Department for Environment Food & Rural Affairs

Future Proofing Plant Health

Valuing Non-Woodland Trees

Project TH4_18, within PH0496

FUTURE PROOFING Plant Health

A Defra Network partnership delivering interdisciplinary plant health research to improve biosecurity and build capability

High level summary

Introduction

- An estimate of the value to society of the UK's *ca*. 0.75 million hectares of non-woodland trees is required. By comparison, the value to society of the UK's *ca*. 3 million hectares of woodlands has been estimated at *ca*. £4.9 billion per year (Defra, 2018).
- Non-woodland trees are defined as urban and rural single trees, groups of trees (less than 0.1 hectares in extent), and small woods (between 0.1 hectares and 0.5 hectares).
- The importance to society of trees outside woodland is evident *inter alia* in Defra's England Tree Action Plan (Defra, 2021), which sets out the government's long-term vision for the treescape in England and provides a strategic framework for implementing the £640 million Nature for Climate Fund.
- The purpose of this 'Valuing Non-Woodland Trees' project is to generate initial estimates of the economic value of non-woodland trees to assist government in resource allocation, intervention decisions, and policy development. Providing a range of estimates from multiple tools allows decision makers greater consideration of the scientific and statistical confidence in ecosystem service quantification models, regional and country variation.
- The critical review of the tools and the valuation estimates highlights the relative importance of the different benefits of non-woodland trees and allows for the identification of future work, including research needs.

Methodology

- A review of eight tools, methods, and approaches led to the selection of:
    - i-Tree Canopy,
    - Capital Asset Valuation for Amenity Trees (CAVAT), and
    - woodland Natural Capital Accounting (NCA) benefit transfer methodologies

  for generating the range of initial estimates of the economic value of non-woodland trees.
- i-Tree Canopy is one of the i-Tree suite of tools (i-Tree, 2020). It is used to classify ground cover types and estimate tree cover. It is also used to estimate and value ecosystem services provided by trees: carbon stock, carbon sequestration, air pollution removal, and avoided runoff.
- Capital Asset Valuation for Amenity Trees (CAVAT; Doick et al., 2017) is a depreciated replacement cost (DRC) method for valuing amenity trees in urban areas. It provides a means of valuing trees as public assets so that appropriate compensation or replacement can be sought when trees are removed.

- Woodland Natural Capital Accounting (NCA) benefit transfer methodologies involve the application of average ('unit') values from the ONS woodland Natural Capital Accounts to non-woodland trees.
- A natural capital logic chain framework approach was adopted, following the steps: 1) Asset characterisation; 2) Physical account of ecosystem services; 3) Benefits valuation; and 4) Monetary account.
- Logic chains summarise the steps used to describe the quantity, location, and quality of the asset; quantify ecosystem services provided by the asset; and value the benefits of services arising are presented for each valuation approach. Assumptions are stated throughout.
- Valuation is intrinsically limited to the benefits considered by the three adopted approaches: i-Tree Canopy, CAVAT, and woodland Natural Capital Accounting (NCA) benefit transfer methodologies.
- Benefits are valued following HM Treasury Green Book (2003, 2020) guidance.
- Annual flow values for a single year (2020), and Natural Capital values (using the 100-year Net Present Value approach) are calculated.

Non-woodland tree coverage of Great Britain and Northern Ireland

- The Forestry Commission's 2017 Tree Cover Outside of Woodland (TCOW) dataset Table I, below) was used as a single source of non-woodland tree canopy coverage, providing consistency between valuation approaches and hence increasing comparability of the associated monetary accounts.
- TCOW can be disaggregated to regional scale, and for lone trees, groups of trees, and small woods, as well as by rural and urban location at country level, allowing for selection of the most appropriate tree-cover dataset for the benefit valuation.

Table I. Asset size and location: non-woodland tree coverage of GB (for disaggregated regional figures, lone trees, groups of trees, and small wood coverage see main report).

Country	Non-woodland canopy cover (000's ha)	Relative Standard Error (%)
England	565.0	5
Scotland	84.5	13
Wales	92.7	7
Northern Ireland	31.1	5
GB [a]	742.2	5
UK [b]	773.3	5

[a] sum of England; Scotland; Wales.
[b] sum of England; Scotland; Wales; Northern Ireland.

Physical accounts: non-woodland tree canopy coverage of GB

- The benefits arising from the non-woodland trees were quantified and valued according to whether they are a '**flow**' (a service provided over time) or a '**stock**' (a discrete service provided once over the lifetime of the existing tree population).
- Quantification required the use of **unit factors** (a measure of the average ecosystem services provision per quantity of tree cover or, for annual flow benefits, the average ecosystem services provision per quantity of tree cover per year). The unit factors used are presented in Table II.
- Valuation was performed by multiplying the level of ecosystem services provided by the appropriate **unit value** (the average value of ecosystem services provision per physical quantity e.g., £ per tonne of CO_2e). The unit values units are presented in Table III.

Table II. Unit factors: UK-wide unit factors used for i-Tree Canopy and Woodland NCA Benefit Transfer approach. (See General Discussion for commentary on the use of unit factors.)

Ecosystem service	i-Tree Canopy unit factors [a]	NCA unit factors [b]
Carbon storage (tonne CO_2e per ha)	281.776	-
Carbon sequestration (tonne CO_2e per ha per year)	11.2	5.08
Air pollution removal (tonne per ha per year) [c]	-	0.093
NO_2 removal (tonne per ha per year) [d]	0.038	-
SO_2 removal (tonne per ha per year) [d]	0.004	-
$PM_{2.5}$ removal [d]	0.005	-
PM_{10}* removal [d]	0.025	-
Temperature regulation (degrees Celsius per ha per year) [e]	-	0.00000058
Noise reduction (buildings per ha per year) [f]	-	1.68
Avoided runoff (m^3 per ha per year) [c]	283.2	-
Flood mitigation (m^3 per ha per year)	-	10.53

[a] i-Tree Canopy unit factors were provided by i-Tree support. See Appendix D for details.
[b] NCA unit factors were calculated by dividing the physical account of each ecosystem service (e.g., buildings per year) by the extent (in hectares) of woodland providing the service (benefit transfer approach). Based on data presented in ONS accounts this approach enables calculations of value using the logic chains presented in the main text and facilitates comparison between the different methodologies used in the current valuation. See Table 14 and Table 15 for details.
[c] The unit factor for air pollution absorption is for the sum of pollutants (PM_{10} and $PM_{2.5}$, SO_2, NH_3, NO_2 and O_3), with the breakdown of pollutants detailed in CEH (2017).
[d] Indicative UK average. Refer to Table 4 for regional unit factors used in the calculations.
[e] The average cooling effect of woodlands is marginal when expressed as degrees Celsius, hence the physical unit factor for temperature reduction appears relatively small per hectare.
[f] The number of buildings benefiting from the 1 dB noise reduction effects from small urban woodlands (area of 99,141 ha in 2011) was calculated using OSMM data (Eftec, 2018b).

Table III. Unit values: UK-wide average (mean) unit values used by i-Tree Canopy and the Woodland NCA Benefit Transfer approach (in 2020 prices). (Unit values for i-Tree Canopy avoided runoff are regional only; see main text for details.)

Ecosystem service	i-Tree Canopy unit values [a]	NCA unit values [b]
Carbon sequestration (£ per tonne CO_2e in 2020)	241	241
NO_2 removal (£ per tonne)	6,385	
SO_2 removal (£ per tonne)	13,026	
$PM_{2.5}$ removal (£ per tonne)	73,403	
PM_{10}* removal (£ per tonne)	52,176	
Air pollution removal (£ per tonne) [c]	-	3,778
Temperature regulation (£ per degrees Celsius) [d]	-	1,023,800,000
Noise reduction (£ per building)	-	99
Avoided runoff (£ per m^3)	1.49 [e]	-
Flood mitigation (£ per m^3)	-	9.1

[a] i-Tree Canopy unit values are latest UK government social costs where available (carbon, air pollution) and regionally specific wastewater treatment charges. See Table 6 and Table 7 for details.
[b] The social cost of carbon is adopted as the NCA unit value for carbon sequestration. The other monetary unit values are estimated from woodland NCAs by dividing the total value of the ecosystem services by the total quantity. As such, the air pollution removal unit value was estimated by dividing the total value of air pollution removal by the tonnes of pollutants removed. It represents the unit value for the mixture. A breakdown of the pollutants is detailed in CEH (2017). See Table 17 for further details on computing the average values.
[c] The unit value for air pollution removal is for the sum of pollutants (PM_{10} and $PM_{2.5}$, SO_2, NH_3, NO_2 and O_3), with the breakdown of pollutants detailed in CEH (2017). The average mainly reflects the unit value for O_3 as this pollutant accounted for 79% of pollutants removed by mass reported in the woodlands NCA 2020 (ONS, 2020a).
[d] The average cooling effect of woodlands is marginal when expressed as degrees Celsius, hence a large monetary unit is generated when expressing temperature regulation as £ / degree Celsius. This estimate is also relatively large as it refers to the average effect for the whole woodland estate.
[e] Indicative UK average. Refer to Table 7 for actual regional unit values used in calculations.

Valuing the annual flow of benefits from non-woodland trees

- Country-level estimates of annual flow values of individual benefits from non-woodland trees are shown in Table IV, as well as GB and UK totals. A total annual value is provided by summing the value of the individual benefits within each methodology.
- The total value of the UKs non-woodland tree estimates ranges from £1.39 billion per year (woodland NCA Benefit Transfer approach) to £3.83 billion per year (i-Tree Canopy) at 2020 prices.
- For ease of comparison with the Tree Health Resilience Strategy’s estimate of the annual flow of benefits from woodlands of £4.9 billion per year (Defra, 2018), the total

annual flow values of non-woodland trees were also calculated in 2017 prices using the BEIS social values of carbon that applied at that time (which were less than one third of the level of current ones): £0.57 billion per year (woodland NCA approach) and £1.38 billion per year (i-Tree Canopy approach). Non-woodland trees are of considerable value to society.

- The Natural Capital Value of the UK's non-woodland trees ranges from £68.5 billion (woodland NCA Benefit Transfer Approach) to £151.5 billion (i-Tree Canopy) at 2020 prices.

Table IV. Annual flow values (in 2020 prices). (Annual flow values of individual ecosystem services can be summed within each approach to give a total annual flow value, but the estimates from the two approaches cannot readily be summed).

		Annual Flow Values (£ million per year)					
		England	Scotland	Wales	Northern Ireland	GB[a]	UK[b]
i-Tree Canopy	Carbon sequestration	1,528	229	251	84	2,008	2,092
	Air pollution removal	921	119	282	82	1,322	1,404
	Avoided runoff	223	39	54	21	316	337
	Total	2,672	387	587	187	3,646	3,833
Woodland NCA Benefit Transfer approach	Carbon sequestration	692	103	113	38	908	946
	Air pollution removal	199	30	33	11	262	273
	Temperature regulation [c]	74	7	17	5	98	103
	Noise reduction [c]	9	1	2	1	12	13
	Flood mitigation [d]	40	7	6	2	53	55
	Total	1,014	148	170	56	1,333	1,390

[a] sum of England; Scotland; Wales.
[b] sum of England; Scotland; Wales; Northern Ireland.
[c] Urban non-woodland trees only.
[d] Rural non-woodland trees only.
Note: carbon sequestration annual flow value is for 2020, thereafter it increases in line with BEIS recommended carbon values. The NCA methodology also requires income and population growth uplift to be applied to the air pollution removal benefit; future annual values will differ.

Stock valuation of non-woodland trees

Two stock valuations of the UK's non-woodland trees could be derived from the adopted valuation approaches: carbon stock, and CAVAT valuation. The values are presented in Table V.

- Carbon stock refers to the carbon currently stored in the biomass of non-woodland trees; it has a static value for a specific year (2020). Carbon stock increases when trees are planted and when existing trees grow; it decreases when trees are lost. (Carbon sequestration represents the change in carbon stock from one year to the next).
- The carbon stock of the UK's non-woodland trees is valued at £52.5 billion using the i-Tree Canopy tool. The value is derived from the quantity of carbon stored in the trees' above and below ground biomass and represents the value of avoiding emission of that carbon (see also Levasseur et al., 2012). The proportion of the existing carbon stock lost will depend on the severity and nature of the disturbance.
- The CAVAT 'amenity' value of Great Britain's urban non-woodland trees is an estimated £429 billion. The value is a replacement cost estimate; it may be likened to the insurance (replacement) value of a precious asset and is a means of indicating the value of the asset to society.

Table V. Carbon stock and CAVAT (Amenity stock) values (in 2020 prices) of non-woodland trees.

Country	i-Tree Canopy Carbon stock [a] (£ million)	CAVAT (Amenity stock) [b] (£ million)
England	38,371	329,468
Scotland	5,740	20,785
Wales	6,295	78,657
Northern Ireland	2,112	-
GB [c]	50,406	428,910
UK [d]	52,518	-

[a] urban and rural non-woodland trees.
[b] urban non-woodland trees, only.
[c] sum of England; Scotland; Wales.
[d] sum of England; Scotland; Wales; Northern Ireland.

Using the valuation estimates

- The valuation approaches encompass multiple ecosystem services and all types of urban and rural non-woodland trees. To achieve this breadth of application and to make use of valuation logic chains assumptions have been made throughout each approach.
- Uncertainties are associated with the data describing the extent of non-woodland tree cover, provision of ecosystem services and benefits, and the value of those benefits.
- The values arising from this study are first estimates. When using the results of this work to estimate the value of some or all of the benefits of non-woodland trees, values from the different approaches should be considered in order to account for the range reported here and indicate uncertainty.
- The difference between the total annual flow value estimates arising from the i-Tree Canopy and woodland NCA methodologies is *ca.* 3-fold. Influential factors include:
  i) differences in the underlying methodologies: i-Tree uses a bottom-up (per-tree multiplier) approach and the NCAs use a range of top-down (habitat-scale) assessments. Further, the unit factors arising from the approaches differ in magnitude.
  ii) the difference in the ecosystem services considered by each tool (see General Discussion).
- Within each approach, national average per hectare values may be determined. There is close agreement in the per hectare valuation estimates across the four countries. For the woodland NCA methodology normalised total annual flow values range from £1,741 per ha per year (Scotland) to £1,828 per ha per year (Wales). See Table 22 for England, Northern Ireland, GB, and UK values.

Future work options

- The aim to generate a range of initial valuation estimates was hampered by the limited availability of non-woodland tree statistics. Expanding data collection and updating the statistics available would facilitate refinement of valuation estimates. Estimates of non-woodland tree coverage from differing assessment methodologies are available to purchase; other free of charge resources are pending (see General Discussion). Application of such estimates to the developed logic chains could provide further valuation estimates and sensitivity analysis of the associated monetary accounts.
- Non-woodland trees were categorised only as urban or rural; other categorisations including peri-urban, sub-urban, ex-urban, and conurbation were not considered. With ecosystem service delivery dependent on tree location and spatial arrangement to other trees, future work should seek to apply the developed logic chains to a broader range of non-woodland tree categorisations.

- The social and cultural values of non-woodland trees have not been included. Few of these values have been monetised, and those that have relate to woodland and street trees only (see General Discussion). As on-going research in this area reports, future valuations should seek to expand non-woodland tree valuation estimates through a more comprehensive consideration of the range of benefits that these trees are credited to provide to society.
- Future work should also seek to test the range of assumptions employed in the implementation of the logic chains, including the high-level assumptions that apply across each of the valuation estimates. These include assuming static state tree populations for stock assessment, due to uncertainty in urban tree populations, and not accounting for climate change impacts on ecosystem service provision.
- Further work is also needed to explore differences between estimates from the different approaches to help underpin advice on which approach to use for particular purposes.

Contents

List of Tables

Introduction

The purpose of this project is to provide an initial estimate of the economic value of non-woodland trees (NWT) that will be useful for policymakers in considering resource allocation and intervention decisions (for example, in the context of pest or disease outbreaks at national and regional scales) and in the preparation of future policy.

The importance to society of trees outside woodland is revealed in Defra's 'England Tree Action Plan 2021-2024' (Defra, 2021) and in the HM Treasury's Shared Outcomes Fund. The ETAP sets out government's long-term vision for the treescape in England by 2050 and provides a strategic framework for implementing the £640 million Nature for Climate Fund; while the shared outcomes fund invests £2.5 million over three years to support increasing tree cover, ecological restoration, resilient landscapes and climate change mitigation and adaptation.

In this work, urban, peri-urban, rural, and hedgerow NWT are considered at the spatial scales of England, Scotland, Wales, Northern Ireland (NI), Great Britain (GB), and United Kingdom (UK).

The work comprised two parts:

- Part 1. A review of tools, methods, and approaches to present options for valuing different types of non-woodland tree, and
- Part 2. The valuation.

Part 1 was completed between November 2020 and March 2021. The tools, methods, and approaches (hereafter: tools) considered were:

i. i-Tree Canopy
ii. i-Tree Eco
iii. The Helliwell System
iv. Council of Tree and Landscape Appraisers (CTLA)
v. Capital Asset Value for Amenity Trees (CAVAT)
vi. Greenkeeper
vii. Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)
viii. Urban and woodland Natural Capital Accounts

These tools were pre-selected during project definition, as such the review was inherently limited in the range of ecosystem service(s) (ES) considered. Part 1 was reported to the project steering group and concluded with recommendations for the best tools to take forward to Part 2. For each tool, the recommendation was based on suitability to meet the project aim, confidence in estimate, resource requirement, reproducibility, and identified which ES or asset was valued.

Part 2 was completed between April and December 2021. Three valuation tools were considered: 'i-Tree Canopy', 'CAVAT' (Capital Asset Valuation for Amenity Trees), and the woodland Natural Capital Accounting methodologies. Key summary information from Part 1 required to introduce each tool's suitability to Part 2 is in Appendix A. The approach proposed at Part 1 was developed and refined throughout Part 2 and this progression is detailed herein. Summary information for the five tools, including substantiation of recommendation to not progress them to Part 2, is included in Appendix B.

This Project Report presents the key findings and conclusions arising from the Project. It features the overall Project approach to valuing NWT; estimates arising from use of the three valuation tools, including ranges in valuation estimate where appropriate; and suggested future work.

Comprehensiveness of the valuation

Urban trees provide a wide range of ES and benefits to society. These services and benefits have been categorised as:

Provisioning services: including the production of food products (berries, nuts, and fruit), wood-fuel, and items such as horse chestnut conkers for games, and holly leaves and berries for seasonal decoration.
Regulating services: including the cooling of local climates, air quality improvement through the trapping of particulate air pollution, noise abatement, carbon sequestration, interception of rainwater, and the regulation of storm water run-off.
Cultural ecosystem services: including opportunities for exercise and relaxation through inspiration for art, by connecting people to nature in cities and towns, by providing space for socialising and 'de-stressing', through adding landscape structure and colour, via cultural, social and family links and histories, and through opportunities for education, learning and development.
Supporting services: including the cycling of nutrients and the provision of habitat for wildlife. These are the overarching services needed to produce the other categories of ES.

A comprehensive valuation of each benefit is not currently possible and the initial overall estimate of the economic value of NWT presented in this report is limited to those covered under the approaches and considered applicable to valuation of NWTs (see Table B6). Urban trees in some cases can also provide disservices, which have negative impacts on human health and well-being. For example, pollen that triggers allergies, wildlife that may be considered a pest, or damage to infrastructure (Carinanos et al., 2017; Hall et al., 2018). Consideration of the impact of the other goods, services, and disservices on the initial valuation is included in the General discussion (page 57).

Key definitions: Non-Woodland Tree

For the purposes of this project, the National Forest Inventory (NFI) definition of NWT has been adopted (a full list of definitions is provided in Appendix C).

The NFI considers trees outside woodland as:

- Lone trees - A single tree, greater than 3 metres tall located in a hedgerow or greater than 2 metres tall elsewhere, the canopy of which does not touch that of another tree.
- Group of trees - A configuration of 2 or more trees of less than 0.1 hectare in extent.
- Small woods - Areas of tree cover greater than 0.1 hectare and less than 0.5 hectare in extent, and therefore too small or too narrow to qualify as NFI woodland.

Key definitions: Ecosystem services

The ecosystem services considered in this report are defined separately for each valuation tool used:

i-Tree Canopy ecosystem services

- Air pollution removal: the masses of NO_2, SO_2, $PM_{2.5}$, and PM_{10}* (PM_{10} minus $PM_{2.5}$) removed from the atmosphere by deposition to bark and leaves of urban and rural NWT, and by uptake through stomatal surfaces.
- Climate regulation (carbon sequestration): the mass of carbon (as CO_2e) absorbed by urban and rural NWT per year.
- Climate regulation (carbon storage): the mass of carbon (as CO_2e) stored in total (above and belowground) dry weight biomass of urban and rural NWT.
- Stormwater regulation (avoided runoff): the volume (m^3) of surface runoff avoided during and after a precipitation event because of the presence of urban and rural NWT.

Capital Asset Value for Amenity Trees (CAVAT) ecosystem services

- Amenity (replacement cost): benefits derived from the positive elements that urban NWT contribute to overall character or enjoyment of an area.

Woodland NCA ecosystem services

- Air pollution removal: masses of NO_2, O_3, NH_3, $PM_{2.5}$ and PM_{10} absorbed annually by urban and rural NWT.
- Climate regulation (carbon sequestration): mass of carbon (as CO_2e) absorbed annually by urban and rural NWT.
- Climate regulation (cooling): degree Celsius cooling per hectare of urban small woods and groups of trees.
- Flood mitigation: volume (m^3) of floodwater prevented by presence of rural NWT.
- Noise abatement: number of buildings benefitting from noise abatement by urban small woods.

Key definitions: Other

- Ecosystem service '**flow**': a service provided over time.
- Ecosystem service '**stock**': a discrete service provided once over the lifetime of the existing tree population.
- **Unit factor**: measure of ES provision per quantity of tree cover per year (for annual flow benefits) or ES provision per quantity of tree coverage.
- **Unit value**: value of ES provision per physical quantity (e.g., £ per tonne of CO_2).

Methodology

Logic Chains

The 'logic model' was developed in the 1970s by Joseph Wholey as a general framework for describing work in organizations (Millar et al., 2001). Logic models categorise work as inputs, processes, outputs, and outcomes; they represent the logical flow from one step to the next, to guide and evaluate efficiency and effectiveness. Subsequently, logic models have been adapted for a range of uses, including business planning, marketing, and natural capital accounting (Lusardi et al., 2018). Logic models are also referred to as: Logic chains, Block chains, Chain models, or Keystone Theory.

Here logic chains are employed as a framework for mapping the steps in estimating the value of NWT using various tree valuation approaches.

