner, A., Smith, G., Faccioli, M., Bateman, I. J., Day, B. H., Agarwala, M., & Harwood, A. (2018). *Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales*.

- Black, A., Peskett, L., MacDonald, A., Young, A., Spray, C., Ball, T., Thomas, H., & Werritty, A. (2021). Natural flood management, lag time and catchment scale: Results from an empirical nested catchment study. *Journal of Flood Risk Management*, 14(3). <https://doi.org/10.1111/jfr3.12717>
- Broom, C. (2017). Exploring the Relations Between Childhood Experiences in Nature and Young Adults' Environmental Attitudes and Behaviours. *Australian Journal of Environmental Education*, 33(1), 34–47. <https://doi.org/10.1017/ae.2017.1>
- Burns, F., Mordue, S., al Fulaij, N., Boersch-Supan, PH., Boswell, J., Boyd, R. J., Bradfer-Lawrence, T., de Ornellas, P., de Palma, A., de Zylva, P., Dennis, E. B., Foster, S., Gilbert, G., Halliwell, L., Hawkins, K., Haysom, K. A., Holland, M. M., Hughes, J., Jackson, A. C., ... Gregory, R. D. (2023). *State of Nature*. https://stateofnature.org.uk/wp-content/uploads/2023/09/TP25999-State-of-Nature-main-report_2023_FULL-DOC-v12.pdf
- Burton, V., Moseley, D., Brown, C., Metzger, M. J., & Bellamy, P. (2018a). Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom. *Forest Ecology and Management*, 430, 366–379. <https://doi.org/10.1016/j.foreco.2018.08.003>
- Burton, V., Moseley, D., Brown, C., Metzger, M. J., & Bellamy, P. (2018b). Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom. In *Forest Ecology and Management* (Vol. 430, pp. 366–379). Elsevier B.V. <https://doi.org/10.1016/j.foreco.2018.08.003>
- Castells-Quintana, D., Dienesch, E., & Krause, M. (2021). Air pollution in an urban world: A global view on density, cities and emissions. *Ecological Economics*, 189, 107153. <https://doi.org/10.1016/j.ecolecon.2021.107153>
- Chen, B., & Nakama, Y. (2013). Thirty years of forest tourism in China. *Journal of Forest Research*, 18(4), 285–292. <https://doi.org/10.1007/s10310-012-0365-y>
- Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, 12(6), 064016. <https://doi.org/10.1088/1748-9326/aa6cd5>
- Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., ... Forouzanfar, M. H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *The Lancet*, 389(10082), 1907–1918. [https://doi.org/10.1016/S0140-6736\(17\)30505-6](https://doi.org/10.1016/S0140-6736(17)30505-6)
- Coleman, A. F., Eisenman, T. S., Locke, D. H., & Harper, R. W. (2023). Exploring links between resident satisfaction and participation in an urban tree planting initiative. *Cities*, 134, 104195. <https://doi.org/10.1016/j.cities.2023.104195>
- Committee on Climate Change. (2018). *Land use: Reducing emissions and preparing for climate change*. <https://www.theccc.org.uk/wp->

- Content/Uploads/2018/11/Land-Use-Reducing-Emissions-and-Preparing-for-Climate-Change-CCC-2018.Pdf.
- Committee on Climate Change. (2020). *Land use: Policies for a Net Zero UK*. <https://www.theccc.org.uk/wp-content/uploads/2020/01/Land-use-Policies-for-a-Net-Zero-UK.pdf>
- Connolly, R. (2020). *Silvopasture: a sustainable method to improve soil quality and productivity on farms in the North-West region of Ireland*.
- Cooper, M. M. D., Patil, S. D., Nisbet, T. R., Thomas, H., Smith, A. R., & McDonald, M. A. (2021). Role of forested land for natural flood management in the UK: A review. In *Wiley Interdisciplinary Reviews: Water* (Vol. 8, Issue 5). John Wiley and Sons Inc. <https://doi.org/10.1002/wat2.1541>
- Cordingley, J. E., Newton, A. C., Rose, R. J., Clarke, R. T., & Bullock, J. M. (2016). Can landscape-scale approaches to conservation management resolve biodiversity-ecosystem service trade-offs? *Journal of Applied Ecology*, *53*(1), 96–105. <https://doi.org/10.1111/1365-2664.12545>
- Dabaja, Z. F. (2022a). Reviewing two decades of research on the Forest School impact on children: The sequel. *Education 3-13*, *50*(6), 737–750. <https://doi.org/10.1080/03004279.2021.1905019>
- Dabaja, Z. F. (2022b). The Forest School impact on children: reviewing two decades of research. *Education 3-13*, *50*(5), 640–653. <https://doi.org/10.1080/03004279.2021.1889013>
- Davies, H. W. J. D. K. O. L. H. P. (2017). *Delivery of ecosystem services by urban forests*.
- Defra. (2018). *Impacts of Vegetation on Urban Air Pollution. A report by the Air Quality Expert Group prepared for Defra, Scottish Government, Welsh Government, and Department of the Environment in Northern Ireland*.
- Defra. (2023). *Environmental Improvement Plan 2023: First revision of the 25 Year Environment Plan*. <https://assets.publishing.service.gov.uk/media/64a6d9c1c531eb000c64fffa/environmental-improvement-plan-2023.pdf>
- Defra. (2024a). *Accredited official statistics - Chapter 11: Agri-environment*. <https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2023/chapter-11-agri-environment>.
- Defra. (2024b). *Agriculture in the United Kingdom 2023*. <https://assets.publishing.service.gov.uk/media/669e4777ab418ab055592a2c/uk-2023-06jun24iii.pdf>
- Defra. (2024c). *Research and analysis: Farming evidence - key statistics*. <https://www.gov.uk/government/publications/farming-evidence-pack-a-high-level-overview-of-the-uk-agricultural-industry/farming-evidence-key-statistics-accessible-version>.
- Defra. (2024d). *UK Food Security Report 2024: Presented to Parliament pursuant to Section 19 of the Agriculture Act 2020*. https://assets.publishing.service.gov.uk/media/6756e300a63e1781efb877a1/United_Kingdom_Food_Security_Report_2024_11dec2024_printable.Pdf

