Forest Research

NHS Trees and Woodland Valuation Pilot Study

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The Research Agency of the
Forestry Commission

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A report for the Centre for Sustainable Healthcare.

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Key Definitions

Capital Asset Value: The present value of the future flow of services from an asset, typically summed over 100 years.

Carbon dioxide equivalent (CO_2e): the number of tonnes of a greenhouse gas with the same global warming potential as one tonne of CO_2 (IPCC, 2001).

Ecosystem services: Benefits provided to people by the natural environment, such as clean air, food, places for exercise, and connection to our surroundings (UK National Ecosystem Assessment, 2023).

Natural capital: Environmental assets that may provide benefits to humanity (Office for National Statistics, 2023a).

Natural capital accounting: A structured process for classifying, measuring, and recording the condition of environmental assets, and assigning monetary values to the benefits those assets provide (Office for National Statistics, 2023a).

Small wood: Wooded features exceeding 0.1 hectares and less than 0.5 hectares in extent; or exceeding 0.5 hectares and less than 20 m in width and therefore not qualifying as woodland (National Forest Inventory, 2017).

Trees outside woodland: Small woods, groups of trees, and lone trees (National Forest Inventory, 2017).

Unit factor: Rate of provision of a service per unit of the asset, such as carbon storage per hectare of woodland.

Unit value: Value of a single unit of an ecosystem service, such as £ per tonne of carbon storage.

Woodland: Woods exceeding 0.5 hectares in extent, and at least 20 m wide (National Forest Inventory, 2017).

Executive summary

The purpose of this study is to explore options for valuation of ecosystem services provided by trees and woodland on the NHS estate.

Four NHS sites were selected for this pilot study of the value of trees and woodland in the NHS green estate: Meanwood in Leeds, Fazakerley in Liverpool, Southmead Hospital in Bristol, and Royal United Hospitals, Bath. The extents of woodland and trees outside woodland were quantified for each site (Table S1).

Table S1. Extents of woodland and trees outside woodland on the four study sites.

Site	Woodland extent (ha)	Trees outside woodland extent (ha)
Meanwood, Leeds	12.68	n/a[1]
Fazakerley, Liverpool	5.05	n/a[1]
Southmead Hospital, Bristol	0.83	1.98
Royal United Hospitals, Bath	0.95	4.06

A benefit transfer method has been used to apply information from existing studies of ecosystem service provision to trees and woodland on the study sites. Woodland and urban natural capital accounts by ONS and DEFRA, Valuing Non-Woodland Trees report by Forest Research for DEFRA, i-Tree Canopy, and i-Tree Eco software tools have been used to estimate ecosystem service provision. We have calculated the quantity and value of carbon storage, carbon sequestration, air pollution removal, flood regulation, temperature regulation, and noise mitigation for each of the four study sites (see Table S2).

Annual values of the benefits provided by trees and woodland on the study sites are presented in Table S3. These benefits have the potential to make significant contributions to key NHS priority actions, including reaching net-zero, reducing air

[1] n/a indicates that there are no trees outside woodland on the Meanwood, Leeds and Fazakerley, Liverpool sites.

pollution, and reducing the pressure on health services by mitigating negative health impacts for people inside and outside healthcare settings. The values of the benefits represent avoided costs to society and to the NHS, rather than income or financial wealth. The importance of these benefits is reflected in the high capital asset values for each site (Table S4).

Table S2. Ecosystem services quantified for woodland, and trees outside woodland, at each site. "Y" indicates where ecosystem service provision has been calculated for the tree typology at a site. Text gives details of which typologies were included in the calculation.

		Ecosystem service					
Site	Tree typology	Carbon storage	Carbon sequestration	Air pollution removal (NO_2, NH_3, SO_2, O_3, $PM_{2.5}$)	Flood reduction (flood water storage and avoided runoff)	Temperature regulation	Noise mitigation
Meanwood, Leeds[2]	Woodland	Y	Y	Y	Y	Y	Y
Fazakerley, Liverpool[2]	Woodland	Y	Y	Y	Y	Y	Y
Southmead Hospital, Bristol	Woodland	Y	Y	Y	Y	Y	Y
	Trees outside woodland	Y	Y	Y	Y	Small woods and groups of trees	Small woods
Royal United Hospitals, Bath	Woodland	Y	Y	Y	Y	Y	Y
	Trees outside woodland	Y	Y	Y	Y	Small woods and groups of trees	Small woods

We recommend quantification of trees and woodland on the wider NHS estate, followed by the application of the woodland and urban natural capital accounts

[2] The Meanwood, Leeds and Fazakerley, Liverpool sites are taken to be 100% woodland in this study.

methodologies to future NHS green estate studies. We propose methodological developments for estimation of noise and temperature reduction for further work.

Table S3. Annual monetary flow estimates from ecosystem services provided by four NHS sites.

	Site			
Ecosystem service	Meanwood, Leeds	Fazakerley, Liverpool	Southmead Hospital, Bristol	Royal United Hospitals, Bath
Carbon sequestration (woodland natural capital accounts)	£21,647	£8,621	£4,794	£8,559
Air pollution removal (woodland natural capital accounts)	£8,595	£3,423	£1,903	£3,398
Flood regulation (woodland natural capital accounts)	£2,126	£847	£442	£781
Noise mitigation (Valuing Non-Woodland Trees)	£2,109	£840	£138	£158
Temperature reduction (Valuing Non-Woodland Trees)	£7,529	£2,999	£1,579	£2,043
Total	£42,006	£16,730	£8,856	£14,939

Table S4. Estimated capital asset values of trees and woodland on the four study sites.

Site	Capital asset value (£)
Meanwood, Leeds	£1,429,731
Fazakerley, Liverpool	£569,411
Southmead Hospital, Bristol	£292,996
Royal United Hospitals, Bath	£477,002

1 Purpose

The purpose of this study is to explore options for valuation of ecosystem services provided by trees and woodland on the NHS estate. This is a pilot study designed to:

- test the applicability of existing ecosystem services quantification and valuation methods to the NHS estate,
- illustrate the insight that can be gained from the process,
- investigate options for development of quantification methods for the NHS estate, and
- make recommendations for the roll-out of the methodology to the wider NHS estate.

The NHS green estate is wide and varied, and its stakeholders have competing priorities for use and management. The NHS green estate is not mapped in a single dataset, and its value is not well understood.

The NHS in England is organised into 42 Integrated Care Systems (ICS), each with their own strategy and Green Plan. The Green Plans focus on reaching net zero through consideration of energy, waste, food, and biodiversity. In the next round of Green Plans there will be a focus on proving space for nature and adapting the NHS estate to climate change. Woodland and tree planting is already taking place on the NHS estate, with some targeted planting to enhance tree cover connectivity and air pollution removal. Trees and woodland have the potential to provide a range of benefits, also known as ecosystem services, including reducing health inequality, reducing temperatures on hospital wards, contributing to achieving net zero, providing access to greenspace in and around hospital sites, and improving the physical health and wellbeing of people.

An estimate of ecosystem service provision and the value of the NHS green estate can help support effective conversations amongst stakeholders.

This work explores options for quantification and valuation of some of the ecosystem services provided by woods and trees on the NHS estate.

2 Approach

Urban trees, including woodland and trees outside woodland, provide a host of benefits to people and the wider environment (Davies *et al.*, 2017). These benefits can be categorised as regulating, provisioning, supporting, and cultural (UK National Ecosystem Assessment, 2023). The monetary value of ecosystem services, representing cost savings to society, can be calculated following agreed guidelines for natural capital accounting (Defra, 2023c; Office for National Statistics, 2023a).

In this study we have explored multiple quantification and valuation approaches, and where appropriate have applied them to the woodland and trees outside woodland on four NHS green estate sites, to generate a range of estimates for the quantity and value of some of the ecosystem services provided.

3 Data

Shapefiles of the boundaries of four NHS green estate sites were provided by the Centre for Sustainable Healthcare. Two of the sites are fully wooded with no buildings. The other two are hospital sites with a mixture of small wooded areas, groups and lines of trees, and individual trees interspersed within the hospital grounds. Each is described in more detail below.