A logic chain for the application of tree valuation approaches to the valuation of non-woodland trees

Part 1 recommended the adoption of i-Tree Canopy (complemented by i-Tree Eco as required), the urban and woodland NCA approaches, and CAVAT (for a replacement cost valuation) to determine a first estimate valuation of a range of ES and benefits provided by NWT. Further, Part 1 required the creation of logic chains for the process of valuation of each ES by each tool, and description of the NWT groups that will be considered. Logic chains are useful to support testing, repeating, and updating the methodology at a later stage; for use where a range of valuation approaches are to be compared; where the valuation methods to be employed are being used beyond their typical or stated design; or, where there may be *a priori* uncertainty in the quality or availability of required data.

Mirroring natural capital accounting methodologies and with clear parallels to Natural England's 'Natural Capital Logic Chain framework' (Natural England, 2020) this work adopted an asset-services-benefits-valuation approach. The logic chain is presented in Figure 1 and described in detail below. Steps within the Natural England framework but not used herein are identified.

The logic chain used contains the following discrete steps:

1. Asset characteristics
   1a. Asset location
   - Country and region in which asset is located.

   1b. Asset quantity

- Extent of NWT in **hectares**. Some data are not available directly but can be estimated. In these cases, the available data, assumptions, and calculation are presented. Where knowledge of the asset quantity is not comprehensive at national and regional scales, existing data is extrapolated to 100% coverage. Method and assumptions are described in detail
- Uncertainty in quantity. Where available, uncertainties are reported for raw data and are propagated and reported for calculated and extrapolated quantities.

1c. Asset quality

- Age & health of asset
- Accessibility
- Species [Not considered in this report]
- Arrangement of components [Not considered in this report].

2. Physical account of ESs. **Stocks** (carbon; amenity) and **Flows** (carbon sequestration, air pollution removal, flood mitigation and stormwater regulation, local (air temperature) cooling, recreation, education, culture, noise abatement) of ES provided by assets are quantified.
   2a. Where known, ES **unit factors** (ES provision per quantity or per quantity per year) are used, and assumptions are reported. Where unit factors are missing these are estimated. Assumptions and details of calculation are reported. Uncertainties are estimated and reported where possible.
   2b. Physical accounts are estimated by multiplying unit factors by asset quantities. Uncertainties are propagated from asset quantity and unit factor error estimates.
3. Benefits valued. Benefits arising from ES are quantified using **unit values** (£ per unit of ES). Unit values are calculated from existing valuations (CAVAT and NCA approaches) or from UK costs of carbon, air pollution, and water treatment (i-Tree Canopy approach).
4. Monetary account
   4a. Annual flow value. The ES or benefit value for the year 2020, and where appropriate the projected annual flow values for subsequent years.
   4b. Natural capital value using net present value approach. Estimated using the discount period of 100-years asset life applied to all renewable natural capital assets, including trees (HM Treasury, 2020) and a discount rate of: 3.5% for projections up to 30 years; 3.0% from 31 to 75 years; 2.5% after 75 years (HM Treasury, 2003; Office for National Statistics, 2020a).

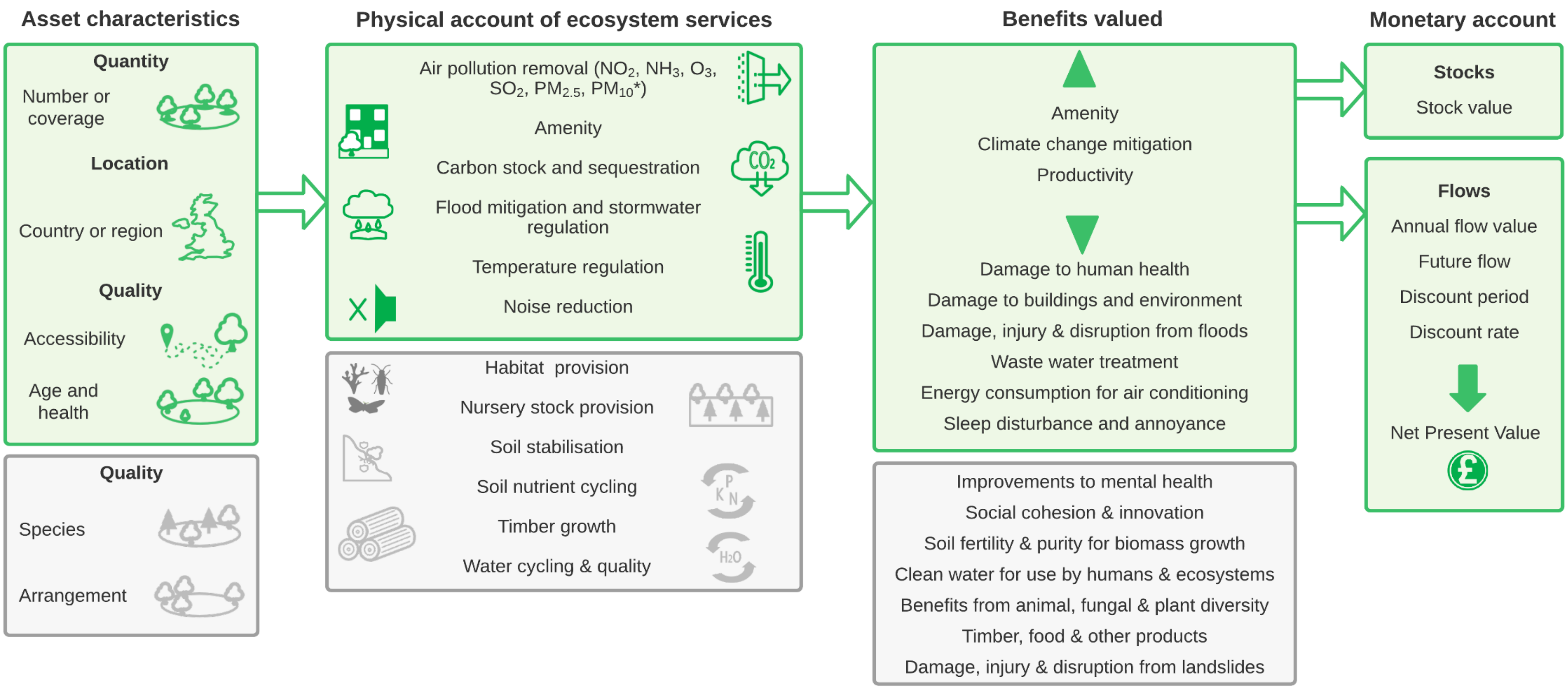

Figure 1. Logic chain for estimating the value of non-woodland tree ecosystem services across GB countries and regions. The chain reveals the steps to describe the quantity, location, and quality of the asset, to quantify ecosystem services provided by the asset, and to value the benefits of those services. The chain is generalised across methodologies: green indicates components used in at least one valuation approach; grey indicates characteristics, ecosystem services and benefits not considered. The ecosystem services and benefits listed in the figure represent a subset of the total benefits from non-woodland trees. Assumptions and uncertainties are considered throughout the logic chain.

Estimating the value of non-woodland trees

Tool 1: i-Tree Canopy

i-Tree Canopy is one of the i-Tree suite of tools (www.itreetools.org). It is used to classify ground cover types and estimate tree cover. For countries where it has been parameterised to do so it is also used to estimate and value ES provided by trees: carbon stock, carbon sequestration, air pollution removal, and avoided runoff. This functionality has been available in the UK since early 2021.

A review of the i-Tree Canopy tool, including a critique of its limitations and assumptions and suitability to this project, is provided in Appendix A.

Ecosystem services quantified using i-Tree Canopy are based on ES provision per hectare (hereafter: unit factors) calculated by the i-Tree partnership and provided by personal communication for use in this report. Unit factors for carbon storage and sequestration were calculated as described by Nowak et al. (2013). Unit factors for air pollution removal and avoided runoff were calculated by running the i-Tree Eco model for 19 UK regions (see Appendix D).

The i-Tree Eco model uses data on the structure of a population of trees (number, species, size, etc.) and local environmental data to estimate tree functions such as gas exchange and tree growth. These functions are converted to services such as pollution removal and carbon sequestration, which can in turn be converted to benefits and values. The i-Tree Eco model is typically informed by individual tree data collected in a city-wide survey. In contrast each of the 19 i-Tree Eco “batch” model runs that determined the UK-specific i-Tree Canopy unit factors was informed by regional data from 2015: tree cover and dominant leaf type from the Copernicus Land Monitoring Service, leaf area index from the MODIS satellite, weather and radiosonde data from the station closest to the centroid of the region, and average pollution data from across the region.

For each region the ecosystem services estimated by the model were divided by the extent of tree cover to give unit factors which can subsequently be applied to tree extents measured using the i-Tree Canopy tool.

The ES quantified using this tool are defined as follows:

- **Carbon storage** (stock) – the mass of carbon (as CO_2e) stored in total (above and belowground) dry weight biomass of urban and rural NWT.

Estimates of carbon storage for i-Tree Canopy are calculated using a national (US) standardised unit factor of 281.78 tonnes CO_2e per hectare. This unit factor was calculated as described in Nowak et al. (2013). Briefly, urban tree data from random samples in 28 US cities were analysed using the i-Tree Eco model. i-Tree Eco models the biomass of each tree using measured tree data and allometric equations from the literature. Equations that predict aboveground biomass only were converted to whole tree biomass using a root-to-shoot ratio of 0.26. Equations that predict fresh or green weight biomass were converted to dry biomass using species- or genus-specific conversion factors, averaging 0.48 for conifers and 0.56 for hardwoods. Multiple equations for individual species are combined to provide one equation for a maximum range of stem diameters. Where no equations are available for a species or genus, the average of results from the same genus or next phylogenetic level is used. Biomass results of open-grown trees are multiplied by 0.8. Carbon storage is estimated as one half of dry weight biomass. For deciduous trees, only carbon stored in wood biomass is calculated. Conifer leaf biomass is calculated from leaf area using species-specific conversion factors. Total carbon storage is capped at 7,500 kg of carbon.

- **Carbon sequestration** – the mass of carbon (as CO_2e) absorbed by urban and rural NWT per year.

  Estimates of annual gross carbon sequestration within i-Tree Canopy are based on a national (US) standardised rate of 11.22 tonnes CO_2e per hectare per year. This rate was calculated by Nowak et al. (2013) using the i-Tree Eco model informed by measured tree data from random samples in 28 US cities. Briefly, carbon sequestration is calculated in i-Tree Eco as the difference in carbon storage in a tree between two successive years of growth. Tree stem diameters are incrementally increased in the model based on estimated annual growth rates. Tree diameter growth rates are calculated from a base growth rate of 8.4 mm per year which is adjusted to account for the length of the growing season, species growth rates, tree competition, tree condition, and tree height. Carbon sequestration for trees whose carbon storage is capped at 7,500 kg (see carbon storage, above) is estimated at 25 kg per year.

- **Air pollution removal** – the masses of NO_2, SO_2, $PM_{2.5}$, and PM_{10}* (PM_{10} minus $PM_{2.5}$) removed from the atmosphere by deposition to bark and leaves of urban and rural NWT, and by uptake through stomatal surfaces.

  Air pollution removal in i-Tree Canopy is estimated based on regional standardised per hectare removal rates specific to the UK. These rates were calculated by the i-Tree partnership by running the i-Tree Eco model for 19 regions in the UK. i-Tree Eco models hourly dry deposition to a regional tree population using regional tree data, regional pollution data, and regional weather data. Deposition velocities are held at zero during periods of precipitation. Deposition velocities for NO_2 and SO_2

are dependent on modelled transpiration. Deposition velocities for particulate matter are based on values from the literature adjusted for actual leaf area index and length of growing season. Particle resuspension is set at 50% for PM_{10} and is dependent on wind speed for $PM_{2.5}$.

- **Avoided runoff** (Stormwater regulation) – the volume (m^3) of surface runoff avoided during and after a precipitation event because of the presence of urban and rural NWT.

  Avoided runoff in i-Tree Canopy is estimated based on regional standardised per hectare volumes specific to the UK. These volumes were calculated in the 19 i-Tree Eco batch model runs as the difference in volumes (m^3) of surface runoff during and after a precipitation event, with and without trees. i-Tree Eco estimates hourly rain interception, evaporation from leaves, potential evapotranspiration, transpiration, and avoided runoff using leaf and bark area and local weather data.

The benefits valued using this tool are defined as follows:

- Climate change mitigation – the continued presence of trees represents an avoided release of carbon into the atmosphere, as well as ongoing sequestration. These benefits are valued using the carbon values from the UK valuation of greenhouse gases for policy appraisal (BEIS, 2021).
- Avoided loss of productivity attributable to reduced emissions of air pollutants – valued using UK air quality damage costs (Defra, 2021), which account for avoided labour productivity losses (Ricardo, 2019a).
- Reduced detrimental impacts on human health – the continued presence of trees represents ongoing absorption of air pollutants, resulting in avoided impacts on human health and the associated economic and social costs. These are valued using UK air quality damage costs, which account for:
  - Reduced chronic mortality attributable to the impacts of air pollution.
  - Fewer hospital admissions for respiratory and cardiovascular illnesses.
  - Fewer cases of coronary heart disease, bronchitis, asthma, lung cancer, stroke, and diabetes.
  - Fewer deaths brought forward by impacts of air pollution.
- Reduced detrimental impacts on buildings and ecosystems and their associated economic and social costs. These are valued using UK air quality damage costs, which account for:
  - Reduced material damage to buildings.
  - Reduced soiling of buildings.
  - Reduced damage to ecosystems.
- Reduced wastewater treatment – trees reduce the volume of wastewater that must be treated by water companies. This benefit is valued as an avoided cost for water

companies and/or customers using regional volumetric wastewater treatment charges (see Table 7 and Table D4).

The logic chain for estimating the value of NWT across UK using i-Tree Canopy is presented in Figure 2, below.

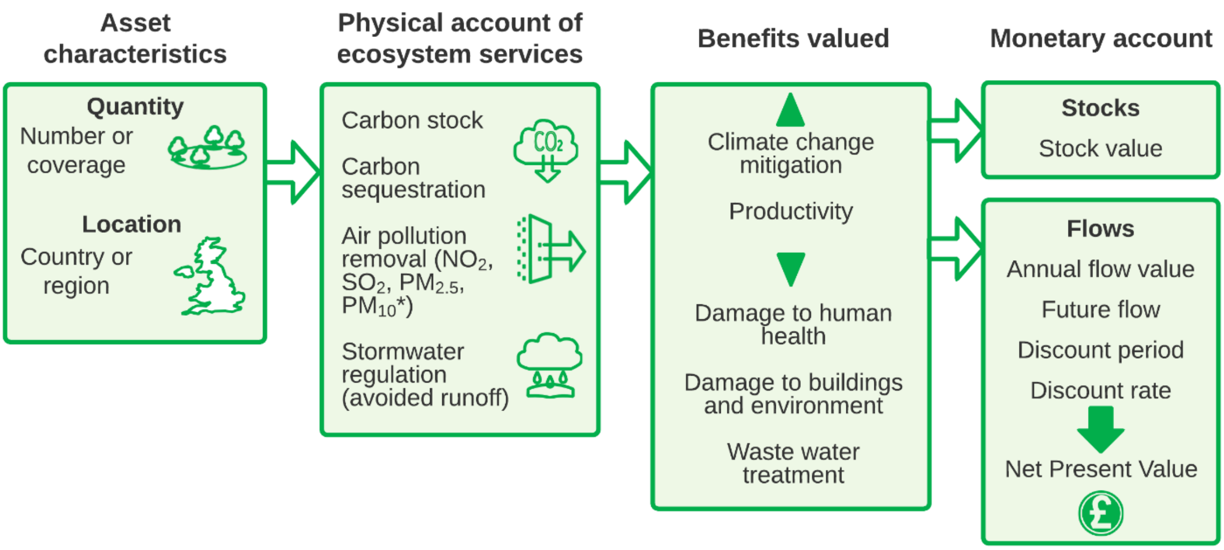

Figure 2. Logic chain for estimating the value of non-woodland trees using the i-Tree Canopy tool. Note: only those parts of the full logic chain (see Figure 1) considered within this approach are shown.

Application of the i-Tree Canopy logic chain to the valuation of non-woodland trees: i) using Forest Research's 'UK Urban Canopy Cover'

Figure 3 presents the application of the i-Tree Canopy logic chain to the valuation of the UKs non-woodland tree using data from Forest Research's 'UK Urban Canopy Cover' web map (NB. the project data set includes urban and rural).

Logic chain step	i-Tree Canopy Valuation of Non-Woodland Trees
1a. Asset quantity	Regional and UK extents of Total tree canopy cover (TTCC), Woodland Canopy cover (WCC) and Non-woodland tree (NWT) coverage are given in Table 1. **Uncertainty**: Uncertainty in ward level estimates is reported as standard error of the mean by i-Tree Canopy. Regional and national uncertainties, estimated from first principles using ward level data, propagate into relative uncertainties ranging from 0.4% to 13.9%. Details are presented in Appendix D. Uncertainties for woodland canopy cover at regional and national scales are reported in Forestry Commission (2017). **Assumption 1**: Non-woodland canopy cover is equal to Total tree canopy cover minus Woodland canopy cover. **Assumption 2**: Raw ward-level data can be extrapolated to region and country scales (i.e., tree canopy cover of assessed wards is representative of unassessed wards). **Assumption 3**: NFI woodland coverage is unchanged since publication.
1b. Location	Non-woodland canopy cover has been calculated for each NFI region so that regionally specific unit factors and values can be applied in steps 2 to 4. National numbers were calculated by summing regional numbers.

Figure 3. Partial logic chain for estimating the value of non-woodland trees across GB using the Forest Research web map and the i-Tree Canopy tool. The logic chain ends at Step 1.

Differences in the i-Tree Canopy and TCOW methodologies for the quantification of canopy cover (see Appendix D) result in negative numbers in estimated non-woodland canopy cover in Scotland and Wales, and an English region (Table 1). Consequently, the web map-derived Step 1: Asset characteristics cannot be meaningfully carried forward in the logic chain and the valuation terminates.

Table 1. Asset quantity and location: Total, woodland, and non-woodland canopy cover data (urban plus rural) derived from NFI and the web map.

Country	Region	Urban plus rural total tree canopy cover (000 ha)[1]	Urban plus rural woodland tree canopy cover (000 ha)[2]	Urban plus rural non-woodland tree canopy cover (000 ha)[3]
England	North West England	220	120	100
	North East England	96	117	-21
	Yorkshire and the Humber	205	117	87
	East Midlands	192	101	91
	East England	226	156	69
	South East and London	429	333	96
	South West England	326	266	60
	West Midlands	198	126	72
	(Whole)	**1,893**	**1,336**	**556**
Scotland	North Scotland	154	237	-84
	North East Scotland	226	237	-11
	East Scotland	135	140	-6
	South Scotland	322	435	-114
	West Scotland	350	379	-30
	(Whole)	**1,185**	**1,429**	**-244**
Wales		**308**	**309**	**-1**
Northern Ireland		**159**	**119***	**40**
GB[a]		**3,386**	**3,075**	**312**
UK[b]		**3,545**	**3,194**	**352**

[1] Forest Research Tree Canopy Cover web map (48% combined urban and rural coverage, August 2021). https://www.forestresearch.gov.uk/research/i-tree-eco/urbancanopycover/
[2] Forestry Commission (2017). Tree Cover Outside Woodland in Great Britain (2017) - Statistical Report. Combined urban and rural coverage.
[3] This study. Combined urban and rural coverage.
* Forest Research (2021). Forestry Statistics 2021. Combined urban and rural coverage. https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2021/
[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Application of the i-Tree Canopy logic chain to the valuation of non-woodland trees: ii) using NFI's Tree Cover Outside of Woodland

The NFI's TCOW report provides regional non-woodland tree canopy cover estimates for GB (Forestry Commission, 2017). Figure 4 presents the application of the i-Tree Canopy logic chain to the valuation of NWT using the NFI's TCOW.

Logic chain step	i-Tree Canopy Valuation of Non-Woodland Trees
1a. Asset quantity	See Figure 4 for regional and GB NWT combined urban and rural coverage (hectares), including respective uncertainties. Estimates for NWT coverage of Northern Ireland are derived from Northern Ireland woodland coverage, and the proportion of GB NWT coverage to woodland coverage. Northern Ireland estimates of NWT coverage are combined with GB data for an estimate of UK NWT coverage. **Assumption 1**: NFI's NWT coverage remains unchanged since the data were recorded. **Assumption 2**: Northern Ireland estimates of NWT coverage can be reasonably assumed using the proportion of GB NW-to-woodland coverage.
1b. Location	Non-woodland canopy cover is provided for NFI regions as well as for countries, so regionally specific unit factors and values can be applied in Steps 2 to 4 of the logic chain. **Assumption 3**: i-Tree Secondary Partitions can be matched to NFI regions so that regionally specific unit factors can be applied. The overlap between NFI regions and i-Tree Secondary Partitions is imperfect but sufficient to enable the calculations. Details are presented in Appendix D.
2. Physical account of ecosystem services	The ES considered were: - Carbon stock (tonnes CO_2e per hectare) - Carbon sequestration (tonnes CO_2e per hectare per year) - Air pollution removal, for NO_2, SO_2, $PM_{2.5}$, and PM_{10}* (PM_{10} – $PM_{2.5}$) (grams per hectare per year) - Avoided runoff (stormwater regulation) (m^3 per hectare per year) Regionally specific physical accounts of ES were estimated by multiplying hectares of non-woodland canopy cover (Step 1 output) by the unit factor for each ES (unit factors are presented in Table 3 and Table 4). See Table 5 for the ES provided by NWT at regional and country scale. **Uncertainties.** Uncertainty estimates associated with ES provision unit factors are unavailable. Relative standard errors in stocks and flows of ES are the same as those given in Step 1. **Assumption 4**: Air pollution removal unit price assumed equal for all regions. **Assumption 5**: Carbon unit price assumed to be equal for in all regions. **Assumption 6**: For avoided runoff (stormwater regulation) the unit price is the standard domestic volumetric wastewater treatment cost, charged per cubic metre. Typically, one water treatment company predominated a region, so their unit price was used. Where two companies co-dominated a region, an average unit price was calculated. **Assumption 7:** Avoided runoff unit factors were not available for all i-Tree Secondary Partitions. Met Office UK climate averages were used to find the closest match in annual rainfall. Details are presented in Appendix D.