- Deniz, M., De-Sousa, K. T., Vieira, F. M. C., Vale, M. M. do, Dittrich, J. R., Daros, R. R., & Hötzel, M. J. (2023). A systematic review of the effects of silvopastoral system on thermal environment and dairy cows' behavioral and physiological responses. In *International Journal of Biometeorology* (Vol. 67, Issue 3, pp. 409–422). Springer Science and Business Media Deutschland GmbH. <https://doi.org/10.1007/s00484-023-02431-5>
- Department for Energy Security and Net Zero. (2025). *UK territorial greenhouse gas emissions statistics*. <https://www.gov.uk/government/collections/uk-territorial-greenhouse-gas-emissions-statistics>.
- Diener, A., & Mudu, P. (2021). How can vegetation protect us from air pollution? A critical review on green spaces' mitigation abilities for air-borne particles from a public health perspective - with implications for urban planning. *Science of The Total Environment*, 796, 148605. <https://doi.org/10.1016/j.scitotenv.2021.148605>
- Doick, K. J., Handley, P., Sales, K. R., Sparrow, K. A., Vaz Monteiro, M., Walker, H., Bursnell, W., Saraev, V., & Valatin, G. (2021). *Valuing Non-Woodland Trees Future Proofing Plant Health*.
- Donovan, G. H., & Butry, D. T. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings*, 41(6), 662–668. <https://doi.org/10.1016/j.enbuild.2009.01.002>
- Douglas, D. J. T., Groom, J. D., & Scridel, D. (2020). Benefits and costs of native reforestation for breeding songbirds in temperate uplands. *Biological Conservation*, 244. <https://doi.org/10.1016/j.biocon.2020.108483>
- Duan, Y., & Li, S. (2022). Study of Different Vegetation Types in Green Space Landscape Preference: Comparison of Environmental Perception in Winter and Summer. *Sustainability*, 14(7), 3906. <https://doi.org/10.3390/su14073906>
- Dugdale, S. J., Malcolm, I. A., & Hannah, D. M. (2024). Understanding the effects of spatially variable riparian tree planting strategies to target water temperature reductions in rivers. *Journal of Hydrology*, 635. <https://doi.org/10.1016/j.jhydrol.2024.131163>
- Dwyer, J., McPherson, E. G., Schroeder, H., & Rowntree, R. (1992). Assessing the Benefits and Costs of the Urban Forest. *Arboriculture & Urban Forestry*, 18(5), 227–234. <https://doi.org/10.48044/jauf.1992.045>
- Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, 116(11), 5188–5193. <https://doi.org/10.1073/pnas.1807504116>
- England, J. R., O'Grady, A. P., Fleming, A., Marais, Z., & Mendham, D. (2020a). Trees on farms to support natural capital: An evidence-based review for grazed dairy systems. *Science of The Total Environment*, 704, 135345. <https://doi.org/10.1016/j.scitotenv.2019.135345>
- England, J. R., O'Grady, A. P., Fleming, A., Marais, Z., & Mendham, D. (2020b). Trees on farms to support natural capital: An evidence-based review for grazed