3.1 Meanwood, Leeds

The Meanwood, Leeds site is a ring of broadleaf woodland surrounding a modern housing estate, at the centre of which is the former Meanwood Park Hospital. The hospital was closed and the land has been developed into housing but the surrounding woodland still belongs to the NHS. To the north of the site is the Leeds Outer Ring Road (A6120), and to the west of the site is Meanwood Beck. A public bridleway runs through the woodland and connects with Meanwood Park to the south-west. There are informal footpaths into and through the woodland. Minor roads surround the south and east sides of the site, and at the centre are houses, gardens, residential roads, and a few businesses. Most of the woodland has been present for over 100 years (National Library of Scotland, 2023).

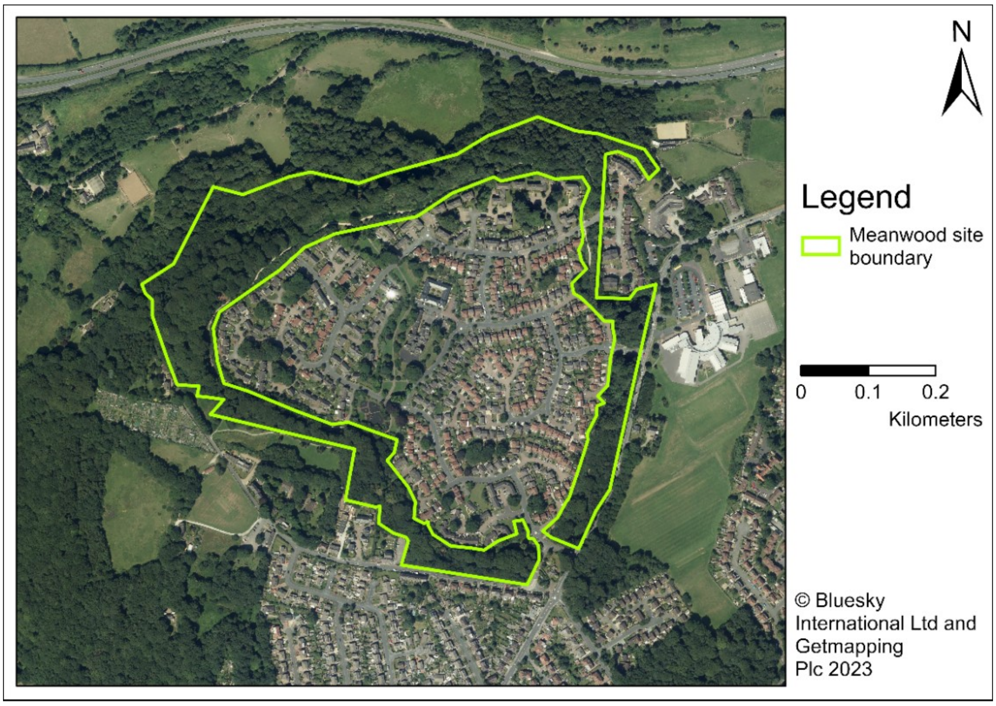

Figure 1. Map of the Meanwood, Leeds site.

3.2 Fazakerley, Liverpool

The Fazakerley site, known locally as Bluebell Woods, is a broadleaf woodland to the south of Aintree University Hospital in Liverpool. Immediately north of the hospital runs the dual-carriageway A506. To the south of the site is a prison, and to the west are allotments, houses, gardens, and residential streets. North-west of the residential area is a railway. There are no right-of-way footpaths or bridleways through the woodland but there are informal footpaths. To the south of the site runs Fazakerley Brook. Some of the trees in the woodland could date from the late 1800s or earlier. An avenue of trees was planted before 1935, and the remainder of the trees on the site grew or were planted after 1949 (National Library of Scotland, 2023).

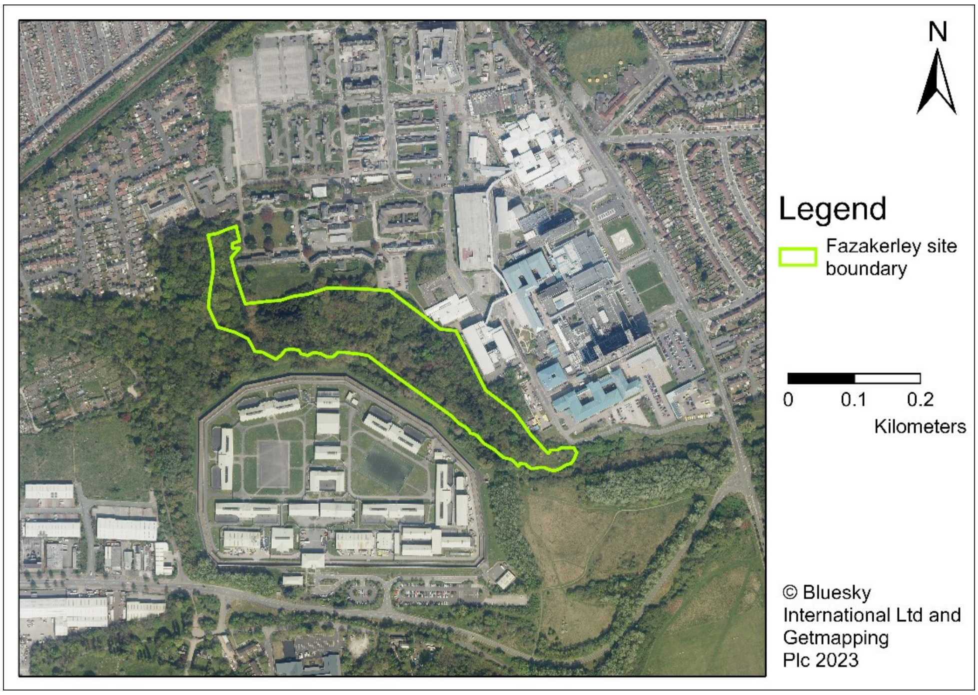

Figure 2. Map of the Fazakerley, Liverpool site.

3.3 Southmead Hospital, Bristol

The Southmead site is the site of Southmead Hospital in Bristol. The site is surrounded by residential areas comprising houses, residential roads, gardens, schools, and leisure facilities. Gloucester Road (the A38) runs to the east of the site, and minor roads run to the north, west, and south.

There was a workhouse and hospital on the site from the early 1900s, and by the mid 20th century the hospital had grown in size and trees were present on the site (National Library of Scotland, 2023). There are now lone trees, lines of trees, groups of trees, and small woods on this hospital site.

Figure 3. Map of the Southmead Hospital (Bristol) site.

3.4 Royal United Hospitals, Bath

The Bath site is the site of the Royal United Hospitals, Bath. The site is surrounded by residential areas comprising houses, roads, sports pitches, schools, and businesses. Further to the west and north is agricultural land. To the south of the site is Newbridge Hill (the A431), and the A4, and further south is the River Avon.

By 1933 three hospitals were present on the site. Aerial photos show trees present on site from the mid 20th century, and the patches of woodland date from this time or earlier (National Library of Scotland, 2023).

Figure 4. Map of the Royal United Hospitals, Bath site.

3.5 Woodland and trees outside woodland

We use the National Forest Inventory (NFI) definition of woodland: wooded areas exceeding 0.5 hectares in extent and not less than 20 metres wide.

Trees outside woodland are all trees that do not meet the NFI woodland definition, and are sub-categorised as:

- small woods (woodland greater than 0.1 hectares and less than 0.5 hectares in extent, or less than 20 metres wide),
- groups of trees (0.1 hectares or less in extent, including linear and non-linear features), and
- lone trees

  (National Forest Inventory, 2017).

Woodland and trees outside woodland deliver ecosystem services at different rates and through different mechanisms. The Meanwood, Leeds and Fazakerley, Liverpool sites are taken to be 100% woodland for this study. To enable calculation of ecosystem service provision by both woodland and non-woodland trees, wooded areas were hand-mapped and their areas quantified for the Royal United Hospitals, Bath and Southmead Hospital, Bristol sites using 2017 aerial imagery (Bluesky International Ltd and Getmapping Plc 2023) in ESRI ArcGIS Pro 2.8.2 and ESRI ArcMap 10.6.1. The wooded areas were categorised into woodland, small woods, and groups of trees according to their extent and width.