3. Benefits valued	The benefits valued are: - Climate change mitigation (through carbon stock and sequestration). Valued using UK value of greenhouse gas emissions for policy appraisal, which represents the monetary value that society places on one tonne of carbon dioxide equivalent. - Reduction in allergy, respiratory, and cardio-vascular stress; reduction in morbidity; reduction in damage to buildings and environment; increase in productivity. UK air quality damage costs account for impacts on human health, productivity, wellbeing, and the environment resulting from small changes in pollutant emissions. - Avoided wastewater treatment. **Assumption 8**: The benefit of avoided stormwater runoff is the avoided cost of treating wastewater, as it was not possible to value avoided damage, injury, or disruption from floods (through avoided runoff).
4. Monetary account	Annual values of ES provided by NWT are estimated by multiplying the physical account of ES (Step 2 output, Table 5) by unit values for each respective benefit. See Table 6 and Table 7 for GB and regional unit values. See Table 8 for stock and annual flow values of ES and benefits. **Uncertainties**: No additional sources of uncertainty have been quantified at this step. Relative standard errors in values are as given in Step 1. **Natural Capital Values** Natural Capital values were estimated for ES benefit flows using the Net Present Value approach recommended for UK Natural Capital Valuation (Office for National Statistics, 2020a). **Assumption 9**: The future flow of services is assumed to be unchanged from the present estimated value, so the same unit factor is used for each year of calculation. **Assumption 10**: The value of greenhouse gas emissions for policy appraisal (£ per tonne CO_2e) is calculated for all years from 2020 to 2050. Post-2050 values are calculated by applying an annual growth rate of 1.5% starting at the most recently published value for 2050 (BEIS, 2021). See Table 9 for Natural Capital values.

Figure 4. Completed logic chain for estimating the value of non-woodland trees across GB using for NFI NWT data and i-Tree Canopy. Assumptions and uncertainties are stated step.

Table 2. Step 1 Output: Asset quantity and location: Combined urban and rural non-woodland canopy cover from NFI.

Country	Region	Urban plus rural non-woodland canopy cover (000's ha)	Relative Standard Error (%)
England	North West England	51.4	6
	North East England	21.4	9
	Yorkshire and the Humber	43.9	8
	East Midlands	57.0	6
	East England	80.4	6
	South East and London	123.8	6
	South West England	113.0	7
	West Midlands	74.2	8
	(Whole)	**565.0**	**5**
Scotland	North Scotland	10.8	42
	North East Scotland	13.0	23
	East Scotland	19.6	28
	South Scotland	34.3	14
	West Scotland	6.9	28
	(Whole)	**84.5**	**13**
Wales		**92.7**	**7**
Northern Ireland[a]		**31.1**	**5**
GB[b]		**742.3**	**5**
UK[c]		**773.4**	**5**

[a] Northern Ireland NWT coverage estimated through GB proportion of NWT coverage to woodland coverage.
[b] sum of England (whole); Scotland (whole); Wales.
[c] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

The precision of NWT estimates (Forestry Commission, 2017) are given in percentages as relative standard errors. The high relative standard errors for Scotland and regions in Scotland are the result of the underlying spatial data (details are presented in Appendix D).

Table 3. Step 2: UK-wide unit factors used in the i-Tree Canopy tool.

Ecosystem service	i-Tree Canopy unit factors
Carbon storage (tonne CO_2e per ha)	281.776
Carbon sequestration (tonne CO_2e per ha per year)	11.2

Table 4. Step 2: Regional unit factors used in i-Tree Canopy tool.

		i-Tree Canopy unit factors#				
Country	**Region**	NO_2 removal (tonnes per ha per year)	SO_2 removal (tonnes per ha per year)	$PM_{2.5}$ removal (tonnes per ha per year)	PM_{10}* removal (tonnes per ha per year)	Avoided runoff (m^3 per ha per year)
England	N.W. England	0.033	0.004	0.00005	0.024	301
	N.E. England	0.028	0.008	0.00005	0.018	223
	Yorkshire & Humber	0.029	0.005	0.006	0.022	223
	E. Midlands	0.024	0.004	0.005	0.021	196
	E. England	0.026	0.003	0.010	0.016	313
	S.E. & London	0.034	0.005	0.002	0.024	195
	S.W. England	0.020	0.003	0.006	0.020	261
	W. Midlands	0.028	0.002	0.007	0.014	285
Scotland	N. Scotland	0.043	0.005	0.0001	0.024	301
	N.E. Scotland	0.043	0.005	0.0001	0.024	301
	E. Scotland	0.043	0.005	0.0001	0.024	301
	S. Scotland	0.032	0.004	0.0001	0.017	301
	W. Scotland	0.043	0.005	0.0001	0.024	301
Wales		0.027	0.007	0.019	0.027	386
Northern Ireland		0.060	0.002	0.005	0.036	361

Regional unit factors are averages of i-Tree Canopy factors for NFI regions. i-Tree Canopy unit factors were provided in a personal communication from i-Tree support on 21st May 2021 consortium. See Table D3 in Appendix D for source data and references.

Table 5. Step 2 Output: Physical account of ecosystem services provided by the urban plus rural non-woodland trees of GB, estimated using NFI NWT data and i-Tree Canopy unit factors.

		Physical account of ecosystem services			
Country	Region	Carbon stock (million tonnes CO_2e)	Carbon sequestration (thousand tonnes CO_2e per year)	Air pollution removal (thousand tonnes per year)	Avoided runoff (million m^3 per year)
England	North West England	14.5	576.6	3.2	15.5
	North East England	6.0	240.5	1.2	4.8
	Yorkshire and the Humber	12.4	492.6	2.7	9.8
	East Midlands	16.1	639.2	3.1	11.2
	East England	22.7	902.3	4.4	25.1
	South East and London	34.9	1,388.6	8.0	24.1
	South West England	31.8	1,267.6	5.5	29.5
	West Midlands	20.9	832.4	3.7	21.1
	(Whole)	**159.2**	**6,339.8**	**31.8**	**141.0**
Scotland	North Scotland	3.0	121.4	0.8	3.3
	North East Scotland	3.6	145.3	0.9	3.9
	East Scotland	5.5	219.4	1.4	5.9
	South Scotland	9.7	384.5	1.8	10.3
	West Scotland	2.0	77.9	0.5	2.1
	(Whole)	**23.8**	**948.4**	**5.4**	**25.5**
Wales		**26.1**	**1,040.0**	**7.4**	**35.8**
Northern Ireland		**8.8**	**348.9**	**3.2**	**11.2**
GB[a]		**209.2**	**8,328.2**	**44.7**	**202.3**
UK[b]		**217.9**	**8,677.2**	**47.9**	**213.5**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Table 6. Step 4: GB-wide unit values used in the i-Tree Canopy tool.

Ecosystem service	i-Tree Canopy unit values (£ per tonne)
Carbon storage (stock) and sequestration (as CO_2e)	241 *
NO_2 removal	6,385 #
SO_2 removal	13,026 #
$PM_{2.5}$ removal	73,403 #
PM_{10}* removal	52,176 #

* Department for Business, Energy & Industrial Strategy (2021). Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal; Table 3; 2020 values. Available at: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal.

Department for Environment Food & Rural Affairs (2021). Air quality appraisal: damage cost guidance; Table 10; 2020 values. Available at: https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance.

Table 7. Step 4: Regional unit values (in 2021 prices) used in i-Tree Canopy tool.

Country	Region	Avoided runoff unit value (£ per m^3 avoided wastewater)*
England	N.W. England	1.12
	N.E. England	0.80
	Yorkshire & Humber	1.66
	E. Midlands	0.98
	E. England	1.57
	S.E. & London	2.05
	S.W. England	2.22
	W. Midlands	0.98
Scotland	N. Scotland	1.53
	N.E. Scotland	1.53
	E. Scotland	1.53
	S. Scotland	1.53
	W. Scotland	1.53
Wales		1.52
Northern Ireland		1.87

* Unit values are average volumetric wastewater treatment charges for NFI regions. See Table D4 in Appendix D for source data and references.

Table 8. Step 4a Output: Stock and annual flow values (in 2020 prices) of ecosystem service benefits provided by urban plus rural non-woodland trees, estimated using NFI NWT data and i-Tree Canopy tool.

		Stock (£ million)	Annual flows (£ million per year)			
Country	**Region**	**Carbon stock**	**Carbon Sequestration**	**Air pollution removal**	**Avoided runoff**	**Total**
England	North West England	3,490	139	79	17	235
	North East England	1,456	58	26	4	88
	Yorkshire and the Humber	2,981	119	81	16	216
	East Midlands	3,869	154	96	11	261
	East England	5,461	217	144	39	400
	South East and London	8,405	335	206	49	590
	South West England	7,672	305	185	65	555
	West Midlands	5,038	201	105	21	327
	(Whole)	**38,371**	**1,528**	**922**	**222**	**2,672**
Scotland	North Scotland	735	29	17	5	51
	North East Scotland	880	35	21	6	62
	East Scotland	1,328	53	31	9	93
	South Scotland	2,327	93	39	16	148
	West Scotland	471	19	11	3	33
	(Whole)	**5,740**	**229**	**119**	**39**	**387**
Wales		**6,295**	**251**	**282**	**54**	**587**
Northern Ireland		**2,112**	**84**	**82**	**21**	**187**
GB[a]		**50,406**	**2,007**	**1,323**	**317**	**3,647**
UK[b]		**52,518**	**2,091**	**1,405**	**338**	**3,834**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Table 9 presents the regional and national natural capital values for the three ES benefit flows quantified and valued by the i-Tree Canopy tool, estimated using NFI NWT data (Forestry Commission, 2017).

Table 9. Step 4b Output: Regional and national Natural Capital values (2020 prices) for a range of ecosystem service benefit flows estimated using i-Tree Canopy tool and NFI urban plus rural NWT data.

Country	Region	Natural Capital Values (£ million)			
		Carbon Sequestration	Air pollution removal	Rainfall interception	Total
England	North West England	6,665	2,350	519	9,534
	North East England	2,781	779	114	3,674
	Yorkshire and the Humber	5,694	2,405	485	8,584
	East Midlands	7,389	2,855	327	10,571
	East England	10,431	4,284	737	15,452
	South East and London	16,052	6,150	1,468	23,670
	South West England	14,653	5,524	1,951	22,128
	West Midlands	9,622	3,126	619	13,367
	(Whole)	**73,287**	**27,473**	**6,220**	**106,980**
Scotland	North Scotland	1,403	511	149	2,063
	North East Scotland	1,680	612	178	2,470
	East Scotland	2,536	924	269	3,729
	South Scotland	4,445	1,164	472	6,081
	West Scotland	900	328	96	1,324
	(Whole)	**10,964**	**3,539**	**1,164**	**15,667**
Wales		**12,022**	**8,419**	**1,268**	**21,709**
Northern Ireland		**4,034**	**2,456**	**624**	**7,114**
GB[a]		**96,275**	**39,431**	**8,652**	**144,358**
UK[b]		**100,309**	**41,887**	**9,276**	**151,472**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

i-Tree Canopy discussion

Challenges

- The canopy cover web map and the NFI account of woodlands and trees outside woodlands use different methods to estimate tree coverage (see Appendix D for details), making it impractical to subtract woodland tree cover from total tree cover from the web map as planned.

Opportunities

- The web map coverage for the UK is 48% at the time of writing. As the citizen science project progresses coverage will improve and with it our knowledge of tree canopy cover, which will improve the accuracy of the assessment of extent of non-woodland tree cover.
- The canopy cover web map includes canopy cover assessment in Northern Ireland, which is not available in the NFI report (Forestry Commission 2017), which could enable a UK-wide natural capital valuation using this tool.
- i-Tree Canopy can be used to estimate separate non-woodland canopy cover for lone trees, lines of trees, trees in hedgerows, groups of trees, and small woods, to enable an estimate of the extent of these features in addition to the NFI assessment (Forestry Commission, 2017) and comparison of the ES provision by these different non-woodland features.
- Data from the web map can be used as an alternative to NFI data to disaggregate rural and urban canopy cover in regions and countries.
- Incorporation of local, recent i-Tree Eco data into this tool to calculate ES provision unit factors would further enhance the regional specificity of the valuations.
- Electoral ward level calculations of non-woodland tree coverage using either the web map data or the NFI NWT data are possible.

Tool 2: CAVAT

CAVAT (Capital Asset Value for Amenity Trees) is an expert-based amenity tree valuation tool; it is a depreciated replacement cost (DRC) method of valuation. DRC is used when there is no active market for the asset being valued and when it is impractical to use other methods (RICS, 2018). The CAVAT practitioner calculates the cost of replacing a tree with a theoretical ideal specimen of the same stem diameter (known as the modern equivalent asset), and then reduces and/or increases that cost according to the visibility of the tree to people, the suitability of the tree to its setting, its condition, and its life expectancy. The final number represents the cost of replacing the actual asset, which is an accepted method of estimating its value to a community (Doick et al., 2018; RICS, 2018). CAVAT has been critically examined, including i) whether CAVAT fully accounts for depreciation

(RICS, 2010) as required to determine the replacement cost of an asset (Hollis, 2009), and ii) whether the need for expert judgement complies with Green Book guidance for estimating value (Binner et al., 2017). Redress to these concerns has been subsequently published (Doick et al., 2018).

The CAVAT methodology comprises both the Full Method and the Quick Method. The Full Method has been used in the UK by local authorities to gain compensation from developers, insurance losses, and out-of-court settlements (Doick et al., 2018). The Quick Method is used by some local planning authorities as a management tool to define an asset value of their tree stock. Approximately one-third to half of all local planning authorities use at least one of the CAVAT Methods in the management of their trees (Vaz Monteiro and Doick, 2019).

The benefits valued using this tool are defined as follows:

- **Amenity** – benefits derived from the positive elements that urban NWT contribute to overall character or enjoyment of an area (Planning Portal, 2021).

The logic chain for estimating the value of NWT using CAVAT is shown in Figure 5. CAVAT values amenity services and the benefits pertaining from them in aggregate, rather than as individual ES and benefits. The logic chain reflects this.

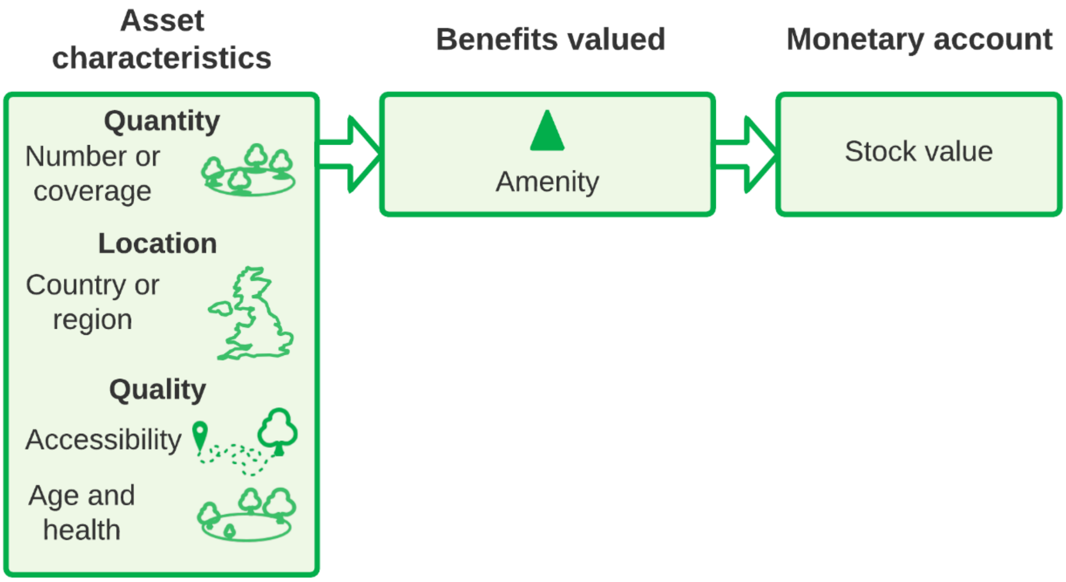

Figure 5. Logic chain for estimating the value of non-woodland trees using CAVAT. Note: CAVAT values trees based on their amenity, which is poorly defined. The ecosystem services and benefits here are indicative, only. Only those parts of the full logic chain (see Figure 1) considered within this approach are shown.

Application of the CAVAT logic chain to the valuation of non-woodland trees

CAVAT valuations were taken from 20 reports of plot-based i-Tree Eco surveys in towns, cities, and regions in GB which include the:

- Total CAVAT value for each urban forest,
- Estimated total number of trees in each urban forest and, either
- Total tree coverage in hectares, or
- Tree cover percentage and total study area (from which total tree cover area was determined).
  (The urban forest is defined as "all the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem" Davies et al., 2017).

The total CAVAT value for each urban forest was divided by the total tree cover in hectares to give a CAVAT value per hectare of urban trees (see Table E1 in Appendix E). These values were averaged within NFI regions of GB to give a single CAVAT unit value for each region (see Table 11). CAVAT unit values were multiplied by hectares of urban NWT to arrive at a total CAVAT value for each region.

Figure 6 presents the application of the CAVAT logic chain to the valuation of GBs urban NWT using NFI NWT coverage data (Forestry Commission, 2017).

Full details of the data and methodology used in this tool are given in Appendix E.

Logic chain step	CAVAT Valuation of non-woodland trees
1a. Asset quantity	See Table 10 for regional and GB urban non-woodland canopy cover (hectares) data, including respective uncertainties. **Assumption 1**: NWT coverage unchanged since reported in 2017. See discussion in Appendix E for details of the data and methodology.
1b. Asset Location	Non-woodland canopy cover is provided for NFI regions as well as for countries, so regionally specific values can be applied in steps 2 to 4. Regionally specific CAVAT unit values are applied where available. Where there is no data for an NFI region, the mean CAVAT unit value is used.
1c. Asset Quality	The CAVAT amended Full Method accounts for accessibility. The Quick method does not. Both methods account for tree age and health through the Life Expectancy and Functionality assessments. See Appendix E for details. **Assumption 2:** CAVAT unit values estimated from a mix of CAVAT methods can be applied in this logic chain.
2.	The ES considered were: - Amenity (e.g., experiences, recreation, aesthetic appeal).

Physical account of ecosystem services	This ES was not quantified. Rather, the value of the benefits was estimated directly in Step 4 by multiplying hectares of non-woodland canopy cover by the CAVAT unit value. See Appendix E for unit factors. **Uncertainties** No information about uncertainties associated with unit factors for ES provision is available at the time of writing. Relative standard errors in stocks and flows of ES are the same as those given in Step 1.
3. Benefits valued	Values were applied to benefits derived from the ES. The benefit valued is: Amenity (positive attributes contributed to an area e.g., sense of place, sense of history, improved mental health).
4. Monetary account	Annual values of benefits from ES provided by urban NWT are estimated by multiplying the regional physical account of the asset (Table 10) by regional CAVAT unit values for the sum benefits. The CAVAT unit values applied range from £0.1 million to £4.2 million per hectare of tree cover. See Table 11 for all regional CAVAT unit values, and Table E1 in Appendix E for source data. See Table 12 for Stock Values of benefits. **Uncertainties**: No additional sources of uncertainty have been quantified at this step. Relative standard errors in values are the same as those given in Step 1. **Assumption 3:** A single CAVAT unit value has been estimated for each i-Tree Eco study. It is assumed that this average value is applicable to all trees in the study area. **Assumption 4:** Where more than one i-Tree Eco plot-based project was available for a region, the average of the project specific CAVAT unit values was determined. Where no i-Tree Eco plot-based project was available for a region, the average of all CAVAT unit values was determined. It is assumed these average values are applicable to all trees in a region or across GB. **Assumption 5:** CAVAT unit values were estimated from GB i-Tree Eco plot-based studies. The study areas include woodland and NWT. Woodland trees have not been excluded from calculations of CAVAT unit values, and it is assumed that the woodland and NWT have the same average CAVAT value for the purposes of this study. **Assumption 6:** CAVAT unit values were estimated from i-Tree Eco reports that used both the amended Full and Quick methods. No changes have been made to the unit values to account for these differences.

Figure 6. (above) Completed logic chain for valuation of non-woodland trees using CAVAT and NFI non-woodland tree data.

Table 10. Step 1 Output: Asset quantity by location, from NFI.

Country	Region	Urban non-woodland canopy cover (000's ha)	Relative Standard Error (%)
England	North West England	15.6	14
	North East England	5.2	15
	Yorkshire and the Humber	10.8	15
	East Midlands	15.1	12
	East England	29.1	11
	South East and London	42.4	13
	South West England	15.9	18
	West Midlands	15.9	12
	(Whole)	**150.0**	**11**
Scotland	North Scotland	-	-
	North East Scotland	2.1	43
	East Scotland	3.2	29
	South Scotland	6.0	24
	West Scotland	2.1	51
	(Whole)	**13.5**	**18**
Wales		**32.8**	**14**
GB[a]		**196.3**	**10**

[a] sum of England (whole); Scotland (whole); Wales

Table 11. CAVAT unit values.

Country	Region	CAVAT unit value (£ million per ha canopy cover)
England	North West England	1.2
	North East England	2.2
	Yorkshire and the Humber	1.4
	East Midlands	2.2
	East England	1.9
	South East and London	3.3
	South West England	0.7
	West Midlands	2.8
Scotland	North Scotland	1.5
	North East Scotland	1.5
	East Scotland	1.5
	South Scotland	1.5
	West Scotland	1.5
Wales		2.4

Table 12. Step 4 Output: Stock values (2020) using regional and national CAVAT valuations of urban non-woodland trees. Uncertainties are calculated from the relative standard error in NWT coverage (see Table 10).

Country	Region	CAVAT values (£ million)	Uncertainty (£ million)
England	North West England	18,023	2,487
	North East England	11,673	1,763
	Yorkshire and the Humber	14,972	2,259
	East Midlands	33,857	4,218
	East England	55,603	5,929
	South East and London	141,068	18,513
	South West England	10,472	1,833
	West Midlands	43,800	5,473
	(Whole)	**329,468**	**21,057**
Scotland	North Scotland	-	-
	North East Scotland	3,279	1,425
	East Scotland	4,921	1,431
	South Scotland	9,310	2,259
	West Scotland	3,275	1,656
	(Whole)	**20,785**	**3,453**
Wales		**78,657**	**10,789**
GB[a]		**428,910**	**23,911**

[a] sum of England (whole); Scotland (whole); Wales

CAVAT discussion

Challenges

- Amenity is poorly defined and therefore difficult to measure and to value. CAVAT approaches valuation of amenity trees by beginning with a base value of a subject tree and increasing or decreasing that value to account for the local population density, condition and life expectancy of the tree, its appropriateness to its setting, and its visibility to people.
- The above approach excludes quantification of the ES benefits that flow from the subject tree, or valuation of the benefits that result from those services.
- CAVAT unit values vary between i-Tree Eco projects. Using average unit values disguises the variation in value between locations. CAVAT values are notably greater for large trees, in good condition, yet urban forests have in the region of 50% of trees in small-size categories (Vaz Monteiro et al., 2019). Consequently, the average CAVAT value per tree is a few thousand pounds. (The CAVAT value of a large tree in good condition can be tens- or hundreds- of thousands of pounds).