- dairy systems. In *Science of the Total Environment* (Vol. 704). Elsevier B.V. <https://doi.org/10.1016/j.scitotenv.2019.135345>
- Environment Agency. (2019). *The state of the environment: soil*. https://assets.publishing.service.gov.uk/media/5cf4cbaf40f0b63affb6aa55/State_of_the_environment_soil_report.pdf#:~:text=Intensive%20agriculture%20has%20caused%20arable%20soils%20to%20lose,weather%20can%20cause%20widespread%20damage%20to%20soil%20structure.
- Fan, J. X., Wen, M., & Kowaleski-Jones, L. (2014). An ecological analysis of environmental correlates of active commuting in urban U.S. *Health & Place, 30*, 242–250. <https://doi.org/10.1016/j.healthplace.2014.09.014>
- FAO. (2009). *Planted forests: uses, impacts, and sustainability*. <https://openknowledge.fao.org/server/api/core/bitstreams/05c32b97-f097-4ec3-b3de-bb31494bb2e2/content>
- FERA. (2023). *Pesticide Usage Surveys*. <https://pusstats.fera.co.uk/Home>.
- Flack, J., Lukac, M., & Todman, L. (2022). Woodland planting on UK pasture land is not economically feasible, yet is more profitable than some traditional farming practices. *Central European Forestry Journal, 68*(2), 61–71. <https://doi.org/10.2478/forj-2022-0001>
- Fletcher, D. H., Garrett, J. K., Thomas, A., Fitch, A., Cryle, P., Shilton, S., & Jones, L. (2022). Location, Location, Location: Modelling of Noise Mitigation by Urban Woodland Shows the Benefit of Targeted Tree Planting in Cities. *Sustainability (Switzerland), 14*(12). <https://doi.org/10.3390/su14127079>
- Forest Research. (2022). *Forestry Statistics 2022: A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom*.
- Forestry Commission. (2022). *Responding to the climate emergency with new trees and woodlands: A guide to help local authorities and landowning businesses achieve net zero*. <https://assets.publishing.service.gov.uk/media/621cf6b2e90e0710b73fd515/WoodlandsTreesForests.pdf>
- Fowler, D., Skiba, U., Nemitz, E., Choubedar, F., Branford, D., Donovan, R., & Rowland, P. (2004). Measuring Aerosol and Heavy Metal Deposition on Urban Woodland and Grass Using Inventories of ^{210}Pb and Metal Concentrations in Soil. *Water, Air, & Soil Pollution: Focus, 4*(2/3), 483–499. <https://doi.org/10.1023/B:WAFO.0000028373.02470.ba>
- Ghimire, R., Ferreira, S., Green, G. T., Poudyal, N. C., Cordell, H. K., & Thapa, J. R. (2017a). Green Space and Adult Obesity in the United States. *Ecological Economics, 136*, 201–212. <https://doi.org/10.1016/j.ecolecon.2017.02.002>
- Ghimire, R., Ferreira, S., Green, G. T., Poudyal, N. C., Cordell, H. K., & Thapa, J. R. (2017b). Green Space and Adult Obesity in the United States. *Ecological Economics, 136*, 201–212. <https://doi.org/10.1016/j.ecolecon.2017.02.002>
- Goodenough, A., Waite, S., & Wright, N. (2021). Place as partner: material and affective intra-play between young people and trees. *Children's Geographies, 19*(2), 225–240. <https://doi.org/10.1080/14733285.2020.1783435>

- Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *The Lancet Global Health*, 6(10), e1077–e1086. [https://doi.org/10.1016/S2214-109X\(18\)30357-7](https://doi.org/10.1016/S2214-109X(18)30357-7)
- Hall, C., O'Brien, L., Cook, M., & Ambrose-Oji, B. (2021). *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) National Forest in Wales Evidence Review Report-54: National Forest in Wales Evidence Review Annex-8: Benefits to Society*. www.erammp.wales/54
- Hall, C., O'Brien, L., Marzano, M., Dyke, A., & Jones, G. (2020a). *Social and cultural values of trees, woods and forests at risk from tree pests and diseases: Rapid review. Social and cultural values of treescapes*. . <https://cdn.forestresearch.gov.uk/2023/12/Hall-et-al-2020-Social-and-cultural-values-of-trees-woods-and-forests.pdf>
- Hall, C., O'Brien, L., Marzano, M., Dyke, A., & Jones, G. (2020b). *Social and cultural values of trees, woods and forests at risk from tree pests and diseases: Rapid review. Social and cultural values of treescapes*. . <https://cdn.forestresearch.gov.uk/2023/12/Hall-et-al-2020-Social-and-cultural-values-of-trees-woods-and-forests.pdf>
- Hami, A., Moula, F. F., & Maulan, S. Bin. (2018). Public preferences toward shopping mall interior landscape design in Kuala Lumpur, Malaysia. *Urban Forestry & Urban Greening*, 30, 1–7. <https://doi.org/10.1016/j.ufug.2017.12.019>
- Hand, K., & Doick, K. (2019). *Understanding the role of urban tree management on ecosystem services. Research note FRRN039*.
- Hanlon, H. M., Bernie, D., Carigi, G., & Lowe, J. A. (2021). Future changes to high impact weather in the UK. *Climatic Change*, 166(3–4), 50. <https://doi.org/10.1007/s10584-021-03100-5>
- Harris, F. (2021). Developing a relationship with nature and place: the potential role of forest school. *Environmental Education Research*, 27(8), 1214–1228. <https://doi.org/10.1080/13504622.2021.1896679>
- Hauru, K., Lehvävirta, S., Korpela, K., & Kotze, D. J. (2012). Closure of view to the urban matrix has positive effects on perceived restorativeness in urban forests in Helsinki, Finland. *Landscape and Urban Planning*, 107(4), 361–369. <https://doi.org/10.1016/j.landurbplan.2012.07.002>
- Häyrinen, L., & Pynnönen, S. (2020). A Review of the Concepts and Measurements for Connection to Nature and Environmentally Responsible Behaviour—a Call for Research on Human-Forest Relationships. *Current Forestry Reports*, 6(4), 323–338. <https://doi.org/10.1007/s40725-020-00131-6>
- Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing Environment. *Current Environmental Health Reports*, 4(3), 296–305. <https://doi.org/10.1007/s40572-017-0150-3>
- Holtan, M. T., Dieterlen, S. L., & Sullivan, W. C. (2015). Social Life Under Cover: Tree Canopy and Social Capital in Baltimore, Maryland. *Environment and Behavior*, 47(5), 502–525. <https://doi.org/10.1177/0013916513518064>