4 Methods

We have reviewed methodologies for quantification and valuation of ecosystem services provided by trees and woods, and we have applied them in whole or in part to the four case study sites.

4.1 Principles of natural capital accounting

We have followed the principles of natural capital accounting in our calculations. Table 1 lists the components of natural capital accounts (Defra, 2023c) and briefly describes their application in this work. More detail is given in the relevant sections for each ecosystem service.

We have used the benefit transfer method to estimate value for ecosystem services provided by trees and woodland on the NHS sites by applying information from studies completed in different locations and contexts, such as the woodland natural capital accounts (Office for National Statistics, 2022a). Values represent cost savings for society or the NHS, rather than income or financial wealth.

Table 1. Components of natural capital accounts and their application to this work.

Type	Account	Description
Physical	Extent	The extent of trees and woods.
Physical	Condition[3]	The quality of trees and woods in terms of how well they can provide benefits.
Physical	Flow	The magnitude of services provided by trees and woods over one year. Calculated as extent multiplied by the unit factor.
Monetary	Flow	The flow of value from services over one year. Calculated as physical flow multiplied by the unit value.
Monetary	Capital Asset Value	The present value of the expected future flow of services from trees and woods, calculated over 100 years, with a discount rate applied to future values.
Monetary	Maintenance cost[4]	The present cost of expected maintenance of the asset, typically calculated over 100 years.

Figure 5 shows the process of applying natural capital accounting principles to a natural asset, to generate annual physical and monetary flows, and a capital asset value. First, the natural assets are identified (in this case woods and trees on NHS sites). Their extent (area in hectares) is determined by mapping or modelling. We use unit factors, multiplied by the extent, to determine the quantity of multiple ecosystem services provided by the asset (for example, tonnes of air pollution removed per annum). The value of the benefits provided by these services is calculated by multiplying by unit values. Finally, a capital asset value can be calculated by estimating the future flows of value over 100 years.

[3] Data on the condition of trees and woodland is not available for this project; the condition account has not been calculated.

[4] Maintenance costs of trees and woodland are not available for this project; the maintenance cost account has not been calculated.

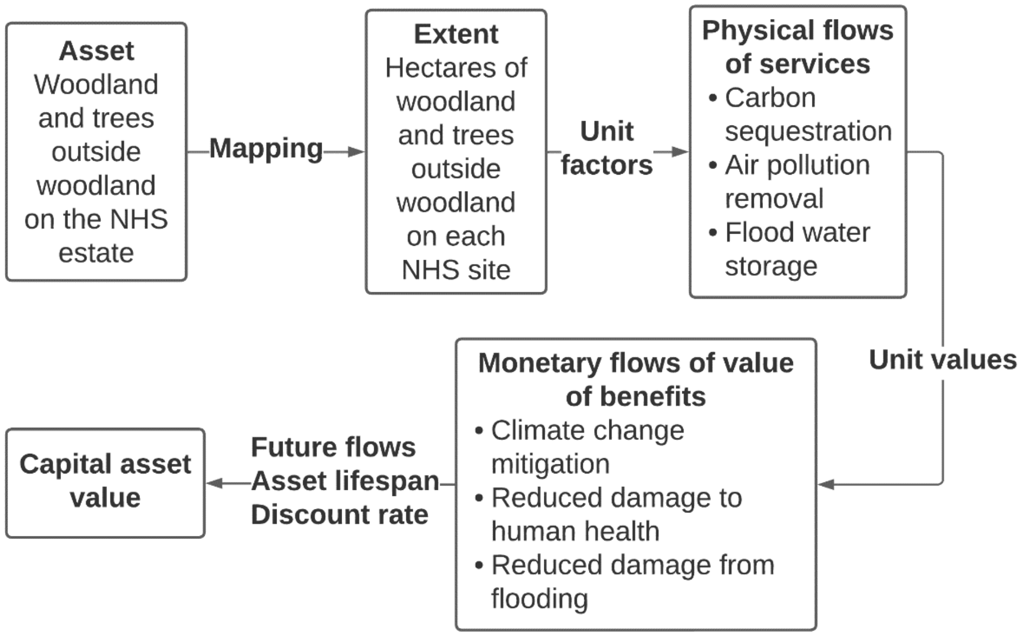

Figure 5. Flow diagram illustrating the natural capital accounting process adopted for this work.

Using the approach outlined in Figure 5 we present annual physical and monetary flows, calculated using several approaches, for each of the ecosystem services we have considered. We present a stock quantity and value for carbon storage, which is not an annual flow. Where 2023 prices for services were not available, study year prices were converted to 2023 prices using the GDP deflator (HM Treasury, 2023). In some cases we also present approximate capital asset values, using per-hectare “capital asset unit values” from the publications underlying the woodland and urban natural capital accounts, following the example of Broadmeadow et al. (2023).

4.2 i-Tree Canopy and i-Tree Eco

i-Tree is a state-of-the art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools, including i-Tree Eco and i-Tree Canopy.

i-Tree Eco[5] combines a tree sampling and surveying methodology with a collection of interlinked numerical models describing the biological function of trees and some of the ecosystem services those functions provide.

Forest Research holds data from completed i-Tree Eco studies across the UK. Of those studies, six were chosen to match the geographical regions of the NHS sites in this pilot study, and location-specific unit factors for ecosystem provision were calculated, from these studies, for application in valuing the NHS trees and woodland.

i-Tree Canopy[6] is an online tool for the assessment of canopy cover within a defined boundary. It also features approximate ecosystem service quantification and valuation. Ecosystem service quantification is estimated from 'batch runs' of the i-Tree Eco model, using regional average input data.

4.3 Physical Account: Tree canopy cover quantification

Woodland sites: The Meanwood, Leeds and Fazakerley, Liverpool sites were taken to have 100% tree canopy cover. The areas and hence canopy cover of these sites were calculated in ESRI ArcGIS Pro 2.8.2.

Hospital sites: i-Tree Canopy was used to assess the tree canopy cover on the Royal United Hospitals, Bath and Southmead Hospital sites. Sample points were added and analysed until the standard error on the estimated canopy cover was less than 2.0% (467 points for Royal United Hospitals, Bath; 311 for Southmead Hospital). Date information is not given for the aerial/satellite imagery in i-Tree Canopy, so the results were checked by importing the sample points into Google Earth Pro, using the most recent single-date, high-quality imagery available (2022), and sample points were re-classified where necessary.

[5] https://www.itreetools.org/tools/i-tree-eco
[6] https://canopy.itreetools.org/

4.4 Physical Account: Ecosystem service quantification

4.4.1 Carbon storage

Three approaches were used for the quantification of carbon storage.

i-Tree Eco

The mass of carbon (as CO_2e) stored in the above and below-ground dry weight biomass of trees. We have calculated unit factors from previously completed i-Tree Eco projects.

i-Tree Canopy

The mass of carbon (as CO_2e) stored in the above and below-ground dry weight biomass of trees. We have used the unit factors provided within the tool.

Forest Research Forestry Statistics

The mass of carbon (as CO_2e) stored in above and below-ground biomass, dead wood, litter, and in woodland soil (Forest Research, 2022). We have calculated unit factors from this work and applied them to the areas of trees and woodland at the NHS sites. For the trees outside woodland, carbon stored in dead wood, litter and woodland soils have been omitted from the calculations.

4.4.2 Carbon sequestration

Three approaches were used for the quantification of carbon sequestration.

i-Tree Eco

The mass of carbon (as CO_2e) absorbed by trees per year, from field data and growth rates. We have calculated unit factors from previously completed i-Tree Eco projects.

i-Tree Canopy

The mass of carbon (as CO_2e) absorbed by trees per year. We have used the unit factors provided within the tool.

Woodland natural capital accounts

The mass of carbon (as CO_2e) absorbed by trees per year (Office for National Statistics, 2022a, 2022b), from the National Atmospheric Emissions Inventory (Smith *et al.*, 2021). We have calculated unit factors from this work and applied them to the areas of trees and woodland at the NHS sites.