- CAVAT valuation source data is currently limited to what is reported in i-Tree Eco plot-based projects and are not available for all UK regions.

Opportunities

- Woodland trees could be excluded from i-Tree Eco data to compute CAVAT unit values that are specific to NWT.
- Population projections can be used to estimate future Community Tree Index (CTI) factors. Economic projections can be used to estimate future Unit Value Factors (UVF). These factors would enable future projections of CAVAT values of NWT.
- CAVAT is used by local authorities and tree professionals to value amenity trees across the UK, outside the bounds of i-Tree Eco projects. Creating a database of these CAVAT values would enable calculation of more accurate and representative CAVAT unit values for more regions. It would also be possible to distinguish between woodland and non-woodland, urban and rural trees, and trees in different spatial arrangements or typologies using this approach.
- The valuation in this work and any of the above opportunities would be strengthened by an increased number of i-Tree Eco projects, as well as at least one per region.

Tool 3: Woodland NCA methodologies

Natural Capital Accounting (NCA) is an approach increasingly used by governments to monitor and value the environment by integrating information about natural assets into a general decision making and management framework encompassing benefits to society, based on similar lines to conventional national economic accounts. In the UK, work on Natural Capital Accounting (NCA) in government is led by the Office for National Statistics (ONS), the Department for Environment, Food & Rural Affairs (Defra), and corresponding bodies within the devolved administrations.

This study draws upon the most recent publications on NCA for woodlands (ONS, 2020b; ONS, 2020c). A benefit transfer approach is adopted based upon transferring values estimated for woodlands on a per hectare basis to NWT. The following logic chain, Figure 7 describes an overview of these steps. Figure 8 presents the full application of the woodland NCA logic chain to the valuation of GBs NWT using NFI NWT coverage (Forestry Commission, 2017) data, with limitations and assumptions considered at each step. For an alternative presentation of the following logic chain, see Appendix F.

Ecosystem services quantified using the NCA methodology are based on per hectare ES provision (hereafter: unit factors) calculated by dividing the total ES provision by woodland assets by the area of the asset in hectares.

The ES quantified using this tool are defined as follows:

- **Carbon sequestration** – mass of carbon (as CO_2e) absorbed annually by urban and rural NWT. Carbon sequestration was calculated for woodland trees in the UK and the unit factor applied to urban and rural NWT. Carbon stock change for GB woods (>0.5 ha) and trees outside woodlands (0.1–0.5 ha), and for Northern Ireland woods was estimated using the Forest Research CARBINE model, based on planting history, productivity, and assumptions about forest management (Ricardo, 2019b).

- **Air pollution removal** – masses of NO_2, O_3, NH_3, $PM_{2.5}$ and PM_{10} absorbed annually by urban and rural NWT. These were calculated for woodland cover, based on the Centre for Ecology and Hydrology Landcover map, using the EMEP4UK atmospheric chemistry and transport model, which models pollutant concentrations using emissions, transport, deposition, meteorology and pollutant interactions on a 5 km grid. Pollution removal was calculated by comparing model runs with and without vegetation (CEH, 2017).

- **Flood mitigation** – volume (m^3) of floodwater prevented by presence of rural NWT. Flood regulation by existing GB woodland was calculated using the Joint UK Land Environment Simulator (JULES) model. Volumes of flood water used and retained by trees and soils in woodland within flood risk catchments were compared to volumes with a baseline cover of short grass (Broadmeadow et al., 2018).

- **Temperature regulation** – degree Celsius cooling per hectare of urban small woods and groups of trees. The cooling effect of urban woodlands was calculated based on an evidence review of UK studies involving field measurements of cooling effects, and was applied to a temperature map of the UK divided into 1 km grid cells. Aggregated cooling effects for the study cities were calculated from the map (Eftec, 2018a).

- **Noise abatement** – number of buildings benefitting from noise abatement by urban small woods. The reduction of noise from major roads (based on spatial noise data for England, Scotland, and Wales) was modelled using a 2 dB reduction effect for large woodlands (>3,000 m^2) and a 1 dB reduction effect for smaller woodlands (<3,000 m^2). Areas of woodland were calculated from Ordnance Survey Master Map (OSMM), National Tree Map data, and CEH Landcover Map data. The number of buildings benefiting from the 2 and 1 dB effects was calculated using OSMM data (Eftec, 2018b).

The benefits valued in using this tool are defined as follows (note that health benefits from air pollution removal were calculated from the change in pollutant concentration, not from the change in emission):

- Climate change mitigation – ongoing carbon sequestration by trees, valued using the UK value of greenhouse gas emissions for policy appraisal (BEIS, 2021).
- Reduced detrimental impacts on human health – the continued presence of trees represents ongoing absorption of air pollutants, resulting in avoided impacts on human health and the associated economic and social costs. These are valued using health response functions , which account for:
    - Reduced chronic mortality attributable to the impacts of air pollution.
    - Fewer hospital admissions for respiratory and cardiovascular illnesses.
    - Fewer cases of coronary heart disease, bronchitis, asthma, lung cancer, stroke, and diabetes.
    - Fewer deaths brought forward by impacts of air pollution.
- Avoided loss of producitivity attributable to urban cooling – valued as avoided loss of GVA that would have been lost due to additional heat stress in the absense of the cooling effect (Eftec, 2018a).
- Reduced damage, injury, and disruption from floods – valued as the cost per m^3 of replacing the flood storage service provided by trees with built flood storage reservoirs (Broadmeadow et al., 2018).
- Reduced energy consumption for air conditioning – valued as cost savings, based on a literature value for London applied to study cities based on the relative proportion of their air conditioned floor space to London's (Eftec, 2018a).
- Improved amenity (avoided sleep disturbance and annoyance) and health outcomes from noise mitigation – valued using avoided loss of quality adjusted life years (QALYs) (Eftec, 2018b).

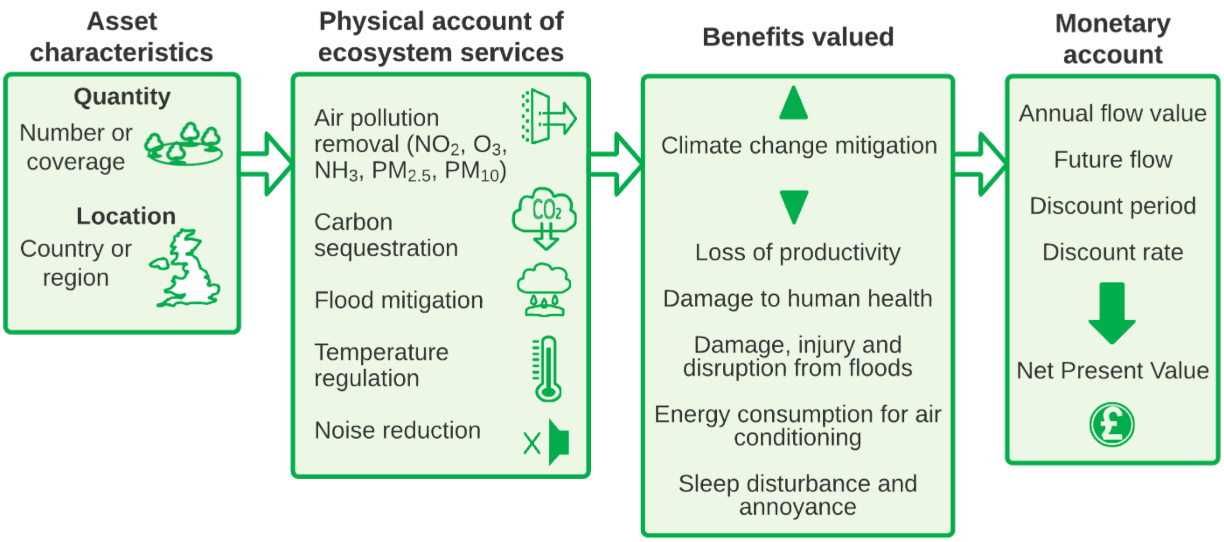

Figure 7. Logic chain for estimating the value of non-woodland trees using UK woodland NCA Benefit Transfer approach.

Logic chain step	UK Woodland NCA Benefit Transfer approach for Non-Woodland Trees
1a. Asset quantity	See Table 13 for NWT coverage by rural and urban land area. Estimates for NWT coverage of Northern Ireland are derived from the proportion of GB NWT coverage to woodland coverage. Northern Ireland estimates of NWT coverage are combined with GB data for an estimate of UK NWT coverage. **Assumption 1**: NWT coverage was the same level in 2020 as that reported above in Forestry Commission data for January 2016 (Forestry Commission, 2017). **Assumption 2**: Northern Ireland estimates of NWT coverage can be reasonably assumed using the proportion of GB NWT coverage to woodland coverage. See Table 14 for the different woodland areas upon which woodland NCA estimates are based for different ES. **Assumption 3**: Tree coverage is accurate and representative for each ES. Note: woodland cover maps used for NCA calculations differ between ES (i.e., 2016 coverage map used for carbon sequestration, 2007 coverage map used for air pollution).
1b. Location	Non-woodland canopy cover is available for NFI regions, countries, as well as for rural and urban land cover. NWT land cover data used for the different ES is as follows: Carbon sequestration – **Total** NWT Cover. Air pollution - **Total** NWT Cover.

Temperature regulation - **Urban** NWT Cover (Small woods and groups of trees, lone trees excluded).
Noise reduction - **Urban** NWT Cover (Small woods only, groups of trees and lone trees excluded).
Flood mitigation - **Rural** NWT Cover.

Assumption 4: NFI dataset coverage adequately represents the scope of NWT coverage for each ES.

Some limitations are present, including the lack of data on NWT coverage in flood-risk catchment areas.

Assumption 5: the unit factor for flood mitigation by NWT coverage is equal to the 10.53 m^3 per ha per year for woodland coverage (see Table 15) (Note: 97% of woodland cover in flood risk catchments occurs in rural areas).

Woodland NCA methodologies solely account for urban trees in their noise mitigation and temperature regulation calculations (see Table 14). Further adjustments are made to NFI NWT urban tree data to improve estimates. The effects of smaller woodlands are not accounted for in either set of woodland NCA calculations. This issue is exacerbated particularly within noise mitigation, where larger woodlands produce a proportionally greater effect. Rather than exclude these ES entirely from NWT estimates, tentative values are provided accounting for NWT small woodlands. In the case of NWT temperature regulation estimates, groups of trees are also accounted for, as the woodland NCA methodology likely underestimates the overall effect with the absence of locally felt shading effects within the model. This could be a significant element for the cooling effects of trees.

2. Physical account of ecosystem services

The ES considered from woodland NCAs were:

- Carbon sequestration (tonnes CO_2e per hectare).
- Air pollution removal (tonnes of pollutant removal per hectare).
- Temperature regulation (degree Celsius cooling per hectare).
- Noise reduction (number of buildings benefiting from noise mitigation per hectare).
- Flood mitigation (m^3 per hectare).

Physical ES flows were estimated in each case by multiplying the physical unit factor per hectare by the relevant area of NWT cover. Table 15 shows the physical unit factor applied for each ES. Table 16 provides estimates of physical ES flows provide by NWT broken down by country and (except for flood risk attenuation, temperature regulation and noise reduction) by region.

Notes: As flood mitigation is based on rural NWT coverage, regional data is unavailable. Similarly, for temperature regulation and noise reduction, estimates were only available at country level, or partial regional. Therefore, only country level estimates were produced for these services.

Uncertainties. The woodland NCAs methodologies remain under development. This is especially the case for noise reduction and temperature regulation, for which novel methodologies were introduced as

	part of the first Urban NCA (2018) and included in the latest woodland NCAs (2020); these are subject to limitations. Further details on uncertainties involved in woodland NCA estimates can be found in the methodology guide: [Woodland natural capital accounts, UK - Office for National Statistics (ons.gov.uk).]() Further, the methodologies require income and population growth uplift to be applied to the air pollution removal benefit. **Assumption 6:** Unit factors are assumed to be equal in all regions. **Assumption 7:** ES provision per ha by NWT is assumed to be equal to that of woodlands. **Assumption 8:** population growth assumed to follow the ONS projections. For some ESs, the effects of woodlands as modelled by woodland NCA methodologies likely operate in a similar magnitude per ha to NWT (carbon sequestration). For other ESs, effects may be underestimated, with NWT potentially producing greater benefit per ha than woodlands (flood mitigation). For noise reduction and cooling the woodland NCA methodology may overestimate the benefits provided by NWT owing to the likely larger effect provided by larger areas of trees. To minimise the potential impact of this overestimation, only urban small woods and urban groups of trees were included in the temperature regulation calculation, and only urban small woods were included in the noise reduction calculation. Permanence is a key issue in valuing carbon sequestration benefits (Valatin and Starling, 2011). **Assumption 9:** Planting of NWT continues at a sufficient rate that the carbon sequestered annually is stored permanently (i.e., represents a net increase in the carbon stock that is sustained over the long-term), rather than being temporary (i.e., and subsequently re-emitted to the atmosphere as part of the normal life cycle of NWT).
3. Benefits valued	The benefits valued are: - Carbon sequestration (valued using UK societal price of carbon). - Air pollution removal (avoided health costs in the form of avoided deaths, avoided life years lost, fewer respiratory and cardiovascular hospital admissions). - Temperature regulation (avoided labour productivity losses and reduced air conditioning costs). - Noise reduction (improved amenity and health outcomes valued using QALYs). - Flood mitigation (damage, injury & disruption from floods, valued as replacement cost of flood storage service provided by trees).
4. Monetary account	The value of each of the ES provided by NWT is estimated by multiplying the quantity of physical ES by the respective monetary unit value. See Table 17 for monetary unit values. Table 18 provides stock and annual flow values for ES and Table 19 provides natural capital values.

Assumption 10: In order to calculate the unit factor and unit value for air pollution removal, we assume that all trees absorb air pollutants in the same ratio as reported in the woodland NCA. The unit value for air pollution removal can therefore be calculated by dividing the total annual value of air pollution removal by woodlands by the number of tonnes of air pollution removed. This unit value represents the mixture and ratio of air pollutants in the ONS woodland NCA, which are also represented in the unit factor.

To illustrate uncertainty ranges, sensitivity analysis is undertaken based upon the most prominent source of uncertainty reported in the woodland NCA methodology guidance for each ES. Where these are quantified, they are used to produce low, mid and high estimates for each ES. Where uncertainties are not quantified, uncertainty ranges are produced based upon NFI standard errors.

- Carbon sequestration: low, central and high estimates for societal carbon value sensitivities.
- Air pollution removal: damage cost sensitivity ranges (low, mid, high) for $PM_{2.5}$, which accounts for 97% of ES value.
- Temperature regulation: NFI NWT coverage groupings (High = small woodlands + groups of trees + lone trees, Low = only small woodlands).
- Noise reduction: welfare value of a QALY estimate ranges (low, mid, high).
- Flood mitigation: low, mid and high sensitivity ranges, based on annual flood severity.

Uncertainty ranges are presented in Table 20.

Assumption 9: Natural capital values for NWT are estimated as the net present value (NPV) over 100 years of annual ES flows based on the approach used in UK woodland NCAs. The approach recommended to estimating natural capital values associated with temperature regulation includes use of an experimental model for climate change impacts which remains under development and is not fully described. The NWT natural capital value associated with temperature regulation have not taken these effects into account, which would otherwise have increased the estimated value.

Figure 8. (above) Completed logic chain for valuation of non-woodland trees using the UK woodland NCA Benefit Transfer Approach and NFI non-woodland tree data (Forestry Commission, 2017).

Table 13. Step 1a Output. Non-woodland tree coverage by rural and urban land area.

	Small woods (000 ha)	RSE* (%)	Groups of trees (000 ha)	RSE (%)	Lone trees (000 ha)	RSE (%)	Total NWT coverage (000 ha)
England (whole)	294.8	7	192.6	6	78.2	7	565.0
Rural	238.0	8	125.2	9	52.0	6	415.1
Urban	56.8	12	67.3	13	26.2	15	150.0
Scotland (whole)	46.2	21	29.5	12	8.9	15	84.5
Rural	41.0	24	22.7	14	7.3	17	71.0
Urban	5.2	24	6.7	26	1.6	31	13.5
Wales (whole)	49.2	8	33.4	9	10.1	17	92.7
Rural	37.5	9	17.1	8	5.0	11	59.9
Urban	11.7	20	16.3	17	5.0	32	32.8
Northern Ireland (whole)[a]	16.3	-	10.9	-	3.9	-	31.1
Rural	13.0	-	6.6	-	2.4	-	22.0
Urban	3.3	-	4.3	-	1.5	-	9.1
GB[b]	390.2	36	255.5	27	97.2	39	742.3
UK[c]	406.6	-	266.1	-	101.0	-	773.4
Rural	329.5	-	171.6	-	66.7	-	568.0
Urban	77.0	-	94.6	-	34.3	-	205.4

* = Relative Standard Error.
[a] Northern Ireland NWT coverage estimated through GB proportion of NWT coverage to woodland coverage. Source: Forest Research Provisional Woodland Statistics 2021.
[b] sum of England (whole); Scotland (whole); Wales (whole).
[c] sum of England (whole); Scotland (whole); Wales (whole); Northern Ireland (whole).

Table 14. Step 1a Output. Area of woodland covered by woodland NCA Benefit Transfer Approach estimates for different ecosystem services.

Ecosystem Service	Woodland Coverage (ha)	Source	Description	Year (as used by woodland NCAs)
Carbon sequestration	3,577,000	UK Greenhouse Gas Inventory, 1990 to 2013 (defra.gov.uk)	**UK** Woodland coverage from NFI Base Map	2016
Air pollution	2,887,500	Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts	**UK** Woodland coverage based on Centre for Ecology and Hydrology Landcover map	2007
Temperature regulation	417,000	Scoping UK Urban Natural Capital Account – Local Climate Regulation Extension	**GB** Urban woodland across 11 city regions within GB, based on ONS Built-Up-Areas dataset	2011
Noise reduction	99,141	Scoping UK Urban Natural Capital Account - Noise Extension	**UK** Urban woodlands large enough to provide a form of noise mitigation, from Ordnance Survey Master Map	2011
Flood mitigation	2,465,533	Valuing flood regulation services of existing forest cover to inform natural capital accounts - Forest Research	**GB** Woodlands in flood risk catchments based on NFI data	2016

Table 15. Step 2 Output. Physical unit factors for woodland NCA Benefit Transfer Approach ecosystem services (Physical service / woodland coverage).

Ecosystem Service	Physical Unit Factor (per ha, per year)	Physical Account			Description
		Value	Year	Source	
Carbon sequestration	5.08 tCO_2e	18,163.9 ktCO2e	2016	UK Greenhouse Gas Inventory, 1990 to 2013 (defra.gov.uk)	$ktCO_2e$ of sequestration by UK woodlands
Air pollution removal	0.093 tonnes	268.72 thousand tonnes	2017	Woodland natural capital accounts, UK - Office for National Statistics (ons.gov.uk)	Thousand tonnes of pollution removed from UK woodland
Temperature regulation	0.00000058 degrees Celsius*	0.242 degrees Celsius	2018	Woodland natural capital accounts, UK - Office for National Statistics (ons.gov.uk)	Average degree Celsius cooling across 11 GB city regions from urban woodland
Noise reduction	1.68 buildings	167,000 UK buildings	2018	Woodland natural capital accounts, UK - Office for National Statistics (ons.gov.uk)	Average number of buildings benefiting from noise mitigation due to UK urban woodlands
Flood mitigation	10.53 flood storage (m^3)	25,957,871 m^3	2018	Valuing flood regulation services of existing forest cover to inform natural capital accounts - Forest Research	Equivalent flood storage (m^3) based on woodland canopy interception loss (for days with >25 mm rainfall) for all woodland within flood risk catchments

*** Note:** The average cooling effect of woodlands is marginal when expressed as degrees Celsius, hence the physical unit factor for temperature reduction appears relatively small per hectare.

Table 16. Step 2 Output. Physical account (woodland NCA Benefit Transfer Approach) of ecosystem services by country and region provided by GB urban and rural Non-Woodland Tree, estimated using NFI data and unit factors.

		Physical account of ecosystem services				
Country	**Region**	**Carbon sequestration** (tonnes CO_2e)	**Air pollution removal** (tonnes of pollution removal)	**Temperature regulation** (degree Celsius cooling)	**Noise reduction** (Number of buildings benefiting from noise mitigation)	**Flood Storage** (m^3 stored per year)
England	North West England	262,128	4,802	-	-	-
	North East England	108,712	1,992	-	-	-
	Yorkshire and the Humber	223,012	4,085	-	-	-
	East Midlands	291,592	5,342	-	-	-
	East England	408,940	7,491	-	-	-
	South East and London	628,396	11,512	-	-	-
	South West England	572,516	10,488	-	-	-
	West Midlands	376,936	6,905	-	-	-
	(Whole)	**2,872,232**	**52,617**	**0.0870**	**256,545**	**4,371,350**
Scotland	North Scotland	54,948	1,007	-	-	-
	North East Scotland	65,801	1,205	-	-	-
	East Scotland	99,327	1,820	-	-	-
	South Scotland	174,081	3,189	-	-	-
	West Scotland	35,249	646	-	-	-
	(Whole)	**429,407**	**7,866**	**0.0078**	**22,740**	**747,509**
Wales		**470,877**	**8,626**	**0.019**	**55,587**	**627,487**
Northern Ireland		**158,118**	**2,897**	**0.005**	**15,330**	**231,687**
GB[a]		**3,772,516**	**69,109**	**0.114**	**334,872**	**5,746,346**
UK[b]		**3,930,634**	**72,006**	**0.0119**	**350,202**	**5,978,033**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Table 17. Step 4 Output. Monetary unit values for each ecosystem service and annual value for UK woodlands (2020 prices).

Ecosystem Service (physical unit)	Monetary Unit Value (£ per physical unit per year))	Annual value for UK woodlands (£ million per year)
Carbon sequestration (tCO_2e)	241*	947
Air pollution removal (tonnes)	3,778**	1,015.3
Temperature regulation (degree Celsius)	1,023,800,000***	247.6
Noise reduction (buildings)	99**	16.5
Flood mitigation (flood storage m^3)	9.1**	236.1

Source: Annual values and physical flows from ONS (2020b) and Woodland natural capital accounts, UK: supplementary information - Office for National Statistics (ons.gov.uk). 2020 prices calculated using HM Treasury GDP deflator.
***** The social value of carbon is adopted as the carbon sequestration unit value. The value presented in the above table reflects the 2020 central price of UK non-traded carbon. When calculating natural capital values, different values are available for each year which are not presented in full in this table.
** These monetary unit values are estimated from woodland NCAs by dividing the total value of the ES by the total quantity.
*** The average cooling effect of woodlands is marginal when expressed as degrees Celsius, hence a large monetary unit is generated when expressing temperature regulation as £ / degree Celsius. This estimate is also relatively large as it refers to the average effect for the whole woodland estate.