- Huang, J., Patino Echeverri, D., Zhang, Z., & Echeverri, D. P. (2024). Planting trees is a cost-effective way to reduce residential electricity consumption and abate atmospheric CO₂. *Applied Energy*, 373. <https://ssrn.com/abstract=4743060>
- Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. *Atmospheric Environment*, 43(1), 51–63. <https://doi.org/10.1016/j.atmosenv.2008.09.051>
- Jordon, M. W., Willis, K. J., Harvey, W. J., Petrokofsky, L., & Petrokofsky, G. (2020). Implications of temperate agroforestry on sheep and cattle productivity, environmental impacts and enterprise economics. A systematic evidence map. *Forests*, 11(12), 1–29. <https://doi.org/10.3390/f11121321>
- Jung, W. H., Woo, J. M., & Ryu, J. S. (2015). Effect of a forest therapy program and the forest environment on female workers' stress. *Urban Forestry and Urban Greening*, 14(2), 274–281. <https://doi.org/10.1016/j.ufug.2015.02.004>
- Karki, U., Paneru, B., Tiwari, A., Ellis, N., Bhattarai, S., Karki, L., & Poudel, S. (2022). Soil quality and growth of southern pines in silvopastures and woodlands integrated with small ruminants. *Agroforestry Systems*, 96(3), 517–526. <https://doi.org/10.1007/s10457-021-00709-4>
- Kay, S., Graves, A., Palma, J. H. N., Moreno, G., Roces-Díaz, J. V., Aviron, S., Chouvardas, D., Crous-Duran, J., Ferreira-Domínguez, N., García de Jalón, S., Măcicășan, V., Mosquera-Losada, M. R., Pantera, A., Santiago-Freijanes, J. J., Szerencsits, E., Torralba, M., Burgess, P. J., & Herzog, F. (2019). Agroforestry is paying off – Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. *Ecosystem Services*, 36, 100896. <https://doi.org/10.1016/j.ecoser.2019.100896>
- Keniger, L., Gaston, K., Irvine, K., & Fuller, R. (2013). What are the Benefits of Interacting with Nature? *International Journal of Environmental Research and Public Health*, 10(3), 913–935. <https://doi.org/10.3390/ijerph10030913>
- Laaksoharju, T., & Rappe, E. (2017). Trees as affordances for connectedness to place – a framework to facilitate children's relationship with nature. *Urban Forestry & Urban Greening*, 28, 150–159. <https://doi.org/10.1016/j.ufug.2017.10.004>
- Lackey, N. Q., Tysor, D. A., McNay, G. D., Joyner, L., Baker, K. H., & Hodge, C. (2021). Mental health benefits of nature-based recreation: a systematic review. *Annals of Leisure Research*, 24(3), 379–393. <https://doi.org/10.1080/11745398.2019.1655459>
- Lee, I.-M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The Lancet*, 380(9838), 219–229. [https://doi.org/10.1016/S0140-6736\(12\)61031-9](https://doi.org/10.1016/S0140-6736(12)61031-9)
- Lestari. (2023). Trees Outside of Woodland: An exploration of social and cultural values. In <https://cdn.forestresearch.gov.uk/2024/01/Trees-Outside-of-Woodland-An-Exploration-of-Social-and-Cultural-Values-Photo-Essay.pdf>. Forest Research.
- Li, H., Zhao, Y., Wang, C., Ürge-Vorsatz, D., Carmeliet, J., & Bardhan, R. (2024). *Cooling efficacy of trees across cities is determined by background climate*,