4.4.3 Flood regulation

Two approaches have been used to quantify flood mitigation.

Woodland natural capital accounts

The annual volume of flood water removed by woodland and trees outside woodland compared to an alternative ground cover of managed grassland, including interception and water storage in woodland soils (Broadmeadow *et al.*, 2023). We have calculated combined unit factors and unit values from this work and applied them to the areas of woodland and trees outside woodland in the NHS sites.

Broadmeadow et al. (2023) restrict their analysis to trees in catchments upstream of communities at risk of flooding. We have taken the same approach in this work. All four sites considered are parts of catchments upstream of flood risk areas (Environment Agency, 2022a, 2022c, 2022b, 2023) and trees on these sites therefore have the potential to provide a flood risk benefit downstream. All four sites are located in Flood Zone 1 (Gov.uk, 2023b), which means trees on the sites do not contribute to flood regulation through hydraulic roughness of the floodplain surface. This component of flood regulation has therefore been omitted from our calculations.

i-Tree Canopy

The volume of surface runoff avoided during and after a precipitation event due to the presence of trees and woodland. We have used the unit factors provided within the tool.

4.4.4 Air pollution removal

Two approaches were used for the quantification of air pollution removal by trees and woods.

Woodland natural capital accounts

The masses of NO_2, SO_2, O_3, NH_3, and $PM_{2.5}$ absorbed by trees in the EMEP4UK atmospheric chemistry transport model (Jones *et al.*, 2017). We have calculated unit factors from this work. (Note, our approach is different to that taken by Jones et al. (2017) and the woodland natural capital accounts, which both report the change in atmospheric concentration of pollutants, requiring a city-wide approach and productivity data.)

i-Tree Canopy

The masses of NO_2, SO_2, and $PM_{2.5}$ deposited to the bark and leaf surfaces of trees, and absorbed through stomatal surfaces. We have used the unit factors provided within the tool.

4.4.5 Temperature regulation

A single approach was used for the quantification of temperature regulation by trees.

Valuing Non-Woodland Trees

Cooling provided by small woods and groups of trees (Defra, 2021b), derived from the urban natural capital accounts (Office for National Statistics, 2023b). We have used the unit factors provided in Valuing Non-Woodland Trees (Defra, 2021b).

4.4.6 Noise mitigation

A single approach was used for the quantification of noise mitigation by trees.

Valuing Non-Woodland Trees

The number of buildings benefiting from noise mitigation provided by woods and small woods (Defra, 2021b), derived from the urban natural capital accounts (Office for National Statistics, 2023b). We have used the unit factors provided in Valuing Non-Woodland Trees (Defra, 2021b).

4.5 Monetary account: Ecosystem service valuation

4.5.1 Carbon storage and sequestration

Carbon storage and sequestration are valued using the social cost of carbon at £273 per tonne of CO_2e (2023 central value uplifted from 2020 price of £252) removed from the atmosphere per year, or stored in existing trees (BEIS and Department for Energy Security & Net Zero, 2021). We have calculated per-hectare "capital asset unit values" from the woodland natural capital accounts, and applied these to the extents of tree and woodland in each site, to estimate capital asset values.

4.5.2 Flood regulation

Natural capital accounts

Broadmeadow et al. (2023) use a cost of £14.00 per m^3 (2021 prices) of flood storage reservoir provision as the basis for the unit value of flood regulation by woodland and trees outside woodland. The study also gives capital asset values for the flood regulation provided by woodland and trees outside woodland over a 100 year period. The authors also estimate annual values of flood regulation. We were unable to calculate unit factors for flood mitigation, but have calculated combined unit factors and unit values in terms of £ per ha per year, and applied these to the extents of woodland and trees outside woodland at each site. We have used per-hectare "capital asset unit values" (Broadmeadow *et al.*, 2023), and applied these to the extents of tree and woodland in each site, to estimate capital asset values.

i-Tree Canopy

Unit values of this service are based on the avoided cost to treat the volume of runoff waste water that would be generated due to a flood event if the trees or woodland were not present. 2023/24 regional volumetric waste water/sewage treatment charges were obtained from the water provider for each site (Table 2).

Table 2. 2023/2024 wholesale or domestic volumetric waste water/sewage treatment charges set by the water provider for each site.

Location	Unit value (£ per m^3)	Source
Royal United Hospitals, Bath (wholesale)	1.7572	Wessex Water[7]
Southmead Hospital, Bristol (wholesale)	1.7572	Wessex Water[7]
Fazakerley, Liverpool (wholesale)	1.2840	United Utilities[8]
Meanwood, Leeds (domestic)	1.7879	Yorkshire Water[9]

4.5.3 Air pollution removal

Defra produce guidance on valuing the removal of air pollution via two approaches: Impact Pathway Approach (IPA) (Defra, 2023b), and damage cost approach (Defra, 2023a). We have valued the annual removal of air pollutants using the damage cost approach, which is appropriate for a study of this scale and depth (Defra, 2023a). The majority of health impacts attributed to particulate matter are caused by the $PM_{2.5}$ fraction, which are a component of PM_{10}. To avoid double-counting we calculate neither a physical nor monetary flow of the removal PM_{10}. The primary health effects of NH_3 occur via ammonium aerosols which are a component of $PM_{2.5}$ (World Health Organisation, 2006). The health effects of NH_3, and therefore the value of its removal, are considered within the $PM_{2.5}$ assessment, rather than

[7] Wessex Water Wholesale Charges 2023-2024, available at https://www.wessexwater.co.uk/media/d2cdijrr/wwsl-wholesale-charges-scheme-2023-24.pdf, accessed on 08/09/2023.
[8] United Utilities Wholesale Charges 2023-2024, available at https://www.unitedutilities.com/Business-services/wholesale-charges/?WSCharges=2023-24, accessed on 08/09/2023.
[9] Yorkshire Water Services Limited Charges 2023/2024, available at https://www.yorkshirewater.com/media/cdvdz4i5/44466_yw_charges-scheme-book_23-24_web.pdf, accessed on 08/09/2023.

separately. 2022 damage costs for $PM_{2.5}$, SO_2, and NO_2 (as NO_x) were uplifted to 2023 prices using the GDP deflator (HM Treasury, 2023) and are given in Table 3.

Table 3. 2023 national average damage costs (2022 prices) for the pollutants valued in this study.

Pollutant	2023 damage cost value (uplifted from 2022 prices) (£ per tonne)
NO_2 as NO_x	8,383
SO_2	17,096
$PM_{2.5}$	76,930

Jones et al. (2017) give a capital asset value for removal of air pollution by woods and trees (including O_3, for which a damage cost is not available in the UK). We have calculated a per-hectare "capital asset unit value" (following Broadmeadow *et al.*, 2023) and applied it to the extent of woods and trees at each site to estimate their 100-year capital asset value.

4.5.4 Temperature regulation

Temperature regulation was valued according to unit values in Valuing Non-Woodland Trees (Defra, 2021b). We have calculated a per-hectare "capital asset unit value" from Valuing Non-Woodland Trees, and applied it to the four sites to estimate capital asset values.

4.5.5 Noise mitigation

Noise mitigation was valued using the unit values in Valuing Non-Woodland Trees (Defra, 2021b). We have calculated a per-hectare "capital asset unit value" from Valuing Non-Woodland Trees and applied it to the four sites to estimate capital asset values.

4.6 Limitations

Currently, not all ecosystem services provided by trees can be quantified, or valued in monetary terms, and where calculations exist they cannot be applied to all trees.

This pilot study report therefore covers a subset of ecosystem services provided by trees, and the valuation is accordingly an underestimate. Table 4 summarises the ecosystem services that have been quantified for woodland and trees outside woodland on each site.

Table 4. Ecosystem services quantified for woodland, and trees outside woodland, at each site. "Y" indicates where ecosystem service provision has been calculated for the tree typology at a site. Text gives details of which typologies were included in the calculation.