Table 18. Step 4a Output: Annual flow values of ecosystem services provided by urban and rural non-woodland trees, estimated using NFI Non-Woodland Tree data and woodland NCA methodologies (2020 prices).

Country	Region	Annual Flow Values of Ecosystem Services (£ million per year)					
		Carbon sequestration	Air pollution removal	Temperature regulation	Noise reduction	Flood mitigation	Total
England	North West England	63	18	-	-	-	-
	North East England	26	8	-	-	-	-
	Yorkshire and the Humber	54	15	-	-	-	-
	East Midlands	70	20	-	-	-	-
	East England	99	28	-	-	-	-
	South East and London	151	43	-	-	-	-
	South West England	138	40	-	-	-	-
	West Midlands	91	26	-	-	-	-
	(Whole)	**692**	**198**	**74**	**9**	**40**	**1,013**
Scotland	North Scotland	13	4	-	-	-	-
	North East Scotland	16	5	-	-	-	-
	East Scotland	24	7	-	-	-	-
	South Scotland	42	12	-	-	-	-
	West Scotland	8	2	-	-	-	-
	(Whole)	**103**	**30**	**7**	**1**	**7**	**148**
Wales		**113**	**33**	**17**	**2**	**6**	**171**
Northern Ireland		**38**	**11**	**5**	**1**	**2**	**57**
GB[a]		**908**	**262**	**98**	**12**	**53**	**1,333**
UK[b]		**946**	**273**	**103**	**13**	**55**	**1,390**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Table 19. Step 4a Output: Natural capital values of urban and rural non-woodland trees, estimated using NFI Non-Woodland Tree data and woodland NCA methodologies (2020 prices).

Country	Region	Natural Capital Values of Ecosystem Services (£ million)					
		Carbon sequestration	Air pollution removal	Temperature regulation	Noise red.	Flood mitigation	Total
England	North West England	3,030	1,074	-	-	-	-
	North East England	1,257	445	-	-	-	-
	Yorkshire and the Humber	2,578	914	-	-	-	-
	East Midlands	3,371	1,195	-	-	-	-
	East England	4,727	1,676	-	-	-	-
	South East and London	7,264	2,575	-	-	-	-
	South West England	6,618	2,346	-	-	-	-
	West Midlands	4,357	1,544	-	-	-	-
	(Whole)	**33,203**	**11,768**	**3,898**	**282**	**1,185**	**50,336**
Scotland	North Scotland	635	201	-	-	-	-
	North East Scotland	761	241	-	-	-	-
	East Scotland	1,148	363	-	-	-	-
	South Scotland	2,012	637	-	-	-	-
	West Scotland	407	129	-	-	-	-
	(Whole)	**4,964**	**1,570**	**374**	**26**	**203**	**7,137**
Wales		**5,443**	**1,755**	**880**	**58**	**170**	**8,306**
Northern Ireland		**1,828**	**592**	**239**	**17**	**63**	**2,739**
GB[a]		**43,610**	**15,093**	**5,152**	**366**	**1,558**	**65,779**
UK[b]		**45,438**	**15,685**	**5,391**	**383**	**1,621**	**68,518**

[a] sum of England (whole); Scotland (whole); Wales.
[b] sum of England (whole); Scotland (whole); Wales; Northern Ireland.

Table 20. Step 4a Output: Uncertainty ranges for annual flow values of ecosystem services provided by non-woodland trees in UK, estimated using NFI Non-Woodland Tree data and woodland NCA methodologies (2020 prices).

Ecosystem Service	Annual Flow Values (£ million per year)			Source for uncertainty ranges
	Low-value	Mid-value	High-value	
Carbon sequestration	472	947	1,419	Projected low, central and high non-traded carbon prices, from Green Book valuation guidance Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal (www.gov.uk)
Air pollution removal	58	272	843	$PM_{2.5}$ damage cost sensitivity range (with $PM_{2.5}$ comprising 97% of all air pollution value) Air Quality damage cost updated 2019 (defra.gov.uk)
Temperature regulation	46	102	122	Urban NWT coverage groupings (Low = small woods, High = lone trees + groups of trees + small woods) National Forest Inventory: tree cover outside woodland in GB - GOV.UK (www.gov.uk)
Noise reduction	6	13	17	Estimated range in the welfare value of a QALY Scoping UK Urban Natural Capital Account - Noise Extension
Flood mitigation	23	54	86	Value estimates ranges modelled to represent summer-type floods (low-value) and winter-type floods (high-value) Valuing flood regulation services of existing forest cover to inform natural capital accounts - Forest Research

Woodland NCA methodologies discussion

Challenges

- The NCA methodology is under active development by ONS and Defra, hence the estimates should be considered experimental (ONS, 2020c). This is especially true for the ES valuations: noise mitigation, urban cooling, and flood mitigation.
- Benefit transfer method assumes close alignment for the physical natural assets under investigation. However, the NFI data used in the ONS woodland NCA (from which unit values are calculated here) differs from the NWT data in terms of the type of natural assets: woodlands greater than 0.5 hectares in extent, versus lone trees, groups of trees and small woods. The effects of smaller woodlands are not accounted for in the ONS woodland NCA. This issue is particularly manifest in the cases of noise mitigation and urban cooling. For noise mitigation, where larger woodlands produce a

proportionally greater effect, the tentative values are provided using only NWT small woodland coverage. In the case of NWT temperature regulation estimates, coverage for groups of trees is also used alongside small woodlands, as the woodland NCA methodology likely underestimates the overall effect with the absence of locally felt shading effects within the model. This could be a significant element for the cooling effects of trees. Alternative methods for valuing the climate regulation-cooling benefit of NWT could also be considered in future NCA methodologies, potentially deepening and strengthening the valuation. For example, the building energy modelling has estimated cost saving, directly attributable to trees, of between £2.1 million and £22.0 million annually for Inner London, arising from reduced loadings on air-conditioning units due to the cooling effect of trees (Moss et al., 2019). Finally, the unit values, and their underlying assumptions, applied in each of the benefit transfers may be further scrutinised, through future research, for their suitability. For instance, the appropriateness of application of the woodland carbon sequestration rate to NWTs; and the rainfall and air pollution interception rates of lone trees and tree clusters in comparison to woodland trees.

- Large uncertainties in physical measurements (e.g., noise mitigation) and economic valuations of most ES remain an issue. For example, even for a relatively well understood ES like carbon sequestration the central carbon price comes with a plus or minus 50% sensitivity range. This monetary valuation uncertainty comes on top of physical carbon measurement uncertainty which could be as high as 35%.

Opportunities

- Present valuations using NCA approach only focused on a minimal set of ES provided by trees for which relevant and sufficiently robust data were available. Further benefits from trees such as recreation, mental and physical health benefits are likely to have significant value and could potentially be included in future valuations.
- Flood mitigation benefit could be estimated using a different more accurate method: use data on NWT in catchments rather than a simple rural-urban breakdown. However, current data is only for broadleaves (i.e., it excludes conifers). Updated model estimates will be released by CEH in 2022.
- Alternative methods for estimates of flood mitigation benefits may shed light on uncertainty ranges but also add to it, since catchments do not coincide with regional and country boundaries; this will be a potential source of discrepancy in future estimates.
- The NCA methodology requires income and population growth uplift to be applied to the air pollution removal benefit; future annual valuation estimates therefore will differ. Some valuations have sought to offset this growth through application of projected reductions to 2030 in ambient air pollution concentrations (for example, CEH 2017).

- Benefits of NWT in agroforestry, for example, the role of shelter belts in reducing soil erosion and increasing productivity in agriculture, could be examined and valued with appropriated primary research and data development.
- Benefits of NWT in terms of linear features and small riparian woodlands in securing good water quality by reducing diffuse pollution from agriculture.

General discussion

The valuation estimates

Table 21 displays the initial valuation estimates of the NWT of England, Scotland, Wales, Northern Ireland, GB, and the UK. The estimates are presented as ‘totals’, representing the sum of the annual flow of benefits valued by each tool. Due to fundamental differences in the methodologies, annual flow values from the two tools have not been aggregated. At the UK scale, the total value estimates arising are £3.83 billion per year and £1.39 billion per year from the i-Tree Canopy tool and the woodland NCA Benefit Transfer approach, respectively. The values are of the same order of magnitude and proportionate to the annual flow of woodlands, given the areas covered by woodlands and NWTs respectively (see ‘Comparison with woodland valuation’ below for further discussion).

One of the most surprising challenges to generating the initial valuation estimates was the lack of freely available data on trees outside woodland. Robust data with associated error estimates are absent or incomplete at a range of spatial scales - including output area (OA), electoral ward, town/city, region, or country. As such, the valuations were restricted to the use of a single data source: TCOW (FC, 2017). The age of this dataset generates uncertainty in the associated valuations. Forest Research’s i-Tree Canopy based ‘tree canopy cover’ web map was considered as a source of additional and complementary data. However, methodological differences between the two approaches prevented its use in this study. (See also Next steps, below).

Comparing the valuation approaches

With an up to 3-fold difference in the total annual value estimates three questions are pertinent in considering the outputs of this study and their future use:

- Q: Why do the values differ?
  A: The estimates for the total annual value of ES flows differ both as result of differences in the ES flows considered and in their respective unit factors. While the i-Tree Canopy approach values three ES flows (carbon sequestration, air pollution removal, avoided runoff), the NCA methodologies value five (carbon sequestration, air pollution removal, temperature regulation, noise reduction, flood mitigation). However,

these differences in coverage do not account for differences in the magnitude of the total value estimates, but instead narrow the gap between the lower estimate (for NCA) and the higher one (for i-Tree). The differences instead arise primarily from the different unit factors applied (e.g., the one for carbon sequestration used under the i-Tree approach is more than twice that applied under the NCA – see Table II). They also stem from different unit values in some cases. For example, i-Tree Canopy uses unit values for air pollution removal that are greater than the average factor applied under the woodland NCA methodology.

- Q: Is one approach better or more accurate than the other?
  A: There are advantages and drawbacks associated with each of the approaches. The benefit transfer approach used to value the ES of NWTs has the advantages of covering a wider range of ES, also offering consistency of approach with woodland NCA methodologies developed by the ONS. However, it assumes that NWT provide the same level of benefits per hectare as woodland trees, which has not been empirically tested. While this study sought to minimise the potential impact of this assumption by limiting valuation to ES where it is considered most likely to apply, this assumption might be considered intuitively weak in some cases. For example, the net carbon sequestration rate of NWT (and the specific categories of NWTs) could differ from that of woodlands for a variety of reasons. Without empirical studies it is difficult to gauge whether the lower estimates from the NCA approach or the higher carbon sequestration estimates under i-Tree are more accurate. The accuracy of the unit factors of i-Tree Canopy can also be questioned (see preceding text). This study was restricted to using unit factors provided by the i-Tree partnership, with further consideration of the i-Tree Canopy unit factors advisable (see Future Work, below).
- Q: Are there differences in how the valuation estimates should be used?
  A: This work sought to generate a range of first estimates of the value to society of NWT, to assist government in policy-making concerning resource allocation, and interventions, utilising available methodologies and information. Both NCA and i-Tree Canopy approaches encompass multiple ES and apply across a wide spectrum of urban/rural settings, yet both have uncertainties with assumptions required in applying the valuation logic chain. When using these initial estimates, it is advisable to consider whether (resources allowing) 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 (i.e., those applying the NCA approach). Options for how to use the estimates are detailed below.

Table 21. Annual flow values (in 2020 prices) for the non-woodland trees of England, Scotland, Wales, Northern Ireland, GB, and the UK.

		Annual flow values (£ million per year)					
		England	Scotland	Wales	Northern Ireland	GB[a]	UK[b]
i-Tree Canopy	Carbon sequestration	1,528	229	251	84	2,008	2,092
	Air pollution removal	921	119	282	82	1,322	1,404
	Avoided runoff	223	39	54	21	316	337
	Total	2,672	387	587	187	3,646	3,833
Woodland NCA Benefit Transfer Approach	Carbon sequestration	692	103	113	38	908	946
	Air pollution removal	199	30	33	11	262	273
	Temperature regulation	74	7	17	5	98	103
	Noise reduction	9	1	2	1	12	13
	Flood mitigation	40	7	6	2	53	55
	Total	1,014	148	170	56	1,333	1,390

[a] sum of England; Scotland; Wales.
[b] sum of England; Scotland; Wales; Northern Ireland.

Comparing the national valuations: 'per hectare' normalisation

The annual flow values in Table 21 are for the total area of NWT. National average values per hectare were also computed; these are presented in Table 22. As expected, the per hectare values for England, Scotland, Wales, and Northern Ireland show a similar difference of magnitude between estimates derived from the i-Tree and NCA approaches to those for the total values). While this normalisation step illustrates the significant local value of NWT to society - irrespective of region or country where these trees are located, that there is a greater range in the i-Tree estimates than the NCA ones. The estimates would seem to support recent national efforts to protect existing NWTs and increase coverage; and provide valuable evidence on the value of NWT at local level.

Per hectare values may be beneficial in raising the awareness of the importance of trees outside of woodland. They may, for example, be used to provide an indicative value of a town or city's urban forest, akin to that provided by the i-Tree Eco urban forest assessment and valuation tool (https://www.itreetools.org/tools/i-tree-eco) and support the business case for investment. They are not, however, a substitute for i-Tree Eco, whose field assessments provide local quantification of the physical asset (including woodland and NWT) from which ES flows can be quantified and valued, and urban forest descriptive statistics (including species composition, size distribution, and condition) that are vital for strategic management of an urban forest.

Trees outside of woodlands are – as their typology suggests – not aggregated in ways which provide contiguous canopy cover. Therefore, further simplification of the national average values is useful. Taking a model small stature tree of canopy radius 3 m (tree canopy cover: 28 m^2), and a large stature tree of radius 15 m (canopy cover: 707 m^2) and using the GB average annual flows values of £4,913 per ha per year (i-Tree Canopy) and £1,796 per ha per year (NCA approach) indicates the average flow of benefits to society from a single tree ranges from £13.76 to £347.34 per year (i-Tree Canopy) or following the woodland NCA Benefit Transfer Approach: £5.03 to £126.98 per year. These indicative average annual flows may be useful in high level policy analysis or determining possible benefit-cost return from a tree fund or tree maintenance budget. While useful for highlighting the value of an 'average' NWT using a top-down valuation approach, these values are not intended for use in the protection of or compensation for single trees, for which dedicated methodologies are available, including i-Tree Eco and CAVAT.

Table 22. Annual flow values (in 2020 prices) per hectare of non-woodland tree coverage.

		England	Scotland	Wales	Northern Ireland	GB[a]	UK[b]
	NWT coverage (000 ha)	565	85	93	31	742	773
i-Tree Canopy	Total annual flow value (£ million per year)	2,672	387	587	187	3,646	3,833
	Total annual flow value per ha of NWT (£ per year)[c]	4,729	4,553	6,312	6,032	4,913	4,959
Woodland NCA Benefit Transfer	Total annual flow value (£ million per year)	1,014	148	170	56	1,333	1,390
	Total annual flow value per ha of NWT (£ per year)[c]	1,795	1,741	1,828	1,806	1,796	1,798

[a] sum of England; Scotland; Wales.
[b] sum of England; Scotland; Wales; Northern Ireland.
[c] Per hectare total annual flow values can be used to calculate indicative values of hectares of aggregate non-woodland trees in preparation for undertaking an in-depth valuation or for prompting further work. They should not be used to calculate the value of individual or small groups of trees, and they should not be used in place of in-depth studies where ecosystem services valuation should be quantified accordingly to the applicable physical asset.

Assumptions

In addition to the method specific assumptions stated with each of the three logic chains, high level assumptions were applied across all of the valuation approaches:

- These initial estimates are average values of existing NWT, not marginal values.
- Stock assessment assumed static state tree populations, due to uncertainty in urban tree populations. While extensive tree planting may be currently underway through, for example, the Urban Tree Challenge Fund; the England Tree Action Plan, and various local ‘One Million Tree’ and ‘One Tree per Person’ initiatives, loss rates of NWT are poorly characterised. Analysis of contemporary trends in urban tree canopy cover revealed negative trends in four out of the ten cities studied (Doick et al., 2020). Pest and disease impacts on NWT survival are also likely to be significant. For instance, common ash comprises *ca*. 10% of many urban forests (Vaz Monteiro et al., 2019) and with Ash-Dieback projected to kill 80% of the ash trees the loss to urban canopy cover will be substantial.
- Uncertainties in changes in stock and flow levels arising from the changing climate, and the impact of current and novel pest and diseases are excluded.
- Source data used in the derivation of unit factors (or the unit factors *per se* where directly sourced) are accurate and correct both in terms of the data used and the methodology applied in the calculation of the unit factors. (See also Appendices A, D, E, and G).

Comparison with woodland valuation

The Tree Health Resilience Strategy (Defra, 2018) estimated the annual flow of benefits from 3 million ha of forest and woodlands in Great Britain to be £4.9 billion per year (the sum of the annual flow of carbon sequestration, air pollution absorption, timber provision by forestry, and a partial assessment of recreation, landscape and biodiversity value). The net present value (100-year asset life) was reported as £175 billion. The valuations of NWT arising through this work are broadly in line with the woodland valuation. Assuming that NWT provide benefits at the same rate as woodland trees, the 0.75 million hectares of NWT (approximately one quarter of the coverage of woodland) could be expected to provide £1.23 billion value to society per annum. For ease of comparison, the total annual flow values of NWT were also calculated in 2017 prices using social values of carbon that applied at that time: £0.57 billion per year (woodland NCA approach) and £1.38 billion per year (i-Tree Canopy approach) (data not shown). At 2020 prices, the values using current social values of carbon ranged £1.33 billion per year (woodland NCA Benefit Transfer Approach) to £3.65 billion per year (i-Tree Canopy) (see Table 21). Comparison of the valuations are discussed below:

- Carbon sequestration by forestry and/or woodland was valued at £1.2 billion per year and was estimated by multiplying Defra data on carbon sequestered by the forestry sector, 2017 (19,309.20 Gg CO_2, equivalent to 6.4 tonnes CO_2e per ha of woodland) by the then current BEIS non-market carbon (central) value of £65 per tonne CO_2e. Using the benefit transfer approach, this equates to 5.08 tonnes CO_2e per ha for NWT NCA. Both values are approximately half the 11.2 tonnes CO_2e per ha unit factor used by i-Tree Canopy. The carbon sequestration rate of single urban trees has been reported to be 0.8-1.2x that of a single rural tree, suggesting a recalibration of i-Tree Canopy would be prudent.
- Air pollution absorption by forestry and woodland and partially covering urban areas was valued at £0.8 billion per year. Estimated using Land Cover Map 2007 and Ecosystem Account for Woodland (ONS, 2017), 3.16 million hectares of woodland (2015) was estimated to remove 315 thousand tonnes of pollutants per year. The resultant unit factor of 0.0998 tonnes per ha is approximately equal to that used herein for the woodland NCA Benefit Transfer approach: unit factor 0.093 tonnes per ha per year; but both are ten-fold greater that the i-Tree Canopy unit factor of 0.0098 tonnes per ha per year. Further work would be required to determine which methodology is most accurate.
- Timber provision by forestry and woodland was valued at £1 billion per year; it was estimated as additional value to the economy every year from forestry and sawmilling. As timber provision was not considered in this report, the valuation of NWT may be expected to be 20% lower than the woodland NCA valuation assuming a simplistic pro rata only comparison.
- The Tree Health Resilience Strategy (Defra, 2018) noted that the flood alleviation benefit of woodland in a recent Forestry Commission catchment case study at Southwell (Nottinghamshire) was valued at £250 per ha per year, with no national estimate included. In comparison, the woodland NCA Benefit Transfer approach estimated the value of flood alleviation by NWT as £89 per ha per year, and i-Tree Canopy at £375 per ha per year indicating a further potential cause of the higher valuation of NWT by i-Tree Canopy.
- The partial assessment of the recreational, landscape and biodiversity value of forest and woodland was estimated in the woodland NCA at £1.9 billion per year (or £633 per ha per year). While these benefits were not for NWT, the estimated GB wide valuations for temperature regulation (£118 million per year) and noise reduction (£33 million per year) do add to the overall valuation of NWT trees and their relative contributions to society, as these two services were not valued within the woodland NCA.

Next steps

This study has provided first estimates of the values of the nation's NWT. Future work may *inter alia* include updating calculations when new valuations, incorporating some of the services valued herein into the UK natural capital accounts, or extending the breadth and depth of this study.

- To update the current valuations as new data becomes available requires reapplication of the documented logic chains (Figures 4, 6 and 8). This work need not be limited to the release of new physical asset estimates or updates to unit factors, it may also include recalculation where information becomes available to address the stated assumptions.
- This study quantified the annual flows of some ES not currently considered in the UK natural capital accounts, specifically flood mitigation through avoided run-off by NWT (i-Tree Canopy approach). Restricting the focus to urban ensures no overlap to the NCA and future work may scope the suitability (e.g., confidence in the unit factor) and feasibility (e.g., data availability) for inclusion into future NCA.

Options that can help improve the valuation of NWT are detailed below.

Future work

The scale of the unit factors employed in the i-Tree canopy valuations are a potential source of error (as discussed in the previous section) and currently confidence intervals are unavailable. In particular, the unit factors for carbon storage and sequestration are based on US tree data and are not specific to the UK. Incorporation of additional i-Tree Eco data into this approach to calculate ES provision unit factors would further enhance the regional specificity of the valuations. The pool of Eco studies completed in the UK increases annually and is currently in the region of twice as large as that used in the parameterisation of i-Tree Canopy. Part 1 of this work also demonstrated the potential to generate unit factors directly from i-Tree Eco (see appendices), rather than relying on those within the i-Tree Canopy tool. Completing this work would provide an additional method and hence increase the pool of estimates of the value of NWTs. Further, testing the ability of i-Tree Eco to model carbon storage and sequestration by UK NWT, and incorporation of the results into future versions of i-Tree Eco, would lead to improvements in valuations of NWT.

The social and cultural values of NWT (which can be categorised into: health; nature and landscape connections; social development and connections; education and learning; economy; and cultural significance; see for example: Davies et al., 2017) have not been considered by this work. Few of these values have been monetised, and those that have relate almost exclusively to woodland. For example, a report just out suggested a per-visit mental health value from woodlands at £0.39. This value was based on the avoided costs spent on mental health via visits to woodlands (Saraev et al., 2021). The extension of the mental health benefits of woodlands to NWTs may not be applicable, and has been excluded from the current work. The report also found that a negative correlation between the presence of street trees and rates of prescriptions for anti-depressant medication could result in avoided costs of £16 million per year across the UK. No data are available on the extent of street trees, so this benefit has not been included in the current work.