- urban morphology, and tree trait*. <https://doi.org/10.5194/egusphere-2024-234-v2>
- Liu, Y., Cao, Z., Wei, H., & Guo, P. (2024). Optimizing Spatial Distribution of Retail Shops against Neighborhood Tree Canopy Shade Using Big Data Extracted from Streetscape. *Land*, 13(8), 1249. <https://doi.org/10.3390/land13081249>
- Majumdar, S., Deng, J., Zhang, Y., & Pierskalla, C. (2011). Using contingent valuation to estimate the willingness of tourists to pay for urban forests: A study in Savannah, Georgia. *Urban Forestry & Urban Greening*, 10(4), 275–280. <https://doi.org/10.1016/j.ufug.2011.07.006>
- Martin, L., White, M. P., Hunt, A., Richardson, M., Pahl, S., & Burt, J. (2020). Nature contact, nature connectedness and associations with health, wellbeing and pro-environmental behaviours. *Journal of Environmental Psychology*, 68, 101389. <https://doi.org/10.1016/j.jenvp.2020.101389>
- Marzano, M., Ambrose-Oji, B., Hall, C., & Moseley, D. (2020). Pests in the city: Managing public health risks and social values in response to oak processionary moth (*Thaumetopoea processionea*) in the United Kingdom. *Forests*, 11(2). <https://doi.org/10.3390/f11020199>
- Matevski, D., Sagolla, V., Beule, L., & Schuldt, A. (2024). Temperate alley-cropping agroforestry improves pest control potential by promoting spider abundance and functional diversity. *Journal of Applied Ecology*, 61(12), 3079–3091. <https://doi.org/10.1111/1365-2664.14797>
- Matthews, T. K. R., Wilby, R. L., & Murphy, C. (2017). Communicating the deadly consequences of global warming for human heat stress. *Proceedings of the National Academy of Sciences*, 114(15), 3861–3866. <https://doi.org/10.1073/pnas.1617526114>
- McPherson, E. G., Herrington, L. P., & Heisler, G. M. (1988). Impacts of vegetation on residential heating and cooling. *Energy and Buildings*, 12(1), 41–51. [https://doi.org/10.1016/0378-7788\(88\)90054-0](https://doi.org/10.1016/0378-7788(88)90054-0)
- Milligan, C., & Bingley, A. (2007). Restorative places or scary spaces? The impact of woodland on the mental well-being of young adults. *Health and Place*, 13(4), 799–811. <https://doi.org/10.1016/j.healthplace.2007.01.005>
- Moore, M., Gould, P., & Keary, B. S. (2003). Global urbanization and impact on health. *International Journal of Hygiene and Environmental Health*, 206(4–5), 269–278. <https://doi.org/10.1078/1438-4639-00223>
- Murphy, T. R., Hanley, M. E., Ellis, J. S., & Lunt, P. H. (2021). Native woodland establishment improves soil hydrological functioning in UK upland pastoral catchments. *Land Degradation and Development*, 32(2), 1034–1045. <https://doi.org/10.1002/ldr.3762>
- Nolan, V., Reader, T., Gilbert, F., & Atkinson, N. (2020). The Ancient Tree Inventory: a summary of the results of a 15 year citizen science project recording ancient, veteran and notable trees across the UK. *Biodiversity and Conservation*, 29(11–12), 3103–3129. <https://doi.org/10.1007/s10531-020-02033-2>

- Nordh, H., Hartig, T., Hagerhall, C. M., & Fry, G. (2009). Components of small urban parks that predict the possibility for restoration. *Urban Forestry & Urban Greening*, 8(4), 225–235. <https://doi.org/10.1016/j.ufug.2009.06.003>
- Nowak, D. J., Appleton, N., Ellis, A., & Greenfield, E. (2017). Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. *Urban Forestry and Urban Greening*, 21, 158–165. <https://doi.org/10.1016/j.ufug.2016.12.004>
- O'Brien, L. (2005). Social and cultural values of trees and woodlands in northwest and southeast England. *Forest Snow and Landscape Research*, 79, 169–184.
- O'Brien, L. (2018). Engaging with and shaping nature: A nature-based intervention for those with mental health and behavioural problems at the westonbirt arboretum in England. *International Journal of Environmental Research and Public Health*, 15(10). <https://doi.org/10.3390/ijerph15102214>
- O'Brien, L. (2019). Carrying out physical activity as part of the active forests programme in England: What encourages, supports and sustains activity?—A qualitative study. *International Journal of Environmental Research and Public Health*, 16(24). <https://doi.org/10.3390/ijerph16245118>
- O'Brien, L., Marzano, M., Dandy, N., Bates, S., Hemery, G., Petrokofsky, G., Dunn, M., & Forster, J. (2024). Managing Trees Species of High Social and Cultural Value: Forest Manager Attitudes towards Pest and Disease Risks to Oak in Britain. *Forests*, 15(10), 1695. <https://doi.org/10.3390/f15101695>
- O'Brien, L., McConnachie, S., Hall, C., Forster, J., Dyke, A., Saraev, V., & Jones, G. (2024). Exploring the social and cultural values of trees and woodlands in England: A new composite measure. *People and Nature*, 6(3), 1334–1354. <https://doi.org/10.1002/pan3.10644>
- O'Brien, L. W. K. S. A. (2010). *Urban health and health inequalities and the role of urban forestry in Britain: A review*.
- Office for National Statistics. (2024a). *Woodland natural capital accounts*. <https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/woodlandnaturalcapitalaccountsuk/2024>
- Office for National Statistics. (2024b, June 5). *UK Environmental Accounts: 2024*. <https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2024>
- Oncini, F., Hirth, S., Mylan, J., Robinson, C. H., & Johnson, D. (2024). Where the wild things are: How urban foraging and food forests can contribute to sustainable cities in the Global North. *Urban Forestry & Urban Greening*, 93, 128216. <https://doi.org/10.1016/j.ufug.2024.128216>
- Ordóñez, C., Kendal, D., Davern, M., & Conway, T. (2024). Having a tree in front of one's home is associated with GREATER subjective wellbeing in adult residents in Melbourne, Australia, and Toronto, Canada. *Environmental Research*, 250, 118445. <https://doi.org/10.1016/j.envres.2024.118445>
- Paddle, E., & Gilliland, J. (2016). Orange is the new green: Exploring the restorative capacity of seasonal foliage in schoolyard trees. *International Journal of*