		Ecosystem service					
Site	Tree typology	Carbon storage	Carbon sequestration	Air pollution removal (NO_2, NH_3, SO_2, O_3, $PM_{2.5}$)	Flood reduction (flood water storage and avoided runoff)	Temperature regulation	Noise mitigation
Meanwood, Leeds[10]	Woodland	Y	Y	Y	Y	Y	Y
Fazakerley, Liverpool[10]	Woodland	Y	Y	Y	Y	Y	Y
Southmead Hospital, Bristol	Woodland	Y	Y	Y	Y	Y	Y
	Trees outside woodland	Y	Y	Y	Y	Small woods and groups of trees	Small woods
Royal United Hospitals, Bath	Woodland	Y	Y	Y	Y	Y	Y
	Trees outside woodland	Y	Y	Y	Y	Small woods and groups of trees	Small woods

[10] The Meanwood, Leeds and Fazakerley, Liverpool sites are taken to be 100% woodland in this study.

5 Results

Summaries of the results using the Forestry Statistics, woodland natural capital accounts, and Valuing Non-Woodland Trees approaches are presented here, with i-Tree Eco and i-Tree Canopy results presented in Appendix B.

5.1 Physical accounts: Extent of trees and woodland

Table 5. Extent of woodland and trees outside woodland at the four NHS sites.

Site	Site extent (ha)	Canopy cover (%)	Canopy cover (ha)	Woodland (ha)	Trees outside woodland (ha)
Meanwood, Leeds	12.68	100	12.68	12.68	n/a[11]
Fazakerley, Liverpool	5.05	100	5.05	5.05	n/a[11]
Southmead Hospital, Bristol	27.29	10.3	2.8	0.83	1.98
Royal United Hospitals, Bath	21.29	23.6	5.01	0.95	4.06

5.2 Physical accounts: Ecosystem service stocks

Table 6. Estimate of carbon stocks in woods and trees at four NHS sites, calculated using the Forest Research Forestry Statistics approach.

Site	Carbon stored (tonnes CO_2e)
Meanwood, Leeds	14,041
Fazakerley, Liverpool	5,592
Southmead Hospital, Bristol	1,607
Royal United Hospitals, Bath	2,465

[11] n/a indicates that there are no trees outside woodland on the Meanwood, Leeds and Fazakerley, Liverpool sites.

5.3 Physical accounts: Ecosystem service annual flows

Table 7. Estimated physical annual flows of ecosystem services from trees and woods at four NHS sites, using the woodland natural capital accounts methodologies. Noise mitigation and temperature regulation are not included here, because their unit factors do not provide meaningful physical flows.

	Ecosystem service		
Site	Carbon sequestration (tonnes CO_2e per year)	Air pollution removal (tonnes per year)	Flood regulation (m^3 per year)
Meanwood, Leeds	79	0.85	4,176
Fazakerley, Liverpool	32	0.34	1,663
Southmead Hospital, Bristol	18	0.09	869
Royal United Hospitals, Bath	31	0.09	1,537

5.4 Monetary accounts: Annual flow valuation

Figure 6 shows the contributions of each ecosystem service to the total annual monetary flow at each site. Carbon sequestration is the most valuable, with significant contributions from temperature regulation and air pollution removal. Details are given in Table 15 in Appendix B.

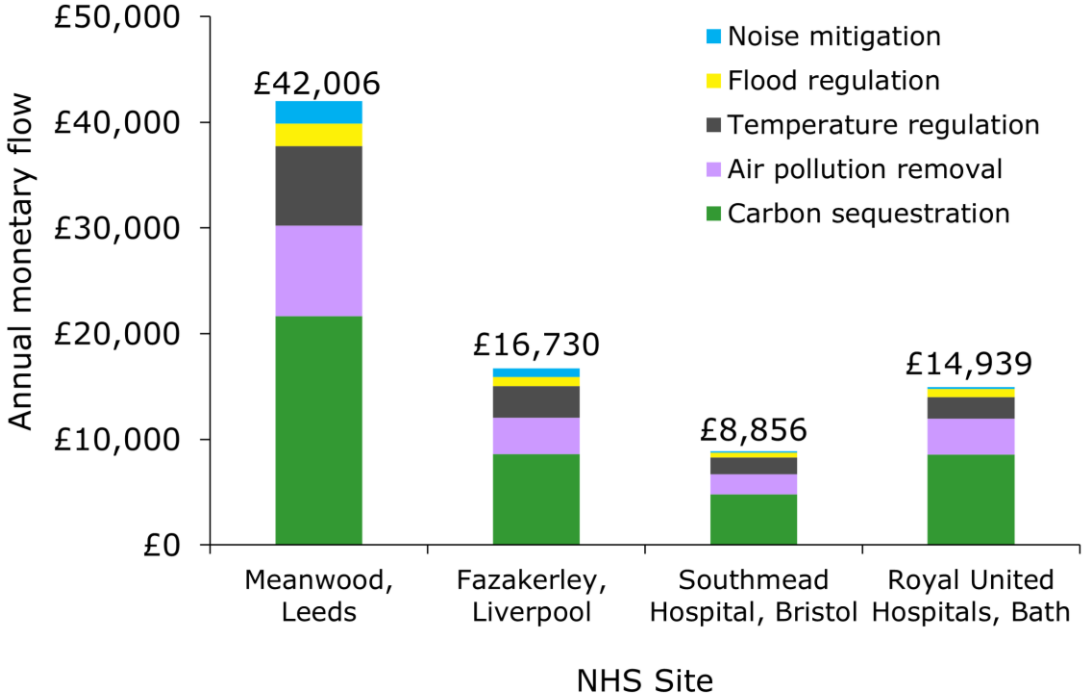

Figure 6. Contributions from five ecosystem services to the total annual monetary flow at each NHS site, based on woodland natural capital account methodologies. Total annual flows are given above each bar.

5.5 Monetary accounts: Capital asset values

Table 8. Capital asset values of ecosystem services provided by trees at four NHS sites.

	Site			
Ecosystem service	Meanwood, Leeds	Fazakerley, Liverpool	Southmead Hospital, Bristol	Royal United Hospitals, Bath
Carbon sequestration (woodland natural capital accounts)	£563,805	£224,544	£124,861	£222,934
Air pollution removal (woodland natural capital accounts)	£346,280	£137,911	£76,688	£136,923
Flood regulation (woodland natural capital accounts)	£58,411	£23,263	£3,823	£4,376
Noise mitigation (Valuing Non-Woodland Trees)	£62,954	£25,072	£4,121	£4,717
Temperature regulation (Valuing Non-Woodland Trees)	£398,281	£158,621	£83,503	£108,052
Total	£1,429,731	£569,411	£292,996	£477,002

6 Discussion

The purpose of this study was to explore options for the valuation of ecosystem services provided by trees and woodland on the NHS estate. It had four key aims, discussed in the sections below.

6.1 Test the applicability of existing quantification and valuation methods to the trees and woodland on the NHS estate

We have used i-Tree Canopy and a geospatial information system to quantify the extent of woodland and trees outside woodland on four NHS sites. We have successfully applied methodologies underlying the woodland natural capital accounts, Valuing Non-Woodland Trees, i-Tree Canopy, and i-Tree Eco to estimate the quantity and value of up to six ecosystem services provided by trees and woodland on the NHS sites.

Table 9 shows the total annual flows of value for each site, using three approaches. There are methodological differences between each approach, and they do not account for the same ecosystem services, and therefore are not directly comparable. When the ecosystem services at each site are combined the total value estimate using the woodland natural capital accounts method is £82,531, using the i-Tree Canopy method is £102,562 and using the i-Tree Eco method, which only accounts for carbon sequestration, is £73,940.

Table 9. Total annual flows of value from the four sites, using three approaches (see footnotes for ecosystem services included in each approach).

Site	Natural capital accounts[12]	i-Tree Canopy[13]	i-Tree Eco[14]
Meanwood, Leeds	£42,006	£51,419	£38,077
Fazakerley, Liverpool	£16,730	£21,108	£14,214
Southmead Hospital, Bristol	£8,856	£10,782	£7,772
Royal United Hospitals, Bath	£14,939	£19,253	£13,877
Total	£82,531	£102,562	£73,940

Why do the values differ?