The UK woodland NCA includes a partial assessment of recreation estimated based upon expenditure per trip data. As only one of the wide range of social and cultural values of woodland trees, this figure represents a conservative valuation. Application of this figure to NWT via benefit transfer is possible, however people are less likely to travel to a single tree, line of trees, or a cluster of trees for recreation, and thus the recreational value of NWTs may be different to woodland trees. A benefit transfer approach was therefore not adopted in this instance. Future valuations of NWT should seek consideration of social and cultural values, as new research and data is published.

Research needs and knowledge gaps

There is a paucity of data on NWT and what is available is dated. This work relied upon the Forestry Commission’s TCOW report. Published in 2017, survey work was completed in the years prior to publication meaning that the information used at the core of this work’s valuation are already at least 5 years old. And while the TCOW typology of lone trees, groups of trees, and small woods, and hedgerow trees is useful, future NWT valuations would benefit from further categorisations and groupings, including ‘lines of trees’ and allocation to land-use types. Additional detail is also required with respect to the extent of data quality assurance (ground truthing) leading to improved statistical confidence and improved spatial coverage (for example, Northern Ireland). The assumption employed in the calculation of Northern Ireland NWT coverage is, at best, optimistic; how robust the employed assumption might be is not known. Confidence in the UK scale valuation of NWTs would doubtless be improved through quantification of Northern Ireland’s NWT cover.

In addition to the lack of contemporary and repeated measures data for NWT from the Forestry Commission’s NFI team, having a range of NWT quantifications from a range of methodologies would help build confidence and robustness into the NWT valuations. Several projects are underway and/or products coming forward that may help in this regard in the short and medium term. For example, the Land Use and Ecosystem Services (LUES) team at Forest Research working with Aberystwyth University and Geosmart Decisions are developing a novel approach using remote sensor data and machine learning to map trees outside of woodland. The Open University has a £7 million grant for ‘TreeView’, a project to scope a near-orbit satellite for measuring and monitoring the health of trees. Furthermore, Bluesky International Limited offer proprietary tree map products at a range of resolutions and price-points. Products include aerial photography up to 5 cm, and a National Tree Map of stands, 3 m or greater in height. It is likely that similar proprietary products are available from international companies. Part 1 of this project also mapped out the logical steps in generating initial estimates of NWT on a ‘per tree’ basis.

The lack of data led to such approaches not being adopted in Part 2. Progress by these three, or similar, tree mapping projects may provide the required data, and allow these options to be re-evaluated for their suitability to the NWT valuation.

The CAVAT approach to the stock valuation of NWT is based upon unit factors of £0.1 million to £4.2 million per hectare of tree cover. These unit factors arise from analysis of CAVAT valuations from the i-Tree Eco projects of twenty towns and cities of the UK. However, during such projects the proportion of trees surveyed is typically small (e.g., within the i-Tree Eco project for Cardiff, 801 trees were assessed across the 199 survey plots; or 0.06% of the estimated total urban tree population for Cardiff of 1.41 million). Many local planning authorities hold a database of trees under their management, typically containing information on thousands of trees, sufficient to enable calculation of CAVAT valuations following the amended Quick Method approach. A broader palate of CAVAT valuations could be used to generate more accurate and representative CAVAT unit values, especially in those regions where data is currently limited. It would also be possible to distinguish between woodland and non-woodland, urban and rural trees, and trees in different spatial arrangements or typologies using this approach.

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Appendix A: Background information on the three tools used in Part 2

Tool 1: i-Tree Canopy

Introduction to i-Tree Canopy

Aim of tool: i-Tree Canopy is one of the i-Tree suite of tools (www.itreetools.org). It is used to classify ground cover types and estimate tree cover. For countries where it has been parameterised to do so it is also used to estimate the tree benefits: carbon storage (carbon stock) and sequestration, and air pollution removal. The amount of avoided run-off is also calculated, but not valued. This functionality has been available in the UK since early 2021.

i-Tree Canopy is an online assessment tool. The user defines a study area and allocates points to a range of predefined descriptors following a random sampling process. Typically, 350-500 points are described, increasing to thousands of points for very large areas. In the UK Canopy Cover Web Map project (https://www.forestresearch.gov.uk/research/i-tree-eco/urbancanopycover/), points are classified as either ‘tree’ or ‘non-tree’. An assessment point is classified as a tree if the tree’s canopy falls within the crosshairs of the assessment point. Shadows of trees, hedges and shrubs are not defined as trees in the context of the UK Canopy Cover Web Map project.

Summary of tool use in the UK: used by a diverse mix of stakeholders in the UK, including charity groups, local planning authorities, and universities. i-Tree Canopy has been used to baseline urban tree canopy cover of 283 towns and cities in England and Scotland (Doick et al., 2017), and as the assessment engine for a citizen science project to determine tree canopy cover at electoral ward level across the UK.

Critique: Assumptions

Assumption (Stated/known) - quantification: The tool assumes that the user can confidently identify trees from other land covers (e.g., shrubs, grass, etc.) The tool also assumes there is inter-user comparability, and that there is no user bias. That there is clarity of distinction between trees and shrubs is another assumption of the tool.

Assumption - valuation: Valuation of ES has recently been parameterised for use in the UK and Sweden, having previously only been available in the US and Canada. The datasets that inform the ES calculations for i-Tree Canopy are derived from UK based i-Tree Eco surveys. The methods employed in i-Tree Eco for ES quantification are:

- Hirabayashi (2010) Air pollution removal: The six air pollutants estimated include: carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide and particulate matter (PM_{10}, $PM_{2.5}$). The default values (air pollution removal rates and monetary values) per unit of tree cover are derived from UK-based i-Tree Eco surveys from 2010. Analysis conducted based on the i-Tree Eco surveys were conducted for rural and urban areas in all counties and then aggregated into county-level values. i-Tree Canopy uses the county-level multipliers (rural and urban areas aggregated) to estimate annual air pollutant removal.

- Nowak et al. (2013) Carbon storage and sequestration: Field data collected on urban forest structure for 28 US cities and urban areas across six states. Within random plot sampling, trees were measured for diameter at breast height (DBH; also known as trunk diameter), height, canopy dimensions, allowing for carbon storage and sequestration calculation using biomass and growth equations. Allometric and biomass equations used within the work were previously produced by the same authors. Differences in carbon storage and sequestration were explored between street, park and forest trees. This was combined with tree cover assessed using aerial imagery to give a mean carbon storage and sequestration value per unit of tree cover.

See Tool 4: i-Tree Eco in Appendix B for a comprehensive review of the models and methods employed in the parameterisation of i-Tree Canopy.

Critique: Limitations

There are few reviews of i-Tree Canopy. Literature is US-centric, with no literature found which critically reviews the tool for use in the UK.

Existing literature regarding the tool largely focusses on the accuracy of the methodology employed for calculating canopy cover values, with little published on the accuracy of the benefit values that are derived from the assessments. Some limitations to the modelling approaches used for calculating the benefit values are explored in published work by Hirabayashi (2010). The main points made include:

- Environmental and climatic factors (e.g., wind, rain, atmospheric mixing height) can affect air pollution interception and accumulation on tree leaves. These factors can also result in negative values, indicating trees decrease air quality.
- Nowak et al. (2013) noted the potential for double counting through overlap with national forestland (FIA) data. This was mitigated by estimating the number of plots

assumed sampled; the same double counting risk would hold in the UK where a mixed methods approach to estimation is employed.

Comparative approaches are occasionally adopted when reviewing i-Tree Canopy. Some studies found no statistically significant difference in canopy cover values derived using different methodologies (Doick et al., 2017).

Accurate canopy cover assessment is dependent on the user's ability to correctly classify each assessment point. This in turn is dependent on the ease of interpretation of the aerial imagery, which can be highly variable due to age of the imagery, presence of shadows and pixel size (Richardson and Moskal, 2014).

The precision of canopy cover values derived from i-Tree Canopy is dependent on the number of points used in the assessment. Precision of the estimate increases as the number of points is increased and the standard error (SE) of the estimate concomitantly decreases. If too few points are classified, the SE will be high; a typical target SE is <2% (e.g., Doick et al., 2017).

An assessment of measurement error has not been determined. Comparative approaches would need to be adopted to determine the level of measurement error and this would be difficult to ascertain with data collected by citizen scientists, as is the case for majority of i-Tree Canopy studies. The SE of the canopy cover value is calculated during each assessment. It is calculated using the proportion of points classified as 'tree' and changes with an increasing number of points and the proportion of tree cover: for a higher canopy cover value more points are needed to reduce the SE. Due to differences in the number of points used in an assessment SE varies for every ward in the UK; this would need to be considered if data from different studies were to be amalgamated.

Assessment area/size is not incorporated in the canopy cover calculation. The output (canopy cover) is expressed as a percentage based on the number of points assessed as 'Tree' versus other land covers, rather than being based on spatial data (e.g., plot-based surveys). The percentage canopy cover is converted into hectares of the study area as an output of each canopy cover survey, and a SE is stated.

It is not possible to differentiate between different types of tree cover unless this is purposefully factored into a study's design (as categorisation is done during the assessment process). Unless there is the opportunity to obtain an estimate of the breakdown of different types of tree cover within an assessed area (e.g., through NFI or another dataset), there is potential for double counting of woodland and little opportunity for disaggregation for non-woodland components.

Air pollution removal estimates are based upon air pollution monitoring stations across the UK. The i-Tree methodology, however, requires concentrations for the full suite of pollutants to all come from the same station within a given town/city; this inherently limits the availability of data used within the parameterisation of both i-Tree Canopy, and i-Tree Eco (Tool 4, Appendix B).

Proposed approach to extrapolation

To be able to use i-Tree Canopy for valuing NWT in the UK, an estimate of the level of ES provision, and monetary value, per unit of tree cover is required, for example, ES delivery per %canopy cover or ES delivery per hectare of canopy cover. These units must then be multiplied by the values for % or ha of NWT canopy cover, respectively, monetised and adjusted to determine the 100-yr natural capital value. While i-Tree Canopy has recently been parameterised for use in the UK, the ES valuations used are unknown and would be required for Part 2 (NB. The authors have requested information to confirm how i-Tree Canopy has been parameterised for the UK; response pending.) Thus, three steps are required:

Step 1: Determine average ES delivery per % canopy cover
Step 2: Apply values to estimates of area of non-woodland canopy cover
Step 3: monetise the ES flows.

Details for each step are expanded below.

Step 1) Determine average ES delivery per % canopy cover.

Conduct a range of i-Tree Canopy studies to determine the ES delivery rates applied to a % canopy cover and, hence calculation, to hectares (ha).

Step 2) Apply values to estimates of non-woodland canopy cover.

Per hectare unit values from Step 1 are then applied to estimates of non-woodland canopy cover by multiplication, at local, regional, or national scale. To do this, either:

i) Canopy cover estimates for the range of NWT are required, or
ii) Estimates for total canopy cover are required, for which a total (woodland plus non-woodland) valuation may be determined, and the non-woodland element calculated by subtracting of a like-for-like woodland estimate.

Canopy cover estimates will thus be required for geographies of known area and aggregated to country and/or UK level, for example, electoral ward, county, or region. Total canopy cover estimates are available for approximately 60% of electoral wards in the UK via the UK Canopy Cover web map and for regions via the Tree Cover Outside of Woodlands (TCOW) reports (Forestry Commission, 2017). Canopy cover estimates for individual categories of NWTs are not currently available, though could be determined from the National Tree Map (NTM), or similar product.

Where a valuation is determined based upon total tree canopy cover a deduction for woodland trees would be required to prevent double counting. Critical to the success of this approach would be ensuring that the values are like-for-like deductions.

Assumptions: Calculating average ES provision and values per hectare of canopy assumes that woodland and NWTs provide ES delivery equally, in quality and quantity, and hence differences in unit values are not considered. Equally, service provision is assumed like-for-like across the different study areas. While this assumption is clearly a simplification, the similarity in the top ten species, the size structures, and the proportion of the total number of species in an urban forest represented by the top twenty species provides a strong basis (Vaz Monteiro et al., 2019). In addition, the greater the range of urban forest composition covered by the set of Eco projects used to generate these average values the greater the likelihood that the average values will be applicable to the range of towns and cities to which the value may be applied, though not necessarily to rural NWTs, and so valuation estimates are likely to increase in accuracy with time (as more and more i-Tree Eco studies are completed and used in the periodic re-parameterisation of i-Tree Canopy). (NB. ‘accuracy’ may be assessed through comparison of the i-Tree Eco models with alternative ES quantification approaches).

Use of the tool to obtain physical estimates of hectares of canopy cover and associated tonnes of pollutants removal and carbon sequestration, then applying carbon sequestration and air pollution removal values developed for the UK, with Treasury Green Book time discount rates applied to future values, would be in line with the Green Book approach.

Recommendation

Fit to Project: Low (Match: Low, due to the non-differentiation of non-woodland canopy cover; Confidence: Low, due to the valuations being created from urban forest valuation projects yet applied to non-urban locations).

Resourcing: Medium (Availability: Partial; Charge: Free (i-Tree Canopy)).

Match to project objectives: MEDIUM.

Table A1. Summary options for extrapolation of i-Tree Canopy data to valuing the UK's non-woodland trees (shading indicates recommended route).

	Option 1	Option 2	Option 3
Outputs	ES estimates: - Carbon storage (stock) - Carbon sequestration - Air pollution removal - [Surface flooding avoided]		
Units	Per total study area		
Normalisation	ES per ha or ES per %CC* (see also Tool 4: i-Tree Eco)		
Data required	Area (ha) of NWT	Canopy cover (%) or canopy cover (ha)	Canopy cover (%) or canopy cover (ha)
Data available	National Tree Map	TCOW (top-down approach using regional non-woodland canopy cover values)	UK Canopy Cover web map (bottom-up approach using ward-level %CC data)
Processing	Sum per tree type	- (ES per %CC) x (%CC) or - (ES per ha) x (CC in ha)	- (ES per %CC) x (%CC) or - (ES per ha) x (%CC) x (area in ha)
Scalability	Sum to required scale	Sum to required scale	Sum to required scale
Comment	- Cost of National Tree Map - Until Jan 21 valuations were US-based; ES per %CC needs to be determined from the i-Tree Canopy tool. - Need to determine the units of monetisation used by i-Tree Canopy	- Non-woodland estimates based on hand-mapping and fieldwork plot samples - For urban TCOW in England, Scotland and Wales SE is between 10 and 18% and higher in some individual regions - Disaggregation as lone trees, tree clusters and small woods possible where appropriate for ES - Option to make region-specific valuations through appropriate selection of benefit values	- Only 58% of wards assessed, and unknown if these are representative; one option is to calculate regional mean ES per ha values from mean ward-level canopy covers (see Box 1). - Double counting: ES per ha is for all tree cover, including woodland. Double counting avoided by subtraction of woodland tree cover. Possible only if assessment of ES and/or value are comparable between Woodland Valuation and i-Tree Canopy (see Table B2) - No disaggregation for non-woodland typology

Tool 2: Capital Asset Value for Amenity Trees (CAVAT)

Introduction to CAVAT

Aim of tool: CAVAT is an expert-based amenity tree valuation tool that was first conceived by Christopher Neilan between 1998 and 2003. It was subsequently adopted by the London Tree Officers Association (LTOA) in 2006, tested and revised to better fit the work of UK tree officers (Doick et al., 2018). The main aim of CAVAT is to allow local planning authorities to achieve a fair compensation for their trees if these are damaged or removed by the wider population and to help manage public trees as assets rather than liabilities (Doick et al., 2018). CAVAT is based on the trunk formula method (TFM) as described for Tool 6: Council of Tree and Landscape Appraisers (CTLA). However, unlike CTLA, CAVAT includes both appreciation and depreciation steps. For example, appreciation in CAVAT considers the human population that can benefit from the tree or group of trees in question, as well as the functional status (amenity benefits) of the tree(s). The user can select from a Quick Method, if the aim is to use CAVAT as a management tool of a population of trees, or a Full Method, if the main aim is to define a more precise compensation value of a single tree or small group of trees (Doick et al., 2018). Both methods require information specific to the tree or trees being valued. For local planning authorities, the primary users of the Quick Method, this information is typically collected during routine tree (safety) inspections and stored in the authorities' tree database. As such, the Quick Method enables valuation of a population of trees faster than the Full method and using information typically at hand, or that can be collected in routine surveys with very little extra effort. The Quick method demands less data input than the Full Method; some input variables, such as DBH, are input according to size-band not as the precise value, and community accessibility and amenity value adjustment are not accessed.

There is no calculation of expected accuracy or error for this tool; this will largely depend on the user's assumptions and scoring and the data availability as highlighted below.

Summary of tool use in the UK: CAVAT has been used by UK based local authorities to gain compensation from developers, insurance losses, and out-of-court settlements (Doick et al., 2018). The Quick Method is used by some local planning authorities as a management tool to define an asset value of their tree stock. Approximately one-third to half of all local planning authorities use at least one of the CAVAT Methods in the management of their trees (Vaz Monteiro and Doick, 2019).

The fact that this tool was specifically created to help UK based local authorities manage their trees and is now well accepted by UK professionals can be seen as an advantage for its inclusion in this study, in contrast to the CTLA for example.

As for the Helliwell and CTLA systems, CAVAT is currently limited in its usefulness to this study due to its incomplete consideration of the benefits of trees, because of its explicit requirement for information to each tree to be valued, and due to the lack of data describing the size, health, and location of the various categories of NWTs.

An average or indicative CAVAT valuation per unit area of land could be determined based upon CAVAT valuations presented in GB i-Tree Eco reports, in a way similar to the approach described above for the CTLA approach (see Appendix B). A major limitation would be the lack of sensitivity that would arise from the application of a single indicative value to a range of trees varying in size and condition (two critical determinants of CAVAT value). For example, the average CAVAT value for trees in an i-Tree Eco report is *ca*. £1,500-3,000 while individual trees within each of those reports are noted to be valued at tens-of-thousands of pounds and, in some cases, hundreds of thousands. It is furthermore noteworthy that CAVAT values presented in many i-Tree Eco studies use an amended form of the Quick Method. In this approach, a single measure – percent of canopy absent - substitutes for the functional crown assessments to enable the CAVAT valuation to be performed using the data collected in the i-Tree Eco field survey campaign. This revision to the Quick Method may allow for future rapid assessment over large areas using remotely sensed data. For example, a recent funding application proposed the use of satellite earth-observation data combined with aeroplane collected hyper-spectral lidar information to model canopy spread, canopy missing and canopy condition for automated determination of CAVAT (amended) Quick Method value. The determination of DBH from canopy spread would remain as a weakness in the approach, as also described CTLA.

Critique

Assumptions - quantification: as for CTLA and Helliwell, CAVAT is an expert-based valuation tool and as such the final valuation is subjective to how the user rates the tree or group of trees.

- Binner et al. (2017): states that CAVAT does not comply with the Green Book guidance for estimating value due to the judgement involved.
- Price (2020): presents a critical overview of CAVAT, noting its aesthetic valuation as “contentious” due to the subjective judgements of its users. Price goes on to note that while some problems of user bias are common to other appraisal systems, some are specific to CAVAT.
- A rebuttal of Price’s critique followed, noting that many of his comments related to the first iteration of CAVAT and demonstrated only a partial understanding of CAVAT (Neilan et al., 2021).

Assumptions - valuation: the replacement value achieved through CAVAT recognises the wider amenity benefits of trees not solely their visual amenity, as in Helliwell (Sarajevs, 2011), or their structural value, as in CTLA (Hollis, 2009). The CTLA’s TFM was the basis for CAVAT (Doick et al., 2018) and while it allows for the incorporation of social/cultural aspects in the valuation of trees which is lacking in both Helliwell and CTLA (Sarajevs, 2011) this has led to CAVAT being criticized for not fully considering depreciation (Hollis, 2009; RICS, 2010). Doick et al. (2018) describe the steps of CAVAT to argue that depreciation is fully considered. The link to economic valuation theory is contested by some economists.

Sarajevs (2011) notes that CAVAT does not consider ES valuations and so its final valuations are limited.

Critique: Limitations

CAVAT focuses on valuing a tree based on the cost of replacement should it be lost (as do CTLA and Helliwell system), not the benefits it can provide to society. This has been highlighted in the 2013 Natural England report “Green Infrastructure – Valuation Tools Assessment” which suggest that CAVAT can only be used for financial compensation not for economic valuation purposes (Natural England, 2013).

Proposed approach to extrapolation

As for the CTLA approach above, two options may be considered: summing across a population on a tree-by-tree basis, or apply an average per unit area value to areas of known size and sum. The former is rejected here due to challenges of obtaining the quantitative and qualitative information required. To apply the latter approach of per unit area, two steps are required:

Step 1: Determine an average CAVAT amended Quick Method value per hectare of canopy cover or per hectare of urban area
Step 2: Extrapolate values to required geographic areas.

Details for each step are expanded below.

Step 1) Determine an average CAVAT amended Quick Method value.

An average CAVAT amended Quick Method value can be determined from the existing i-Tree Eco reports (see Tool 4: i-Tree Eco). In each case, the total CAVAT valuation and the estimated total population are reported, and the average value can be determined by division, to provide an average CAVAT value per tree, per unit canopy cover area (ha) or per unit urban area (hectare or km^2). Standardisation of the unit-value factor will be required as this is annually updated and will be different across the suite of i-Tree Eco reports.

While the approach is not sensitive to the presence of large trees (as noted in section ‘Introduction to CAVAT’ above), urban forests tend to be composed of approximately 40% trees in the size range of 7-20 cm DBH; 30% in the size range 20-40 cm DBH; 20% as 40-60 cm DBH, and 10% as >60 cm DBH, and so the value can be assumed to be a useful average for the purpose of this calculation (Vaz Monteiro et al., 2019).

Step 2) Extrapolate values to required geographic areas.

Average CAVAT valuations will then need to be applied to estimates of area(s) of NWTs to be valued. This could be per urban unit area (as for i-Tree Eco) using the Built-Up Areas dataset or with a dataset of town and city (areal) size and these can be readily aggregated to country, GB, and UK scale. Normalising values to per unit area of canopy cover could be considered to improve the suitability of the estimate, drawing upon town/city average canopy cover values from Doick et al. (2017).

Although developed as an expert system with design principles different to that of ES and NCA approaches with Treasury Green Book discount rates applied to future values, its use would be in line with the Green Book approach.