- Environmental Research and Public Health*, 13(5).
<https://doi.org/10.3390/ijerph13050497>
- Pandit, R., Polyakov, M., Tapsuwan, S., & Moran, T. (2013). The effect of street trees on property value in Perth, Western Australia. *Landscape and Urban Planning*, 110, 134–142. <https://doi.org/10.1016/j.landurbplan.2012.11.001>
- Pantera, A., Burgess, P. J., Mosquera Losada, R., Moreno, G., López-Díaz, M. L., Corroyer, N., McAdam, J., Rosati, A., Papadopoulos, A. M., Graves, A., Rigueiro Rodríguez, A., Ferreiro-Domínguez, N., Fernández Lorenzo, J. L., González-Hernández, M. P., Papanastasis, V. P., Mantzanas, K., Van Lerberghe, P., & Malignier, N. (2018). Agroforestry for high value tree systems in Europe. *Agroforestry Systems*, 92(4), 945–959. <https://doi.org/10.1007/s10457-017-0181-7>
- Paterson, D. B., & Mason, W. L. (1999). *Cultivation of Soils for Forestry. Forestry Commission Bulletin 119*. <https://cdn.forestresearch.gov.uk/1999/03/fcbu119.pdf>
- Pent, G. J., Fike, J. H., & Kim, I. (2021). Ewe lamb vaginal temperatures in hardwood silvopastures. *Agroforestry Systems*, 95(1), 21–32. <https://doi.org/10.1007/s10457-018-0221-y>
- Petri, A. C., Wilson, B., & Koeser, A. (2019). Planning the urban forest: Adding microclimate simulation to the planner’s toolkit. *Land Use Policy*, 88, 104117. <https://doi.org/10.1016/j.landusepol.2019.104117>
- Poore, J., & Nemecek, T. (2018). Reducing food’s environmental impacts through producers and consumers. *Science*, 360(6392), 987–992. <https://doi.org/10.1126/science.aaq0216>
- Poudel, S., Bansal, S., Podder, S., Paneru, B., Karki, S., Fike, J., & Kumar, S. (2022). Conversion of open pasture to hardwood silvopasture enhanced soil health of an ultisol. *Agroforestry Systems*, 96(8), 1237–1247. <https://doi.org/10.1007/s10457-022-00783-2>
- Pugh, T. A. M., Lindeskog, M., Smith, B., Poulter, B., Arneth, A., Haverd, V., & Calle, L. (2019). Role of forest regrowth in global carbon sink dynamics. *Proceedings of the National Academy of Sciences*, 116(10), 4382–4387. <https://doi.org/10.1073/pnas.1810512116>
- Ram Pandit, M. P. R. S. (2012). The importance of tree cover and neighbourhood parks in determining urban property values. *56th AARES Annual Conference of the Agricultural and Resource Economics Society*.
- Rao, M., George, L. A., Rosenstiel, T. N., Shandas, V., & Dinno, A. (2014a). Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. *Environmental Pollution*, 194, 96–104. <https://doi.org/10.1016/j.envpol.2014.07.011>
- Rao, M., George, L. A., Rosenstiel, T. N., Shandas, V., & Dinno, A. (2014b). Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. *Environmental Pollution*, 194, 96–104. <https://doi.org/10.1016/j.envpol.2014.07.011>