The estimates for individual ecosystem service flows differ as a result of their respective unit factors. For example, the i-Tree Canopy unit factor for carbon sequestration is almost double the natural capital accounts unit value, which is a consequence of the construction of the i-Tree Canopy tool, resulting in the i-Tree Canopy annual value being substantially higher. The unit values can also differ between tools due to different valuation methods being applied. For example, when calculating the value of flood mitigation the woodland natural capital account uses the cost to build and maintain flood reservoirs to store the amount of water stored by trees and woodland, while the i-Tree Canopy method bases valuation on the cost to clean the equivalent amount of storm water that the trees and woodland are estimated to remove. This difference in valuations methods contributes to the NCA flood mitigation value being less than half the i-Tree Canopy value.

[12] Value includes carbon sequestration, air pollution removal, flood regulation, and the Valuing Non-Woodland Trees approaches for temperature and noise regulation only.
[13] Value includes carbon sequestration, avoided runoff, and air pollution removal only.
[14] Value includes carbon sequestration only.

Is one approach better or more accurate than another?

There are advantages and drawbacks associated with each of the approaches. The natural capital accounts approach has the advantages of covering a wider range of ecosystem services and offering consistency with approved national natural capital accounting. However, for carbon sequestration and air pollution removal it is assumed that trees outside woodland provide the same level of benefits per hectare as woodland trees, which has not been empirically tested. Without empirical studies it is difficult to gauge which approach is more accurate. The accuracy of the i-Tree tools unit factors can also be questioned. For example, the unit factors for carbon storage and sequestration are based on global tree data and are not specific to the UK, which may be a source of error.

There can also be differences between the approaches in relation to location specificity. For example, the woodland natural capital account's air pollution unit factor is the same for all of England. Therefore, two areas of woodland of the same size will be calculated to remove the same amount of air pollution regardless of their locations in England. Using the same example but applying the i-Tree Canopy or i-Tree Eco approach will result in different pollution removal values due to regional weather and pollution concentration data being factored into the calculations. i-Tree Eco provides a further level of specificity over the natural capital accounts and i-Tree Canopy approaches due to being based on in-situ field measurements that provide local quantification of the physical asset from which ecosystem flows can be quantified and valued.

6.2 Illustrate the insight that can be gained from the process

The results of this study demonstrate that trees and woodland at the four NHS sites provide a variety of valuable benefits.

Carbon sequestration

As the UK's largest public sector employer, the NHS contributes between 4 and 5% of national carbon emissions (The Leeds Teaching Hospitals NHS Trust, 2022). NHS England has a responsibility to reduce carbon emissions in line with UK Government's mandatory commitment to net-zero by 2050 (HM Government, 2021). Reducing emissions is the surest way to reach net-zero, and decarbonising activities is the focus of NHS Green Plans (West Yorkshire Health and Care Partnership, 2022). The removal of carbon dioxide from the atmosphere, such as carbon sequestration by trees, can be used as an additional measure to account for the remainder of carbon emissions in order to reach net-zero (West Yorkshire Health and Care Partnership, 2022).

At each of the four sites carbon sequestration provides the highest annual economic benefit. Using the woodland natural capital accounts approach for Meanwood, Leeds as an example, the woodland is estimated to sequester 79 tonnes of CO_2 per year, providing an economic annual value of £21,647. This represents a cost saving to society, as well as contributing to NHS climate targets. The removal of carbon by the woodland at the Meanwood, Leeds site is approximately equivalent to emissions from the Trust's fleet vehicles (97 tonnes per year, The Leeds Teaching Hospitals NHS Trust, 2022). The Leeds Teaching Hospitals NHS Trust has achieved a 33% reduction in carbon emissions since 2013, and this de-carbonising approach will remain the focus of their journey to becoming net-zero, but carbon sequestration by trees can play a small part.

Air pollution removal

Over a quarter (29%) of British hospitals are located in areas with levels of $PM_{2.5}$ exceeding the World Health Organisation recommended limits (Bond and Edwards, 2021). Air pollution exacerbates existing respiratory conditions such as asthma, and can lead to hospitalisation of those affected (Bond and Edwards, 2021). Air pollution also contributes to heart disease, stroke, and lung cancer (Defra, 2023b).

Reduction of atmospheric concentrations of pollutants has the potential to reduce these negative health effects and reduce associated hospital admissions. Using the RUH Bath site as an example, the trees and woodland have been estimated to remove 0.155 tonnes of pollution from the atmosphere annually with an annual economic value of £3,398 using the woodland natural capital accounts approach. These reductions in air pollutants will have important health benefits for patients, staff and visitors to the site, and support an NHS priority action of reducing air pollution on and around hospital sites (Mersey Care NHS Foundation Trust, 2022).

Flood regulation

In the UK extreme weather including flooding events are forecast to increase as the climate changes (Met Office Hadley Centre *et al.*, 2022). Trees and woodland contribute to flood alleviation, the benefits of which may be amplified as the climate changes (Defra, 2021a). Each of the sites studied is in the upstream catchment of communities at risk of flooding, so the trees and woodland on the sites contribute to flood regulation. For example, the woodland site at Fazakerley, Liverpool stores potential flood water with an estimated value of £847 per year (the cost of building flood storage reservoirs to hold the same volume). The Southmead Hospital, Bristol site is subject to high flood risk from surface water (Gov.uk, 2023a). Trees on the Southmead Hospital site prevent an estimated 534 m^3 of surface runoff per year (using the i-Tree Canopy approach), valued at £947 per year (not accounting for prevention of damage or the negative impact on mental wellbeing of floods). The flood mitigation benefits provided by trees and woodland on the wider NHS estate are valuable to communities living downstream and to the NHS in terms of management of their estate, and have the potential to become more important over time.

Noise mitigation

Exposure to noise pollution is detrimental to health in a variety of ways including sleep disturbance, increased risk of heart disease, and increased risk of stroke

(World Health Organisation Regional Office for Europe, 2018). The impact of night-time noise on hospital patients and staff wellbeing is well documented (Xyrichis *et al.*, 2018), and road traffic noise can be a contributing factor (de Lima Andrade *et al.*, 2021). Using the Valuing Non-Woodland Trees approach the Meanwood, Leeds woodland is estimated to provide a noise mitigation benefit to 21 buildings helping to reduce the consequential noise health impacts for the people in these buildings with an annual economic benefit value of £2,109.

Temperature regulation

In the last 20 years the UK has experienced more frequent, intense, and prolonged periods of high temperatures than in the previous 30 years, and this upwards trend is projected to continue as our climate continues to warm (Met Office, 2023). High daytime and night-time temperatures have adverse effects on people's health, including dehydration, heat stroke, exacerbation of chronic cardiovascular, respiratory, and diabetes-related conditions (World Health Organisation, 2018) and increased risk of heart attack and stroke (UK Health Security Agency, 2023). High temperatures are also associated with increased air pollution (World Meteorological Organisation, 2023) and increased severity of the associated health impacts (Rahman *et al.*, 2022). NHS Trusts have heatwave plans that are put into action when heat health alerts are issued by the Met Office. When a hospital department reaches temperatures of 26 °C, staff are obliged to take action to cool the building, or close the ward to reduce the risk to patient health (The Leeds Teaching Hospitals NHS Trust, 2023). However, increasing the use of air conditioning on hospital wards is incompatible with the NHS reaching net-zero.

Trees and woodland provide cooling of the local environment through shading and evapotranspiration. As an example, trees and woodland on the Fazakerley, Liverpool site provide cooling benefits worth an estimated £2,999 per year. This reduction in temperature could contribute to fewer hours of air conditioning being required to cool Aintree University Hospital and HMP Altcourse as well as local households and businesses. This in turn could result in savings to their utility bills (see for example Moss *et al.*, 2019). This ecosystem service will be increasingly valuable as the frequency and intensity of high temperature events continue to rise.