Recommendation

Fit to Project: Medium (Match: Low due to the non-differentiation of NWTs; Confidence: High, as average per tree CAVATs tend to be similar (certainly same order of magnitude) between i-Tree Eco studies, providing some confidence for extrapolation).

Resourcing: Medium (Availability: Partial; Charge: Free (ONS BUA or town/city size datasets)).

Match to project objectives: MEDIUM.

Table A2. Summary options for extrapolation of the CAVAT Methods data to valuing the UK's non-woodland trees (shading indicates recommended route).

	Option 1	Option 2	Option 3	Option 4
Outputs	Total CAVAT estimate			
Units	Per urban forest			
Normalisation	Per tree	Per urban area	Per urban CC area	Per CC area
Data Required	- Number of trees - Qualitative tree data	Urban area size	Urban area under canopy cover	Area under canopy cover
Data Available	- National Tree Map - N/A (apply standard score)	Area (ha) from ONS	- Town or city (Doick et al., 2017) - For ward options see Tool 1	TCOW (top-down approach using regional non-woodland canopy cover data)
Processing	Sum per tree type	$CAVAT_{mean}$ x $area_{urban}$	$CAVAT_{mean}$ x $area_{UCC}$	(CAVAT per ha of CC) x (CC in ha)
Scalability	Sum to required scale	Sum to required scale	Sum to required scale	Sum to required scale
Comments	- Amended Quick Method only - Key information missing, making this route non-viable	- Amended Quick Method only - Excludes rural NWT - No disaggregation for non-woodland typologies	- Amended Quick Method only - Excludes rural NWT - No disaggregation for non-woodland typologies	- Non-woodland estimates based on hand-mapping and field work plot samples. - For urban TCOW in England, Scotland, and Wales SE is between 10 and 18%, and higher for individual regions - Accuracy (see Tool 1) - Disaggregation for NWT as lone trees, tree clusters and small woods possible, where appropriate to the ES - ES per area values derived from 'urban' studies; their suitability for application to rural areas would be resource intensive

Tool 3: Urban and Woodland Natural Capital Accounts

Introduction to urban and woodland NCAs

The research and applied work on Natural Capital Accounting (NCA) in the UK are led by the Office for National Statistics (ONS) and the Department for Environment, Food & Rural Affairs (Defra). Latest publications (Defra, 2020; ONS, 2019; 2020a; 2020b; 2020c; 2020d; 2020e) for NCA for woodlands and urban accounts together with a general guidance were reviewed.

The environmental 'satellite' accounts developed by ONS using NCA feed into main UK national accounts and are compiled in accordance with the System of Environmental-Economic Accounting (SEEA). The SEEA closely follows the UN System of National Accounts (SNA) which means they are comparable with economic indicators such as Gross Domestic Product (GDP).

Aim of tool: NCA is an approach to monitor and value the environment to integrate information about natural assets into a general decision making and management processes for society's benefits. NCA is "the attempt to bring a systematic, standardised and repeatable framework to assessing and monitoring natural capital and the services it provides, whether those services have a market value or not" (DEFRA, 2020).

General NCA methodology

The Net Present Value (NPV) approach is recommended for valuing natural capital within SEEA. This approach involves valuing the natural capital stock based on annual ES flows.

The value of the annual ES flow is estimated by multiplying a physical measure of the benefit flow by a price. The price can be either an actual market price, or an estimated price for the ES in a hypothetical market.

To calculate the NPV one needs to estimate the stream of services that are expected to be generated over the life of the asset (forest, woodlands, and trees). Four issues related to the NPV calculation are:

Annual values of the service flows provided in constant prices
Pattern of expected future flows of values
Time period over which the flows of values are expected
Choice of discount rate.

NCA methodologies adopted by ONS assume that ES flows and prices (and thus, the annual values) remain constant throughout the life of the asset, except where official projections are available, e.g., for carbon sequestration, recreation, and air pollution. In the case of carbon sequestration, projections are provided up to 2050 by the UK National Atmospheric Emissions Inventory (NAEI) in the Land Use, Land Use Change and Forestry (LULUCF) sector emissions projections. After 2050 the carbon sequestration is assumed to be constant at 2050 levels (ONS, 2020b, p.3). For recreation and air pollution future projections use an average population growth rate and an assumed 2% increase in income per year (declining to a 1.5% increase after 30 years and a 1% increase after 75 years) (ONS, 2020b, p.4). Expected ES values are assumed to be the mean over the latest 5 years, up to and including the reference year in question, see equation below:

$$SV_t = \frac{SV_{t-4} + SV_{t-3} + SV_{t-2} + SV_{t-1} + SV_t}{5}$$

Equation 1: Service value 5-year average

In cases where 5 years of data are not available, the most recent available value is used in forward projections.

In the current guidance a 100-year asset life is applied to all renewable natural capital assets, which include trees.

The discount rate is set out in the Green Book (HM Treasury, 2020). It also suggests using lower rates where the long-term impacts involve very substantial or irreversible wealth transfers between generations, including irreversible changes to the natural environment. Schedule of the declining long term discount rate for the Social Time Preference Rate (STPR) is presented in the table below (HM Treasury, 2008):

Table A3. Declining long term discount rate.

Year	STPR (standard)	STPR (reduced rate where pure STP = 0)
0 - 30	3.50%	3.00%
31 - 75	3.00%	2.57%
76 - 125	2.50%	2.14%
126 - 200	2.00%	1.71%
201 - 300	1.50%	1.29%
301+	1.00%	0.86%

For all price adjustments the UK Government GDP deflator https://www.gov.uk/government/collections/gdp-deflators-at-market-prices-and-money-gdp) for Calendar Year series is used. Given that our analysis focuses on trees, for which an irreversibility argument is not generally applied standard declining discount rate provided in the second column of the Table are recommended (though were climate change and biodiversity tipping points considered, this could potentially justify using reduced the discount rates). ONS methodologies for NCA (ONS, 2017, 2020b, 2020c) provide a balance between complexity and practicality. Methods used to value ES (timber, carbon, air quality, etc) for which well-established ONS methodologies currently exist and are the primary focus of this Appendix, together with more novel experimental approaches to valuing ES such as: flood risk attenuation, noise mitigation and urban cooling (for which an ONS methodology is currently under development).

The table below considers the ES of interest and methodologies from the current NCA publications which are transferable to NWTs by ES benefit:

Table A4. NCA methodologies by ecosystem service.

Ecosystem service / Benefit covered	Present in NCA	Can use for NWT	Comment/Limitations (ONS, 2020a, 2020c, 2020e)
Air pollution removal	Yes	Yes	More work is being conducted in this area.
Amenity tree valuation (Replacement cost)	N.A.	No	
Amenity (structural value) (Replacement cost)	N.A.	No	
Amenity (Recreation/ landscape)	Yes	No	Only recreation is covered using the basic travel cost method.
Climate regulation - carbon (sequestration)	Yes	Yes	No changes in methodology are currently planned. If sequestration moved from a gross to a net sequestration basis the value would fall.
Climate regulation - cooling (A/C energy avoided)	Yes	Potentially	Urban cooling effects are estimated by averaging the effects across greenspace assets of woodland, grassland, and gardens. The effects of assets less than 200m^2 (0.02 ha) in size are not included. The approach also does not account for locally felt cooling effects from individual greenspace characteristics (e.g., the cooling effect of shade from street trees). Future iterations of the account may include methodologies more applicable for understanding the effects of individual trees, such as with i-Tree Eco's energy effects module, if this could be parameterised for UK building types.
Noise mitigation	Yes	Potentially	Benefits from woodlands larger than 200m^2 (0.02 ha) in size only. NWTs would mitigate noise less effectively than woodland patches, although this difference may be difficult to readily quantify.
Social and cultural values – well-being	No	No	Currently not valued.
Stormwater (avoided runoff) regulation	No	No	Currently not valued.
Flood mitigation	Yes	Yes	Valued for the woodland vs no woodland case.

Whether a NCA methodology can transfer for a specific ES to NWTs depends on both the ES and the context of a case study area. For some ES, e.g., timber, wood fuel, food (e.g., apples), carbon sequestration and air pollution removal may be supplied by a single tree. For others, e.g., noise mitigation and amenity recreation, one may require more than one tree, a group, or linear feature; hence methodology applicability is not universal. This context dependency creates problems for extrapolation, upscaling and aggregation.

Summary of tool use in the UK: NCA has been used for several years in the UK. NCAs were produced for the whole of the UK (ONS, 2020b), e.g., woodlands (ONS, 2020d) and urban (ONS, 2019) NCAs, for countries, e.g., Scotland (ONS, 2020a), and separate organisations, e.g., Forestry England estate (Forestry England, 2020).

Critique: Assumptions

Assumptions - Quantification: the 2020 woodland UK NCA (ONS, 2020a, p.5) mentions non-woodland areas: "In addition to woodland areas, the Forestry Commission estimates there are 390,000 hectares of small woods in Great Britain (non-NFI wooded areas of over 0.1 hectare in extent). There are also 255,000 hectares of groups of trees (that is, clusters and linear tree features of less than 0.1 hectare in extent) and an estimated total canopy cover of 97,000 hectares from lone trees in Great Britain. For Great Britain, that is a total woodland area of 3,719,000 hectares." Neither woodland nor urban NCAs (ONS, 2019, 2020a) estimate separate values for the benefits of NWTs. Habitats within the UK urban areas are estimated using the Land Cover Map 2015, which is now over 5 years old and may not reflect latest land use changes.

Assumptions – Valuation: discounting of ES flows for renewable assets to value the stock of natural capital raises issues of appropriate time horizon and discount rate. Different approaches to this have been used in previous NCAs:

Time horizon: FE – to perpetuity; ONS – 100 years
Discount rate: the Green Book and supplements.

In this study we follow the Green Book standard discount rate schedule and adopt the ONS 100-year time horizon in computing natural capital values.

Critique: Limitations

NCA is a set of methodologies for ES benefit valuation. Some of these methodologies are applicable to NWTs. Where applicable, additional data inputs (e.g., area, age, species) for NWTs may be required. The flood mitigation estimates for NWTs could be usefully refined in future once the currently ongoing work to estimate the benefits of woodlands has been completed.

Approach to extrapolation

Only crude 'order of magnitude' estimation is feasible for some ES, e.g., carbon sequestration, air pollution removal and flood mitigation. This is estimated using 2 basic steps: (i) Divide corresponding total values for an ES benefit estimated in the NCA for woodlands by the total woodland area to obtain an average value per hectare estimate. (ii) Apply this average to the relevant total area of NWTs. This approach is used for the flood mitigation ES. Noise mitigation and urban cooling values approximation require further investigation together with the originators of the approach, namely Eftec.

Use of NCA methods to obtain physical estimates of various ES, then applying values developed for the UK and Treasury Green Book time discount rates to future values is in line with the Green Book approach.

Table A5. Summary options for extrapolation of urban and woodland Natural Capital Accounts to valuing the UK's non-woodland trees (shading indicates recommended route).

	Option 1	Option 2
Outputs	Estimates of ES: - Carbon storage (stock) - Carbon sequestration - Air pollution removal - Surface flooding avoided	
Units	Total for woodland	Total for urban area
Normalisation	ES per hectare	
Data Required	Area of NWT	Area
Data Available	National Tree Map	Ward or region (ONS)
Processing	Sum per tree type	(ES per ha) x area
Scalability	Sum to required scale	Sum to required scale
Comments	Cost of National Tree Map	- Need to separate NWT from woodland to avoid double counting - For some ES need to account for differences in canopy cover between towns

Recommendation

Fit to Project: Medium (Match: Medium in terms of Green Book compliant valuation methods potentially applicable to NWT, yet non-differentiation of non-woodland canopy cover; Confidence: Low, order of magnitude only).

Resourcing: Medium (Availability: Partial; Charge: Free).

Match to project objectives: MEDIUM.

Appendix B: Background information on the five tools reviewed for Part 1 that were not progressed to Part 2

Tool 4: i-Tree Eco

Introduction to i-Tree Eco

Aim of tool: i-Tree Eco is one of the i-Tree suite of tools (www.itreetools.org). It is used for detailing urban forest structure and composition for a given study area. The level of ES provided by the urban forests are then modelled and valued. ES quantified by the tool are: avoided surface water run-off, carbon storage and sequestration and air pollution removal. i-Tree Eco utilises data collected from plot-based field assessments, or from existing datasets such as local planning authority tree inventories. For plot-based projects, the collected data is extrapolated to provide values for the entire study area.

There is a core set of data that is collected as part of each project. Minimum data required for an inventory project includes species and DBH. For plot-based projects minimum data is % plot measured, % tree cover, species, and DBH (i-Tree, 2020). However, most plot-based projects collect a range of additional data to provide information on tree health, crown volume, and plot characteristics, including ground cover and land use.

i-Tree Eco uses five models that calculate urban forest structure and leaf area and, from these, ES delivery. The five models are:

- UFORE-A: Anatomy of the urban forest – This model quantifies urban forest structure and composition through providing information on species composition, canopy cover, tree density, tree condition, size distribution, importance value, replacement cost, associate land cover.
- UFORE-B: Biogenic volatile organic compound (VOC) emissions – This model calculates the amount of VOC emissions produced by the urban forest, and O_3 and CO formation based on VOC emissions.
- UFORE-C: Carbon storage and sequestration - This model calculates the total amount of carbon stored and gross and net carbon sequestered annually by urban trees within the study area.
- UFORE-D: Dry deposition of air pollution - This model calculates the hourly deposition of the following air pollutants: O_3, SO_2, NO_2, CO and PM_{10} and the associated improvement in air quality (%) throughout a year.

- UFORE-E: Energy conservation – This model estimates the effect of trees on the energy use of buildings. This model should not be used in the UK.

Summary of tool use in the UK: i-Tree Eco was first utilised in the UK to undertake an assessment of Torbay's urban forest in 2011. Since then, a further *ca*. 34 i-Tree Eco projects have been undertaken across the UK (plot-based and inventory). This includes 2 in Scotland, 5 in Wales and *ca*. 27 in England. The first in Northern Ireland, for Belfast City, will report in 2022.

An evaluation of i-Tree Eco projects incorporating the views of stakeholders who had been involved with completed projects was undertaken by Raum et al., 2019.

Critique: Limitations

i-Tree Eco only estimates structure and functions at a point in time (Nowak et al. 2008). Repeat surveys on the same plots are required to assess changes in urban forest value.

Accuracy of the quantification of ES delivery (and subsequent valuation) is directly proportional to the underlying computer models. These include the model to calculate leaf area from Leaf-Area Index (LAI) developed by Nowak (1996) from a limited field-collected data set encompassing five species. LAI varies between species, thus species-specific LAI values would yield increased accuracy.

The i-Tree Eco handbook indicates 200 and 250 plots achieve a standard error of ~12 and 10%, respectively. This SE is irrespective of study area. The larger the study area the less likely that 200/250 plots will effectively represent heterogeneity, and higher plot numbers should be used for larger study locations (as in the London i-Tree Eco project).

i-Tree Eco does not account for the full range of ES that urban trees can provide. For example, it does not include: cultural value, noise reduction, educational value, temperature regulation, landscape enhancement and recreation value. Disservices also are not considered, such as allergens, and damage to built infrastructure.

When producing estimates for the NWT contribution to air pollution removal at country, GB and UK scales the costs from Table B1 (or updated costs) should be used. Valuation can be based on the proportion of the area covered by NWT in the total vegetation area for which the benefit of air pollution removal was calculated.

Table B1. Pollutants 2020 Damage costs (£/t) National averages (in 2017 prices)

Pollutant	Damage cost (£/t)
NO_x	6,385
SO_2	13,206
NH_3	7,923
VOC	102
$PM_{2.5}$	73,403

For the more local studies where the emissions from large industrial sources can be present, the damage costs varying with the population density and the size of the chimney should be used (see Air quality appraisal: damage costs toolkit).

Recommendation

Fit to Project: Low (Match: Low due to the non-differentiation of NWT; Confidence: Low due to the valuations being created from urban forest valuation projects and applied to non-urban locations).

Resourcing: Medium (Availability: Partial; Charge: Free (ONS BUA or town/city size datasets)).

Match to project objectives: MEDIUM.

Proposed approach to extrapolation

Table B2. Summary of options for extrapolating i-Tree Eco data to valuing the UK's non-woodland trees (shading indicates recommended route).

	Option 1	Option 2	Option 3	Option 4
Outputs	Ecosystem service estimates: - Carbon storage - Carbon sequestration - Air pollution removal - Avoided runoff (stormwater regulation)			
Units	Per urban forest			
Normalisation	Per tree	Per urban area	Per urban area under canopy	Per urban area under canopy
Data required	Number of trees	Urban area size	Urban area under canopy cover	Total area under canopy cover
Data available	National Tree Map	Urban area (ONS)	Partial (314 towns in Doick et al., 2017). For wards: see Tool 1.	TCOW. Top-down approach using regional non-woodland canopy cover values.
Processing	Sum per tree type	ES x urban area	ES x CC area	ES x CC area
Scalability	Sum to required scale	Sum to required scale	Sum to required scale	Sum to required scale
Comments	N/A	- Intercity variability in CC assumed to be dealt with by 'per urban forest' average - Double counting of woodland would need to be corrected for by subtraction of woodland cover estimate - Excludes non-woodland rural trees - No disaggregation for non-woodland typologies		- Non-woodland estimates based on hand-mapping and NTM (not Scotland), with fieldwork sampling for calibration. - For ha of tree cover outside woodlands in urban areas of GB, England, Scotland, and Wales SE is between 10 and 18%, and higher for individual regions - Accuracy (see Tool 1) - Disaggregation for NWT as lone trees, tree clusters and small woods possible, where appropriate to the ES - ES per area values derived from 'urban' studies; their suitability for application to rural areas would be resource intensive

Tool 5: The Helliwell System

Introduction to The Helliwell System

Aim of tool: The *Helliwell system* was first devised in 1967 to quantify the relative contribution of individual trees to the visual quality of the landscape. It has since been adopted and slightly modified by the Tree Council and the Arboricultural Association and expanded to evaluate woodlands (Arboricultural Association, 2008). Those using this method score trees or woodlands for six named characteristics: tree size (given up to 8 points), useful life expectancy, importance of position in the landscape, presence of other trees, relation to setting (all given up to 4 points) and form (given up to 2 points) (Sarajevs, 2011). The points attributed to those characteristics are multiplied to give a comparative final score and this is further multiplied by an agreed monetary conversion factor to arrive to a monetary visual amenity value for that tree or woodland (Arboricultural Association, 2008). The most recent version of the method, published in 2008, suggests using a conversion factor of £25 per point. This value is agreed by experts based on aspects such as property prices, tourist trade, effects on mental health and the money available for tree planting, conservation and tree management costs and can be adjusted for inflation (Sarajevs, 2011).

There is no calculation of expected accuracy or error for this tool, but this will largely depend on the user's assumptions and scoring as highlighted below.

Summary of Approach use in the UK: Since its adoption by the Tree Council, this method has been used in courts, insurance claims and public inquiries to quantify the visual amenity value of individual trees and woodlands (Helliwell, 2008; Doick et al., 2018).

Critique: Limitations

The Helliwell system was only conceived to value the visual quality of a tree or woodland not the regulatory or social benefits they can give to society, or the cost associated with growing those and the associated potential replacement costs (Helliwell, 2008). This can sometimes be an advantage: Sarajevs (2011) noted that an ancient tree may have been grown at very little cost to an individual or organisation but may have great visual quality in the landscape and therefore be awarded a high Helliwell score; whereas an expensive tree may be badly formed and not suitable for its location and so be placed at the lower end of the Helliwell scoring method. However, this also denotes one of the biggest limitations of the method: in limiting valuation to £102,400 and by not focusing on loss of benefit, compensation to society values are lower in comparison to other appraisal methods where, for example, an individual compromises the health of a high scoring tree (Watson, 2002).

Watson (2002) observed that despite species and condition being essential elements defining the amenity that a certain tree or group of trees offers to a place or society the Helliwell system does not consider these attributes directly, rather indirectly only via size and longevity.

Finally, the Helliwell method was created to be limited to the appreciation of visual amenity of trees and woodlands within the landscape (Helliwell, 2008) and so is not designed to give a comprehensive quantification of the value these trees or woodlands give society.

Recommendation

Fit to Project: Low (Match: Low due to the non-differentiation of NWT; Confidence: Low due to requirement in extrapolation to estimate of 2 of the 8 characteristics).

Resourcing: Low (Availability: Partial; Charge: N/a (does not exist so cost involved in creating)).

Match to project objectives: LOW.

Proposed approach to extrapolation

Table B3. Summary options for extrapolation of the Helliwell system to valuing the UK’s non-woodland trees.

Output	Helliwell value estimate
Units	Per tree or per woodland
Normalisation	N/A
Data Required	- Number of trees - Qualitative tree data
Data Available	- National Tree Map - N/A. Apply standard score
Processing	Sum per tree type
Scalability	Sum to require scale
Comments	Key information missing, violative of tool’s method
Progression of Approach to Part 2 of project not recommended	

Tool 6: Council of Tree and Landscape Appraisers (CTLA)

Introduction to the CTLA

Aim of approach: A guide for plant appraisal (which later led to the CTLA method) was first released by a joint commission formed by the American National Arborist Association and National Shade Tree Conference in the 1950s (Cullen, 2007). This guide aimed to propose a way to place a monetary value on individual amenity trees and has been through numerous reviews. It is now endorsed by the Council of Tree and Landscape Appraisers (CTLA) which is formed by a consortium of members of North American green industry organisations (Doick et al., 2018). The 9th edition, currently used in the UK within i-Tree Eco, was published in 2000 but in 2018 the CTLA approved the 10th edition (Dunster, 2019).

The CTLA methodology uses a Depreciated Replacement Cost approach to value trees as replacement cost data are well understood by urban foresters (Cullen, 2007). The 9th edition includes guidance on the Replacement Cost Method (RCM), the Trunk Formula Method (TFM), the Cost of Cure Method, and the Cost of Repair Method, although the first two are the most widely used (Cullen, 2007). As Cullen (2007) explains “both methods depreciate an initial replacement cost estimate for the tree plus its planting and establishment for Species, Condition and Location characteristics to reflect a defined value”. For example, the TFM appraisal’s value comes from the cross-sectional area of the tree trunk multiplied by a unit tree cost, defined by a Regional Plant Appraisal Committee or local wholesale cost. This maximum value is then reduced by ratings given to condition, functional and external limitations (Purcell, 2019; Watson, 2002).

Different in many ways from its predecessor, the 10th edition is still being scrutinised. Dunster (2019) compared the two CTLA versions, noting that the 10th not only includes three new methods (The Cost Approach, the Income Approach, and the Sales Comparison Approach), all of these are untested in plant appraisal practice and have not yet been accepted in (US) policy or law.