- Rašković, S., & Decker, R. (2015). The influence of trees on the perception of urban squares. *Urban Forestry & Urban Greening*, 14(2), 237–245. <https://doi.org/10.1016/j.ufug.2015.02.003>
- Rotherham, I. D. (2022). Challenges for the restoration of cultural values in UK woodlands. *Forest Ecology and Management*, 503, 119756. <https://doi.org/10.1016/j.foreco.2021.119756>
- Rudl, A., Machar, I., Uradnec, L., Praus, L., & Pechanec, V. (2019). Young urban trees as important structures in the cultural heritage of cities - A case study from Prague. *Environmental and Socio-Economic Studies*, 7(3), 14–23. <https://doi.org/10.2478/environ-2019-0014>
- Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., Dirks, K. N., Heaviside, C., Lim, S., Macintyre, H., McInnes, R. N., & Wheeler, B. W. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, 15(S1), S36. <https://doi.org/10.1186/s12940-016-0103-6>
- Salvo, A. (2020). Local Pollution as a Determinant of Residential Electricity Demand. *Journal of the Association of Environmental and Resource Economists*, 7(5), 837–872. <https://doi.org/10.1086/709533>
- Shah, N. W., Nisbet, T. R., & Broadmeadow, S. B. (2021). The impacts of conifer afforestation and climate on water quality and freshwater ecology in a sensitive peaty catchment: A 25 year study in the upper River Halladale in North Scotland. *Forest Ecology and Management*, 502. <https://doi.org/10.1016/j.foreco.2021.119616>
- SHEN, R. F., & TENG, Y. (2023). The frontier of soil science: Soil health. *Pedosphere*, 33(1), 6–7. <https://doi.org/10.1016/j.pedsph.2022.06.007>
- Siriwardena, S. D., Boyle, K. J., Holmes, T. P., & Wiseman, P. E. (2016a). The implicit value of tree cover in the U.S.: A meta-analysis of hedonic property value studies. *Ecological Economics*, 128, 68–76. <https://doi.org/10.1016/j.ecolecon.2016.04.016>
- Siriwardena, S. D., Boyle, K. J., Holmes, T. P., & Wiseman, P. E. (2016b). The implicit value of tree cover in the U.S.: A meta-analysis of hedonic property value studies. *Ecological Economics*, 128, 68–76. <https://doi.org/10.1016/j.ecolecon.2016.04.016>
- Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, 14(2), 94–101. <https://doi.org/10.1002/fee.1225>
- Soga, M., Yamanoi, T., Tsuchiya, K., Koyanagi, T. F., & Kanai, T. (2018). What are the drivers of and barriers to children’s direct experiences of nature? *Landscape and Urban Planning*, 180, 114–120. <https://doi.org/10.1016/j.landurbplan.2018.08.015>
- Song, X. P., Tan, P. Y., Edwards, P., & Richards, D. (2018a). The economic benefits and costs of trees in urban forest stewardship: A systematic review. *Urban Forestry & Urban Greening*, 29, 162–170. <https://doi.org/10.1016/j.ufug.2017.11.017>
- Song, X. P., Tan, P. Y., Edwards, P., & Richards, D. (2018b). The economic benefits and costs of trees in urban forest stewardship: A systematic review. In *Urban*

- Forestry and Urban Greening* (Vol. 29, pp. 162–170). Elsevier GmbH.
<https://doi.org/10.1016/j.ufug.2017.11.017>
- Srivastava, K. (2009). Urbanization and mental health. *Industrial Psychiatry Journal*, 18(2), 75. <https://doi.org/10.4103/0972-6748.64028>
- Staton, T., Walters, R. J., Smith, J., & Girling, R. D. (2019). Evaluating the effects of integrating trees into temperate arable systems on pest control and pollination. *Agricultural Systems*, 176, 102676.
<https://doi.org/10.1016/j.agsy.2019.102676>
- Sterman, J. D., Siegel, L., & Rooney-Varga, J. N. (2018). Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy. *Environmental Research Letters*, 13(1). <https://doi.org/10.1088/1748-9326/aaa512>
- Stone, B., & Norman, J. M. (2006). Land use planning and surface heat island formation: A parcel-based radiation flux approach. *Atmospheric Environment*, 40(19), 3561–3573. <https://doi.org/10.1016/j.atmosenv.2006.01.015>
- Symonds, M. (2021). Faculty Opinions recommendation of Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. In *Faculty Opinions – Post-Publication Peer Review of the Biomedical Literature*.
<https://doi.org/10.3410/f.740796309.793588556>
- Tamaskani Esfehankalateh, A., Ngarambe, J., & Yun, G. Y. (2021). Influence of tree canopy coverage and leaf area density on urban heat island mitigation. *Sustainability (Switzerland)*, 13(13). <https://doi.org/10.3390/su13137496>
- Taylor, M. S., Wheeler, B. W., White, M. P., Economou, T., & Osborne, N. J. (2015). Research note: Urban street tree density and antidepressant prescription rates—A cross-sectional study in London, UK. *Landscape and Urban Planning*, 136, 174–179. <https://doi.org/10.1016/j.landurbplan.2014.12.005>
- Tsai, W.-L., Floyd, M. F., Leung, Y.-F., McHale, M. R., & Reich, B. J. (2016). Urban Vegetative Cover Fragmentation in the U.S. *American Journal of Preventive Medicine*, 50(4), 509–517. <https://doi.org/10.1016/j.amepre.2015.09.022>
- UK Government. (2021). *The England Trees Action Plan 2021-2024*.
<https://assets.publishing.service.gov.uk/media/60a3ddd1d3bf7f2886e2a05d/england-trees-action-plan.pdf>
- Upson, M. A., Burgess, P. J., & Morison, J. I. L. (2016). Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. *Geoderma*, 283, 10–20. <https://doi.org/10.1016/j.geoderma.2016.07.002>
- Valdés, A., Lenoir, J., De Frenne, P., Andrieu, E., Brunet, J., Chabrierie, O., Cousins, S. A. O., Deconchat, M., De Smedt, P., Diekmann, M., Ehrmann, S., Gallet-Moron, E., Gärtner, S., Giffard, B., Hansen, K., Hermy, M., Kolb, A., Le Roux, V., Liira, J., ... Decocq, G. (2020). High ecosystem service delivery potential of small woodlands in agricultural landscapes. *Journal of Applied Ecology*, 57(1), 4–16.
<https://doi.org/10.1111/1365-2664.13537>
- Van den Berg, A. E., Jorgensen, A., & Wilson, E. R. (2014). Evaluating restoration in urban green spaces: Does setting type make a difference? *Landscape and*