Management of assets

Awareness of the benefits trees provide in relation to health and climate mitigation is increasing (Defra, 2021a). As new methods to measure other ecosystem services, not looked at in this study, are developed and applied (see next section) it is likely that our understanding of the benefits will increase further. This has the potential to significantly increase the economic value of trees and woodland on the NHS estate. However, for this to happen it is important that the quality of these trees and woodland is maintained. For example, by removing trees due to poor management practices the carbon stock within them will also be removed devaluing the asset. Effective management plans and the adequate allocation of resources to maintain the trees and woodland in good condition will therefore be required to utilise the health and climate benefits they provide on the NHS estate into the future.

6.3 Investigate options for development of quantification methods for the NHS estate

This study has examined the benefit and valuation of six ecosystem services. However, there are other ecosystem services provided by trees and woodland that could be explored and potentially valued in the future.

Social, cultural and health values of trees

The social and cultural values of trees and woodland (which includes the categories: nature and landscape connections; social development and connections; education and learning and cultural significance) have not been considered in this study. Few of these values have been monetised, and those that have relate almost exclusively to woodland rather than individual trees. That being said a recent report utilising

Outdoor Recreation Valuation (ORVal) model data has predicted per hectare economic values for well-being resulting from visits to open access woodlands in England and Wales (Day and Davis, 2022). This methodology has the potential to be applied at the Meanwood and Fazakerley woodland sites as well as other open access woodland sites across the NHS estate as part of any future work.

The economic valuation of improved mental health due to trees and woodlands requires data on visitor behaviour (annual footfall, duration of time spent in the woods and expenditure). Therefore an analysis of the mental health benefits of trees was not possible as part of this study. If this information was available it may be possible to value these benefits in the future. For example, a 2021 report suggested a per-visit mental health value from woodland at £0.39. This value was based on the avoided costs spent on mental health via visits to woodland (Saraev *et al.*, 2021).

Biodiversity

Urban trees and woodland provide food and habitat for numerous species, can enhance connectivity between urban and rural greenspaces, and are themselves a component of species richness in the urban environment.

There is currently no definitive way to estimate the contribution to biodiversity made by urban trees and woodland. Tree surveys on NHS sites would reveal the species diversity in the tree populations and could provide information to estimate habitat and food provision for populations of some invertebrates. In-situ monitoring of a variety of invertebrate, mammal, bird, fungal, plant and other communities at NHS sites would help to reveal their potential importance as havens for biodiversity and could be an opportunity for community engagement. Mapping of the NHS green estate could facilitate studies to reveal its role in connecting treescapes across urban and rural areas.

Noise mitigation

Studies of noise mitigation by urban trees are restricted to modelled road noise 50 dbA and louder. None of the four NHS sites chosen for this pilot study lie within the Defra road noise mapped areas, which focus on major roads (Defra, 2017, 2019) so there is currently no road noise data for these sites. However, it is likely that the roads in and around the four sites contribute to noise pollution experienced by people on the sites. Noise levels on the sites can be calculated using the UK government traffic noise calculation (Department of Transport Welsh Office, 1988). Noise mitigation by trees on the sites can then be calculated following the urban natural capital accounts methodology, or by application of methods from recent literature. Both approaches would require the mapping of small woods and groups of trees for each NHS site but could be included in future studies.

6.4 Make recommendations for the roll-out of the methodologies to the wider NHS estate

Natural Capital Accounting

We have calculated and applied "unit capital asset values" (100 year present values) to estimate capital asset values. For future work, we propose that capital asset values would be calculated over an asset life of 100 years using estimated future flows, predicted population growth, and HM Treasury Green Book discount rates.

Choice of methodologies

Where we have been able to apply the detailed methodology underlying the woodland natural capital accounts, we would recommend the application of the same approach to the wider NHS estate. We would not recommend the use of unit factors derived from i-Tree Canopy or i-Tree Eco; the natural capital accounting methodologies offer conservative and approved approaches to quantification and valuation.

Where we have used the approaches from Valuing Non-Woodland Trees to approximate the urban natural capital accounts, we recommend a more detailed approach as discussed below.

Temperature regulation

The urban natural capital accounts (Office for National Statistics, 2023b) estimate the cooling effect of urban woodlands larger than 200 m^2, based on a 3.5 °C reduction in temperature within woodlands compared to the surrounding area, and a 0.52 °C reduction within a 100 metre buffer around woodlands larger than 30,000 m^2 (eftec, 2018). The extent of the urban area covered by woodland and buffer is calculated as a percentage, and the percentage is multiplied by the temperature difference to give the presumed temperature reduction across the urban area (e.g. 10% * 3.5 °C = 0.35 °C). The authors calculate the monetary account on a city-wide scale, based on avoided productivity loss and avoided air conditioning costs, using gross value added (GVA) for each labour sector, data on hot days in the study cities, productivity loss functions, and estimates of air conditioning use on hot days.

In this work we were focussing on small sites, so we were unable to replicate the city-wide approach to valuation taken by eftec (2018). Instead, we followed the approach used in Valuing Non-Woodland Trees (Defra, 2021b) in which the authors calculated effective unit factors and unit costs from the urban natural capital accounts.

In further studies, with NHS sites across whole city regions, it would be possible to follow the eftec approach and calculate avoided productivity loss and avoided air conditioning use owing to the presence of trees and woodlands on NHS sites. It would also be informative to calculate the reduction in the number of hot days on NHS sites. Further, we propose undertaking a literature search of the cooling effects of urban trees and woodland and calculating new unit factors from relevant studies.

Air pollution removal

Jones et al. (2017) use the impact pathways approach to calculate the health impacts, and therefore the value, of the change in atmospheric concentrations of air pollutants owing to the presence of vegetation. We chose to use the damage cost approach, which is more appropriate for a study of this scale, and is especially applicable where policy changes are not being examined. Future work, with a national focus, has the potential to be suited to the impact pathways approach, which is a more accurate representation of the benefits of air pollution removal.

Next steps

Optional next steps are outlined in Table 10 with a description of potential advantages and disadvantages in their application.

Table 10. Optional next steps with their advantages and disadvantages.

Options	Advantages	Disadvantages
Further i-Tree Canopy / Google Earth assessments across the wider NHS estate, or purchase of National Tree Map data for the NHS estate. Apply the methodologies set out above to quantify the value of the ecosystem services at these sites.	Likely to be lower cost (desk-based) than some of the other suggested options. Quicker to apply than i-Tree Eco surveys or development of new methodologies. Opportunity to engage with volunteer groups.	Output data less site specific than in-situ, field-based approaches.
Conduct i-Tree Eco surveys across the NHS estate. Apply the methodologies set out above, and in-built modelling in the i-Tree Eco tool, to quantify the value of the ecosystem, services at these sites.	Output data more site-specific. Opportunity to engage with volunteer groups. Provides site specific information such as species composition and condition which is vital for strategic management of tree populations. Estimation of ecosystem service provision accounts for condition of assets.	Likely to be higher cost (fieldwork) than i-Tree Canopy surveys Slower to apply than replicating the current study.
Apply new ecosystem service methodologies to the NHS estate as they are developed.	Provides a fuller representation of the benefits of trees and woodland on the NHS estate.	Further costs. Slower to apply than replicating the current study.
Conduct visitor behaviour surveys for NHS woodland sites.	May allow the social and cultural valuation of NHS woodland sites.	Further costs. Requires fieldwork. Slower to apply than replicating the current study.

This report has demonstrated some of the benefits and values provided by trees and woodland at four NHS sites. It is hoped that the findings of this report will aid stakeholders in directing resources to maximise the benefits trees and woodland provide across the NHS estate going forwards.

Appendix A: Limitations

All of the approaches used here require assumptions in order to apply the benefit transfer method and the process illustrated in Figure 5. When using these initial estimates, it is advisable to consider whether a range of values drawing on the different approaches should be used in order to provide an indication of the uncertainty entailed in the valuations and their underpinning assumptions. Alternatively, if a conservative estimate is desirable, it is recommended to use the low estimates.