- Urban Planning*, 127, 173–181.
<https://doi.org/10.1016/j.landurbplan.2014.04.012>
- Vos, P. E. J., Maiheu, B., Vankerkom, J., & Janssen, S. (2013). Improving local air quality in cities: To tree or not to tree? *Environmental Pollution*, 183, 113–122.
<https://doi.org/10.1016/j.envpol.2012.10.021>
- Walker, H. M., Clarke, T.-K., Doick, K. J., Marshall, H., O'Brien, L., Pollard, C., Vaz Monteiro, M., Ward, L., & Zawadzki, S. (2023). *Wirral i-Tree Eco Technical Report*.
<https://www.forestresearch.gov.uk/research/i-tree-eco/i-tree-eco-projects/i-tree-eco/>
- Wang, X., Scott, C. E., & Dallimer, M. (2023). High summer land surface temperatures in a temperate city are mitigated by tree canopy cover. *Urban Climate*, 51.
<https://doi.org/10.1016/j.uclim.2023.101606>
- Wang, X., Yao, J., Yu, S., Miao, C., Chen, W., & He, X. (2018). Street trees in a Chinese forest city: Structure, benefits and costs. *Sustainability (Switzerland)*, 10(3). <https://doi.org/10.3390/su10030674>
- Wells, N. M., & Lekies, K. S. (2006). Nature and the Life Course: Pathways from Childhood Nature Experiences to Adult Environmentalism. *Children, Youth and Environments*, 16(1), 1–24. <https://doi.org/10.1353/cye.2006.0031>
- Whitburn, J., Linklater, W. L., & Milfont, T. L. (2019). Exposure to Urban Nature and Tree Planting Are Related to Pro-Environmental Behavior via Connection to Nature, the Use of Nature for Psychological Restoration, and Environmental Attitudes. *Environment and Behavior*, 51(7), 787–810.
<https://doi.org/10.1177/0013916517751009>
- Wolf, K. L. (2005). Trees in the small city retail business district: Comparing resident and visitor perceptions. *Journal of Forestry*, 103(8), 390–395.
- Wolf, K. L., Lam, S. T., McKeen, J. K., Richardson, G. R. A., Bosch, M. van den, & Bardekjian, A. C. (2020). Urban trees and human health: A scoping review. In *International Journal of Environmental Research and Public Health* (Vol. 17, Issue 12, pp. 1–30). MDPI AG. <https://doi.org/10.3390/ijerph17124371>
- World Economic Forum. (2020). *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*.
- World Health Organization. (2023). *Step up! Tackling the burden of insufficient physical activity in Europe*. OECD Publishing.
- Wu, J., Rappazzo, K. M., Simpson, R. J., Joodi, G., Pursell, I. W., Mounsey, J. P., Cascio, W. E., & Jackson, L. E. (2018a). Exploring links between greenspace and sudden unexpected death: A spatial analysis. *Environment International*, 113, 114–121. <https://doi.org/10.1016/j.envint.2018.01.021>
- Wu, J., Rappazzo, K. M., Simpson, R. J., Joodi, G., Pursell, I. W., Mounsey, J. P., Cascio, W. E., & Jackson, L. E. (2018b). Exploring links between greenspace and sudden unexpected death: A spatial analysis. *Environment International*, 113, 114–121. <https://doi.org/10.1016/j.envint.2018.01.021>
- Zomer, R. J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., van Noordwijk, M., & Wang, M. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*, 6(1), 29987. <https://doi.org/10.1038/srep29987>

Alice Holt Lodge

Farnham
Surrey, GU10 4LH, UK
Tel: **0300 067 5600**

**Northern Research
Station**

Roslin
Midlothian, EH25 9SY, UK
Tel: **0300 067 5900**

**Forest Research in
Wales**

Environment Centre
Wales
Deiniol Road, Bangor
Gwynedd, LL57 2UW,
UK
Tel: **0300 067 5774**

info@forestresearch.gov.uk
www.forestresearch.gov.uk

Forest Research will consider all requests to make the content of our documents available in alternative formats.

Please send any such requests to: research.info@forestresearch.gov.uk