Modelling ecosystem service provision and benefit value is based on a high number of variables and the interactions between these variables. Models are subject to uncertainty due to the complexity of the calculations and are limited by the number of input variables provided. As with any assessment and modelling framework, there are trade-offs among selected methods in terms of efficiency, cost, practicality, and accuracy. All current estimates and means of estimation can be improved to varying degrees.

i-Tree Eco and i-Tree Canopy carbon storage and sequestration

The i-Tree unit factors for carbon storage and sequestration are based on averaged global allometric equations and are therefore not specific to the UK.

i-Tree Canopy avoided runoff

The volumes of avoided water runoff calculated by i-Tree Canopy are based on assumptions about tree and woodland species composition and weather patterns informed by the i-Tree Eco batch runs (Nowak, 2020). This may mean they are less accurate than an i-Tree Eco survey which uses site specific tree survey and weather data to inform the calculations.

The model calculates the volume of runoff based on the assumption that the ground cover under the trees and woodland is 74.5% pervious and 25.5% impervious

(Nowak, 2020), which is not representative of the actual ground cover at the study sites.

It was not possible to value avoided damage, injury, or disruption from floods through avoided runoff calculations.

Woodland natural capital accounts flood regulation

The species composition and weather input values in Broadmeadow et al. (2023) are based on national averages. The modelled flood mitigations values for the sites may therefore differ from the actual values.

The soil water storage calculations are modelled on pervious soils under trees and woodland (Broadmeadow et al., 2023). In the urban environment trees may be located in planting holes within impervious substrates such as tarmac. This may alter the volume of water that can be stored in the soils around these trees from the values calculated by the model.

The flood mitigation calculations are based on trees and woodland in flood risk catchments as it is these trees and woodland that will help alleviate flooding further downstream (Broadmeadow et al., 2023). The model does not take into account impervious surfaces such as asphalt, tarmac and brick reducing the ability of rainfall to infiltrate into soils and increasing the speed at which it moves over the surface raising the likelihood of flood events. This may mean that the modelled values for flood mitigation resulting from the presence of the trees and woodland at these sites differ from the actual benefits provided by them.

The model uses the FAO Harmonized World Soil Database (HWSD) to assign 6 soil classes (5 mineral and 1 organic) for deriving soil hydraulic parameters across the UK (Broadmeadow et al., 2023). The actual soil types and water contents at each of the sites may differ from those that have been calculated.

It was not possible to value avoided damage, injury, or disruption from floods through the annual volume of flood water removal by woodland and trees outside woodland calculations.

The calculations used in this report are based on the volume of water removed due to the presence of trees when compared to managed grassland (Broadmeadow et al., 2023). Not all areas without trees at the sites will be managed grassland and therefore the actual values may differ from the modelled calculations.

The additional below ground flood water storage under woodland is averaged but will vary greatly during the year, often reaching a peak in late summer. Therefore actual soil water storage values may differ from those calculated by the model at different times of the year (Broadmeadow et al., 2023).

There is an absence of evidence that building reservoirs is the least cost alternative and that the flood protection benefits equal or exceed the construction costs. Therefore the replacement cost approach adopted to estimating the economic contribution of existing trees and woodland for flood risk mitigation represents a first approximation. There is insufficient evidence available at present to determine whether the net present value of annualised benefits of the level of flood protection provided by existing woodland would exceed the initial costs of building a reservoir (Broadmeadow et al., 2023).

The replacement costs are based on a limited number (seven) of reservoir storage schemes and some elements of the costs involved draw on general estimates rather than actual values, which are often difficult to obtain (Broadmeadow et al., 2023).

The calculated values for the flood regulation service draw on data from different time periods. In particular, the interception loss and soil water storage estimates use meteorological data for the ten-year period 2006-2015 (Broadmeadow et al., 2023).

Woodland natural capital account air pollution removal

When calculating air pollution removal values with the EMEP4UK model it was not possible to differentiate coniferous and deciduous woodland, therefore all woodland was assigned as deciduous, since deciduous trees are more common than conifers in UK cities (Jones et al, 2017). This may mean the actual air pollution values for the sites may differ from the values using this method.

The EMEP4UK approach emphasises pollutant transport and chemistry over information on the type and location of vegetation on the ground (Jones et al., 2017). Different models and different approaches may produce varying estimates for air pollution removal as a result.

i-Tree Canopy air pollution removal

The modelled removal of pollution is based on limited spatial concentration data (Nowak, 2020). More accurate concentration data may result in more accurate air pollution removal values.

The estimates for the impacts of trees on $PM_{2.5}$ and PM_{10} concentrations are still being developed (Nowak, 2020). Research in this area may improve the accuracy of these estimates in the future.

Valuing Non-Woodland Trees Noise Mitigation

The noise mitigation unit factors are based on the benefit of the decrease in decibel exposure to residential household buildings due to woodlands. At RUH Bath and Southmead Hospital the occupant capacity of the hospital buildings could be higher than a typical residential building. Therefore, the number of people in those buildings benefiting from the noise mitigation provided by woodlands could be higher. This may mean that the economic value of this service is undervalued in this report. However, when using the current methodology it is not possible to quantify the noise mitigation provided by woodlands specifically to public buildings. It should also be noted that the housing density in residential areas may be higher than the distribution of buildings on a hospital site. This reduction in building distribution could reduce the number of inhabitants in these areas despite the potentially higher occupancy in the hospital buildings.

Appendix B: Additional data

Physical account: Ecosystem service quantification

Table 11. Physical annual flows of ecosystem services calculated by **i-Tree Canopy**.

Site	Carbon stored (tonnes)	Gross carbon sequestration (tonnes per year)	Total air pollution removal (tonnes per year)	Avoided runoff (m^3 per year)
Meanwood, Leeds	3,573	142	0.29	2,662
Fazakerley, Liverpool	1,423	57	0.18	1,154
Southmead Hospital, Bristol	790	31	0.05	539
Royal United Hospitals, Bath	1,411	56	0.08	962

Table 12. Physical annual flows of ecosystem services calculated using unit factors derived from **i-Tree Eco** studies.

Site	Carbon stored (tonnes)	Gross carbon sequestration (tonnes per year)
Meanwood, Leeds	4,070	140
Fazakerley, Liverpool	1,757	52
Southmead Hospital, Bristol	1,188	28
Royal United Hospitals, Bath	2,121	51

Monetary account: Annual flow valuation

Table 13. Stock value (carbon storage) and annual flows of value from the ecosystem services calculated by **i-Tree Canopy**. See Methods for details of unit values applied.

Site	Carbon stored (£)	Gross carbon sequestration (£ per year)	Total air pollution removal (£ per year)	Avoided runoff (£ per year)
Meanwood, Leeds	£974,595	£38,807	£7,853	£4,759
Fazakerley, Liverpool	£388,147	£15,456	£4,170	£1,482
Southmead Hospital, Bristol	£215,529	£8,581	£1,254	£947
Royal United Hospitals, Bath	£384,852	£15,324	£2,239	£1,690

Table 14. Stock value (carbon storage) and annual flows of value from the ecosystem services calculated using unit factors derived from **i-Tree Eco** studies. See Methods for details of unit values applied.

Site	Carbon stored (£)	Gross carbon sequestration (£ per year)
Meanwood, Leeds	£1,110,262	£38,077
Fazakerley, Liverpool	£479,371	£14,214
Southmead Hospital, Bristol	£324,011	£7,772
Royal United Hospitals, Bath	£578,506	£13,877

Table 15. Annual monetary flows from ecosystem services provided by four NHS sites, using **woodland natural capital accounts** and **Valuing Non-Woodland Trees** approaches.

	Site			
Ecosystem service	Meanwood, Leeds	Fazakerley, Liverpool	Southmead Hospital, Bristol	Royal United Hospitals, Bath
Carbon sequestration (woodland natural capital accounts)	£21,647	£8,621	£4,794	£8,559
Air pollution removal (woodland natural capital accounts)	£8,595	£3,423	£1,903	£3,398
Temperature reduction (Valuing Non-Woodland Trees)	£7,529	£2,999	£1,579	£2,043
Flood regulation (woodland natural capital accounts)	£2,126	£847	£442	£781
Noise mitigation (Valuing Non-Woodland Trees)	£2,109	£840	£138	£158
Total	£42,006	£16,730	£8,856	£14,939

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