As for Helliwell, there is no calculation of expected accuracy or error for this approach, and this will largely depend on the user’s assumptions and scoring as highlighted below.

Summary of approach use in the UK: UK practitioners started to show an interest in using other appraisal methods beyond the Helliwell system at the late 1990s to early 2000s. As such a Regional Plant Appraisal Committee (RPAC) was formed in 2005 to adapt the CTLA methods to the UK and Ireland (Anon 2005, in Cullen 2007). CTLA has been used in out-of-courts settlements, and in at least one court case (Hollis, 2007).

The CTLA is currently used within UK i-Tree Eco projects to provide a ‘replacement’ value of the trees based on the physical resource alone (i.e., the cost of having to replace the trees should these be lost) and is oft quoted alongside a CAVAT valuation.

Critique: Limitations

The CTLA method considers the replacement cost of a tree or group of trees based on their structural value not their amenity value. Helliwell (2008) pointed out that basing a value of a tree on its replacement value can be a major limitation as often is either impossible or extremely expensive to purchase replacements for medium or large trees.

The CTLA methods do not consider the wider range of benefits trees offer to society.

A positive of the CTLA system is linked to the fact that at least the 9th edition is used and understood by many professionals around the world and there are local groups that provide the information needed for regional estimations.

Proposed approach to extrapolation

Table B4. Summary options for extrapolation of the CTLA methods to valuing the UK’s non-woodland trees (shading indicates recommended route).

	Option 1	Option 2	Option 3
Output	CTLA estimate		
Units	Per tree	Per tree	Per urban forest
Normalisation	N/A	N/A	Per urban area
Data Required	Number of trees	Qualitative tree data	Urban area size (ha)
Data Available	National Tree Map	Not available. Apply standard score.	Area (ha) ONS
Processing	Sum per tree type	Sum per tree type	$CTLA_{normalized}$ x urban area
Scalability	Sum to required scale	Sum to required scale	Sum to required scale
Comment	Key information missing, making this route non-viable	Key information missing, making this route non-viable	Double counting for woodland Excludes rural non-woodland trees No disaggregation for non-woodland typology

Recommendation

Fit to Project: Low (Match: Low due to the non-differentiation of NWT; Confidence: Low (due to use of an average-tree valuation unit).

Resourcing: Medium (Availability: Partial; Charge: Free).

Match to project objectives: LOW.

Tool 7: Greenkeeper

Introduction to Greenkeeper

Aim of tool: Greenkeeper is used to estimate the monetary value of urban greenspace through four benefit categories: physical health, wellbeing, carbon sequestration and local amenity. The tool allows the user to navigate a map of urban greenspaces in GB and explore and compare the annual value of each greenspace's benefits. Site characteristics can also be compared across the following categories: size, coverage of tree canopy, waterbodies and built facilities, $PM_{2.5}$ removal and predicted annual visits.

Summary of tool use in the UK: released in 2020, Greenkeeper has been used by local authorities across eight different urban areas to quantify the value of greenspaces within their portfolio. The tool has also been used to support development projects in St Albans, Thamesmead, and Coventry.

Critique: Limitations

As a tool that fully released in mid-2020, there is no literature that has provided a review of Greenkeeper. With limited methodology documentation available (Greenkeeper, 2020), there is incomplete understanding for the full calculations undertaken for estimating values.

The monetary value of the four benefit categories are based on different approaches, some of which may be considered more robust than others. Local amenity values are calculated based upon market prices and carbon sequestration values are calculated through the price of untraded carbon.

Physical health benefits are quantified in terms of QALYs. QALYs are calculated through self-survey data that measures improvements in an individual's health across multiple health domains. The value placed on a QALY is subjective and may be valued differently depending on the context and application. The National Institute for health and Clinical Excellence (NICE) values QALYs at around £20,000 - £30,000 (Towse and Raftery, 2009), whereas Green Book guidance values a QALY at £60,000 (HM Treasury, 2020). Greenkeeper adopts Green Book guidance on QALY valuation. Noise mitigation valuation in woodland Natural Capital Accounts also uses QALYs at £60,000 (ONS, 2020a; 2020b).

Wellbeing benefits are valued based on the association between income and life satisfaction (Fujiwara, 2014), generating a welfare value for increases in an individual's life satisfaction. This methodology is recognised as an evolving area of valuation (HM Treasury, 2020) and can give rise to double counting issues. For example, individuals in good physical health are more likely to report high life satisfaction. Given physical health benefits are already valued using a different approach, inclusion of both values may pose significant double counting issues.

Greenkeeper only calculates a value for greenspaces within urban areas of high population (>75,000). Trees in towns, peri-urban and rural settings would not be covered. Trees outside of greenspaces are also excluded.

Greenkeeper is a chargeable tool. Summing the data to the required scale for producing UK estimates may be limited by costs.

Proposed approach to extrapolation

Table B5. Summary options for extrapolation of Greenkeeper to valuing the UK's non-woodland trees (shading indicates recommended route).

	Option 1	Option 2
Output	ES estimates: - Physical health - Wellbeing - Carbon sequestration - Local amenity	
Units	Per greenspace	
Normalisation	Per greenspace	
Data Required	None (Adopt %-based approach for calculating non-woodland tree area)	Total non-woodland green-space area
Data Available	OS Greenspaces map & tree cover % per greenspace	OS Greenspaces map & tree cover % per greenspace
Processing	Sum per greenspace	Sum per area
Scalability	Sum to required scale	Sum to require scale

Comments	- Tool is chargeable, which may impact summing to required scales - Restricted to urban areas >75,000 pop. - Rural NWT excluded - Excludes non-green space trees - Excludes visits by tourists and people under 15 years of age - No disaggregation for non-woodland typologies - Double counting: The approach to value improvements in wellbeing may also capture improvements in physical health, and vice versa. Inclusion of only physical health values for final accounts may be most suitable.

Recommendation

Fit to Project: Low (Match: Low due to the non-differentiation of NWT and the exclusion of non-greenspace trees; Confidence: Low as unclear whether the benefits are associated with the greenspace *per se* or the trees on the greenspace (except carbon sequestration).

Resourcing: Low (Availability: Partial (Northern Ireland excluded); Charge: chargeable).

Match to project objectives: LOW.

Tool 8: Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

Introduction to InVEST

Aim of approach: InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a suite of models that quantify and map the values of ES. The models provide information about how changes in ecosystems are likely to lead to changes in flows and benefits, enabling decision makers to assess quantified tradeoffs associated with different management decisions (Sharp et al., 2020).

The key data inputs for mapping are centred on land use and land cover (LULC) types, where each pixel on a map corresponds to a unique raster. The suite covers terrestrial, freshwater and marine systems. Non-woodland tree-based ES that are valued and monetised include:

- Carbon storage and sequestration
- Urban cooling
- Urban flood risk mitigation
- Visitation: recreation and tourism (Non-monetary valuation).

Summary of tool use in the UK: InVEST has been used widely, as one of the most accessible model frameworks for ES (Sharp et al., 2020). Application in the UK has been diverse for assessing land-use change and quantifying ES (Grafius et al., 2016; Redhead et al., 2016; Jackson et al., 2017).

Critique: Limitations

A major limitation for valuating NWT is that the nature of InVEST predominantly relies on mapping values as rasters of LULC types. As such, benefits are always aggregated across a limited number of LULC types. This approach does not consider the likelihood of variation within the same types of LULC. Characteristics that contribute differently to each raster within the same LULC type, such as varying levels of tree canopy, cannot be readily identified or valued.

The models often suggest inputs for LULC types (forest, pasture, agricultural land, shrubland or urban), but to understand the value of NWT, extensive additional data would be required. Feasibly, a network of different LULC types could be used across the models that solely contain varying levels of NWT, if this data was available.

Given these limitations, the models of carbon storage and sequestration, urban cooling and urban flood risk mitigation are unsuitable for calculating value of NWT without significant additional data.

For recreational benefits, visitation rates can be estimated across discrete areas rather than LULC types, so the effects of individual characteristics such as the presence of trees could feasibly be explored in greater detail across different areas. The model utilises a social-based methodology to understand recreational value, which is relatively novel (Jackson et al., 2017) and generally is not as reliable or detailed as traditional survey-based methodology (Brindley et al., 2019). With the availability of other models that do utilise survey-based methodology to estimate and monetise recreational value (for example Tool 7: Greenkeeper) the relative effectiveness of this model is diminished.

The InVEST models rely heavily on user-submitted data for functionality. Guidance and suggestions are provided for possible data sources to use as inputs, but suggestions are predominantly to understand value at an ecosystem level. There is very limited data available that could support an understanding for the value of NWT.

Proposed approach to extrapolation

Table B6. Summary options for extrapolation of InVEST to valuing the UK's non-woodland trees

Output	Relative change in ES estimate
Units	(eco-system level)
Normalisation	N/A
Data Required	(model parameterization)
Data Available	
Processing	
Scalability	
Comments	
Progression of Approach to Part 2 of project not recommended	

Recommendation

Do not progress with InVEST.

Table B7. Summary table of tool performance with respect to individual ecosystem service assessed. Colour scheme: Green = recommend tool for use in valuing the ecosystem service in Part 2; Amber = tool recommended for use in Part 2, estimate not as robust as for green rated approaches and/or data resource requirements outstanding; Red = tool not recommended for use in Part 2.

Ecosystem service / Benefit covered #	Tool, Method, Approach							
	i-Tree Canopy	i-Tree Eco	Urban + woodland NCAs	CAVAT (QM)	Helliwell	CTLA	Invest	Green-keeper
Air pollution removal	X[1]	X[1]	X[2]					
Amenity tree valuation (Replacement cost)				X[3]	X[4]			
Amenity (structural value) (Replacement cost)		(via CTLA)[5]				X[5]		
Amenity (Recreation)			X[6]					
Amenity (Local house price uplift)								X[7]
Climate regulation - carbon (stored & sequestered)	X[8]	X[8]	X[9]				X[10]	X[11]
Climate regulation - cooling (A/C energy avoided)		[X][12]	[X][13]				X	
Climate regulation - warming (heating energy avoided)		[X][12]						
Climate regulation - cooling (avoided red. in productivity)			X[13]					
Noise mitigation			X					
Social and cultural values –well-being								X[14]

Social and cultural values –physical health								X[14]
Stormwater regulation (avoided runoff)	X[15]	X[15]					X[16]	
Flood mitigation			X					
Comments: Model:	International	International	UK	UK	UK	US	International	UK
			Cooling/noise urban only	Replacement cost	Replacement cost	Replacement cost		
	Urban focus	Urban focus	Flood mitigation in woodland only	Amenity tree focus	Single and small groups of trees	Urban focus		Urban focus
				Expert judge	Expert judge			

Footnotes:
[X] means the tool provides only partial valuation for non-woodland tree ES, e.g., only in urban setting or only $PM_{2.5}$.
1. Annual removal (dry deposition) of CO, NO_2, O_3, SO_2, Particulate matter ($PM_{2.5}$) based on UK i-Tree Eco tree data, meteorology and pollution measurements and static modelling. Monetised using location-specific UK social damage costs.
2. Annual removal (dry deposition) of NO_2, O_3, $PM_{2.5}$ (excluded from totals), PM_{10}, NH_3 by woodland, urban woodland, urban grassland based on CEH UK Land Cover Map and dynamic air pollutant transport modelling. Monetised using health impacts of change in pollution exposure.
3. Depreciated Replacement Cost approach combined with Benefits (income) approach. Compensation value for loss of public asset calculated using trunk area base value depreciated and appreciated for population density, visibility, suitability to location, whole tree completeness and condition, and life expectancy.
4. Benefits (income) approach. Visual amenity value calculated using local base value determined by property prices, tourist trade, mental wellbeing, and financial resources for tree planting, appreciated for tree size, life expectancy, importance in the landscape, presence of other trees, relation to setting, and form.
5. Depreciated Replacement Cost approach. Structural value calculated using CTLA 9th Ed. Trunk Formula Method: trunk area base value depreciated for species rating, crown dieback, and land use type.
6. Recreation value calculated as expenditure per trip. Visitor number data from surveys. Tourism not fully valued in Urban NCA. Aesthetic interactions mentioned in tables, but not described in the report text.
7. Benefits to residents living near urban greenspace are based on property prices.

8. Carbon storage (above- and belowground woody biomass), gross and net carbon sequestration calculated for individual trees. Carbon storage calculated as 0.5*tree biomass. Sequestration calculated using growth rate, determined by growing season, species, competition, condition, and height. Monetised using UK non-traded price of carbon.
9. Gross carbon sequestration only. Removal of CO_{2e} from the atmosphere by woodland in the UK calculated from NAEI data for Land Use, Land Use Change and Forestry Sector: forest land remaining forest land and land converted to forest land. Monetised using the projected UK non-traded price of carbon.
10. Carbon storage and sequestration. User-supplied carbon storage densities mapped to land use/land cover pixels e.g., forest. Carbon storage can be in aboveground biomass, belowground biomass, soil, and dead organic matter.
11. Gross carbon sequestration only. Greenspaces from mapping, tree cover from Sentinel-2, carbon sequestration calculated from tree cover and monetised using UK non-traded price of carbon.
12. Avoided carbon emission and energy use from power plants due to cooling or warming effect calculated for individual trees within 18 metres of residential buildings and 6 metres or more in height. Model designed specifically for US, using characteristics of US climate zones: emission factors, construction practices, building characteristics, and energy composition. Monetised through cost savings from air conditioning and heating using UK electricity and fuel costs.
13. Urban cooling calculated for woodland in 11 UK city regions (urban and rural mix) using cooling data from literature for specific greenspace types. Urban woodlands defined as “natural surface” features larger than 0.02 ha containing trees (excluding gardens, grassland, and street trees) or woodlands. 100m cooling zone buffer applied to woodlands larger than 3 ha. Cooling effect for a city region calculated by multiplying the fraction of the city region covered by a greenspace type by the cooling effect for that greenspace type. Monetised through cost savings from air conditioning and benefit from improved labour productivity.
14. Health and wellbeing benefits to urban greenspace visitors are calculated based on visitor (non-tourist) numbers data from surveys, national averages for activity levels in greenspaces, improvement to quality and length of life and reported increase in life satisfaction.
15. Stormwater regulation calculated using local weather data, leaf and bark area to model hourly rain interception, evaporation from leaves, potential evapotranspiration, transpiration, and avoided runoff. Simplified surface and subsurface hydrology, with impervious cover fixed at the US average 25.5%. Default soil and hydrological conditions are used for regions of the US. Typically monetised using costs avoided relative to household standard volumetric sewerage charge rates.
16. Stormwater regulation calculated using the Curve Number method for each pixel defined by land use type (e.g., urban, urban residential, open spaces, forest) and soil characteristics.

Appendix C: Definitions

Term	Definition
Urban	In 2001 a review commissioned by ODPM defined urban areas in England and Wales as those with a population of 10,000 or more. All other settlements were treated as rural[1]. Within Scotland, however, the cut-off between urban and rural was considered at 3,000[2]. In England and Wales, population density has been calculated within a hectare resolution grid while in Scotland density was set at the postcode level[3]. In the UK, is it recognised that aspects other than population density contribute to the definition of urban/rural, including: land that is built over and land which is not, and urban areas are associated with economic separation from the land[1]. International definitions also tend to focus on population density but the population cut-off between urban and rural in each country depends on how the population is distributed therein[3]. Urban areas are also said to be characterized by the presence of administrative structures and a relative concentration of services such as hospitals and financial institutions[4]. 1 Bibby, P. and Brindley, P. (2013) Urban and Rural Area Definitions for Policy Purposes in England and Wales: Methodology (v1.0). 2 Scottish Government Geographic Information Science & Analysis Team, Rural and Environment Science and Analytical Services Division (2018) Scottish Government Urban Rural Classification 2016. The Scottish Government, Edinburgh. 3 Hopkins, J. and Copus, A. (2018) Definitions, measurement approaches and typologies of rural areas and small towns: a review. The James Hutton Institute. 4 World vision (N.A.). Defining urban contexts.
Peri-urban	The concept of peri-urban has not been used by the 2001 review or the work from the Scottish Government [1,2]. Both urban and rural definitions include different tiers of cities and towns separated by their population density but have not distinguished what constitutes peri-urban. The term has been used and defined by the FAO. A review of definitions for peri-urban areas, supported by the FAO, highlighted that they are often considered as urban fringes [5]. It identified five classes of institutional arrangements for peri-urban which depend on the underlying socio-demographic processes that took place,

	especially migration: Village Peri-urban ("rural" places with "urban" consciousness); Diffuse Peri-urban (in-migration from various places); Chain Peri-urban (in-migration from a single place); In-place Peri-urban (areas close to the urban area that result from in-situ urbanisation), and Absorbed Peri-urban (areas close to or within the urban context that have maintained traditional arrangements from original settlers/residents who have ceased to be a majority in the area) [5]. 5 Iaquinta, D. and Drescher, A. (2000). Defining peri-urban: Rural-urban linkages and institutional connections.
Rural	In the UK, rural areas are defined as those areas that are not urban (see above). Worldwide it is also recognised that rural areas have relatively low to no presence of administrative structures and government services. Livelihood activities in rural areas are predominantly focused on agricultural production [4].
Woodland	NFI woodland is defined as land with a minimum area of 0.5 hectare underneath stands of trees, and tree crown cover of at least 20%, or the potential to achieve this. The minimum width for woodland is 20 metres.
Non-woodland trees: - Single tree - Line of trees - Cluster of trees - Hedgerow	The NFI considers tree cover outside woodland in Great Britain as: Lone trees - A single tree, greater than 3 metres tall located in a hedgerow or greater than 2 metres tall elsewhere, of which the canopy does not touch that of another tree. Group of trees - A configuration of 2 or more trees of less than 0.1 hectare in extent. Small woods - Areas of tree cover greater than 0.1 hectare in extent that is too small or too narrow to qualify as NFI woodland (see above).

Appendix D: Supporting information for i-Tree Canopy

Notes on Methodology (i-Tree Canopy and web map)

i-Tree Canopy uses photointerpretation of aerial imagery to determine tree canopy cover. Contributors to the Forest Research Canopy Cover web map assess whether sample points placed randomly within an electoral ward boundary overlay a tree or non-tree in the image. Percentage canopy cover ($CC_{\%}$) is calculated from the ratio of tree points (n) to non-tree points (N):

$$CC_{\%} = 100 \times \frac{n}{N}$$

The area of canopy cover per ward was calculated by multiplying $CC_{\%}$ by the total ward area (in hectares).

The standard error (SE) in CC% is calculated as:

$$SE = \sqrt{\frac{p \cdot q}{N}}$$

where p = n/N and q = 1-p. SE was determined to range from 0.33% to 2.89% (percentage canopy cover).

Canopy cover web map data coverage is incomplete for regions and countries. Hectares of canopy cover for NFI regions and countries were calculated from ward-level data. Percentage canopy cover ($CC_{\%}$) was calculated per NFI region as:

$$CC_{\%} = 100 \times \frac{\sum CC_{ha}}{\sum A_{ha}}$$

where CC_{ha} is the area of canopy cover in each completed ward in hectares and A_{ha} is the area of each *completed* ward in hectares. The total area of each NFI region was multiplied by the regional percentage canopy cover to give hectares of canopy cover for each region. Hectares of canopy cover in regions were summed to give national numbers.

Uncertainties in hectares of canopy cover per ward propagate into relative uncertainties in canopy cover for regions and countries ranging from 0.4% to 13.9%.

Notes on Methodology (i-Tree Canopy and NFI data)

Asset characteristics: quantity

Table 1 gives hectares of non-woodland canopy cover in the NFI regions, countries, and GB from Forestry Commission (2017).

The estimates of trees outside woodland in England and Wales were calculated using the National Tree Map of England and Wales from Bluesky International combined with aerial photography hand-mapping for 217 randomly selected one-by-one kilometre squares, and fieldwork mapping of a subset of these squares. The National Tree Map is a spatial dataset containing polygons representing individual tree canopies, which were categorised into:

- individual trees
- groups of trees (less than 0.05 ha)
- small woods (0.1 ha to 0.5 ha)
- NFI woods (over 0.5 ha).

The estimates of trees outside woodland in Scotland were calculated using the Native Woodland Survey of Scotland woodland map combined with aerial photography hand-mapping for 60 randomly selected one-by-one kilometre squares, and fieldwork mapping of a subset of these squares. The Native Woodland Survey of Scotland woodland map is a spatial dataset containing polygons representing woodland areas with a minimum size of 0.1 hectares. This underlying dataset therefore provides no information on NWTs, and the estimates were based solely on the aerial and field hand-mapping, leading to relatively high uncertainties.

Physical account of ecosystem services: unit factors

Values of NWTs have been estimated for NFI regions; regional values were summed to give valuations for countries. A significant advantage of the i-Tree Canopy tool for assessing natural capital value is the specificity of ES provision unit factors to geographic regions.

Progress by the US i-Tree Cooperative in the parameterisation of i-Tree Canopy for estimating ES provision in the UK in the intervening period between Part 1 and Part 2 of this project enabled the use of i-Tree Canopy without the Part 1 proposal to supplement the tool with UK i-Tree Eco data. Rather, the ES provision unit factor required to convert the stock assessment into an estimate of ES provision was obtained from i-Tree Support and applied directly in Step 2.

ES provision unit factors are calculated by the i-Tree Cooperative for regions of the UK called Secondary Partitions. The i-Tree Eco model is run once for each Secondary Partition, using regional weather and pollution data, leaf area data, tree canopy cover, and species information. Boundaries of Secondary Partitions do not align exactly with NFI regions (Figure D1). Where there was good overlap it was assumed that the Secondary Partition was representative of the NFI region. Where required, unit factors were averaged or duplicated (see Table D3 and Table 4).

Table D1. NFI regions and corresponding i-Tree Canopy secondary partitions. Where two secondary partitions are listed, the mean of the two-unit factors was applied.

NFI Country	NFI Region	i-Tree Secondary Partition(s)
England	North West England	North West
	North East England	North East
	Yorkshire and the Humber	Yorkshire and the Humber
	East Midlands	East Midlands
	East England	Eastern
	South East and London	South East England; London
	South West England	South West
	West Midlands	West Midlands
Scotland	North Scotland	North Scotland
	North East Scotland	North Scotland
	East Scotland	North Scotland
	South Scotland	South Scotland
	West Scotland	North Scotland
Wales	Wales	North Wales; South Wales

i-Tree Canopy relies on hourly rainfall data from selected UK MIDAS weather stations to calculate unit factors for avoided runoff. No rainfall data was available for eight secondary partitions for the i-Tree Eco batch runs, so no unit factor for avoided runoff was provided for these regions. UK Met Office annual rainfall data was used to match secondary partitions without avoided runoff data to those with data, which was used as a substitute (see Table D2).

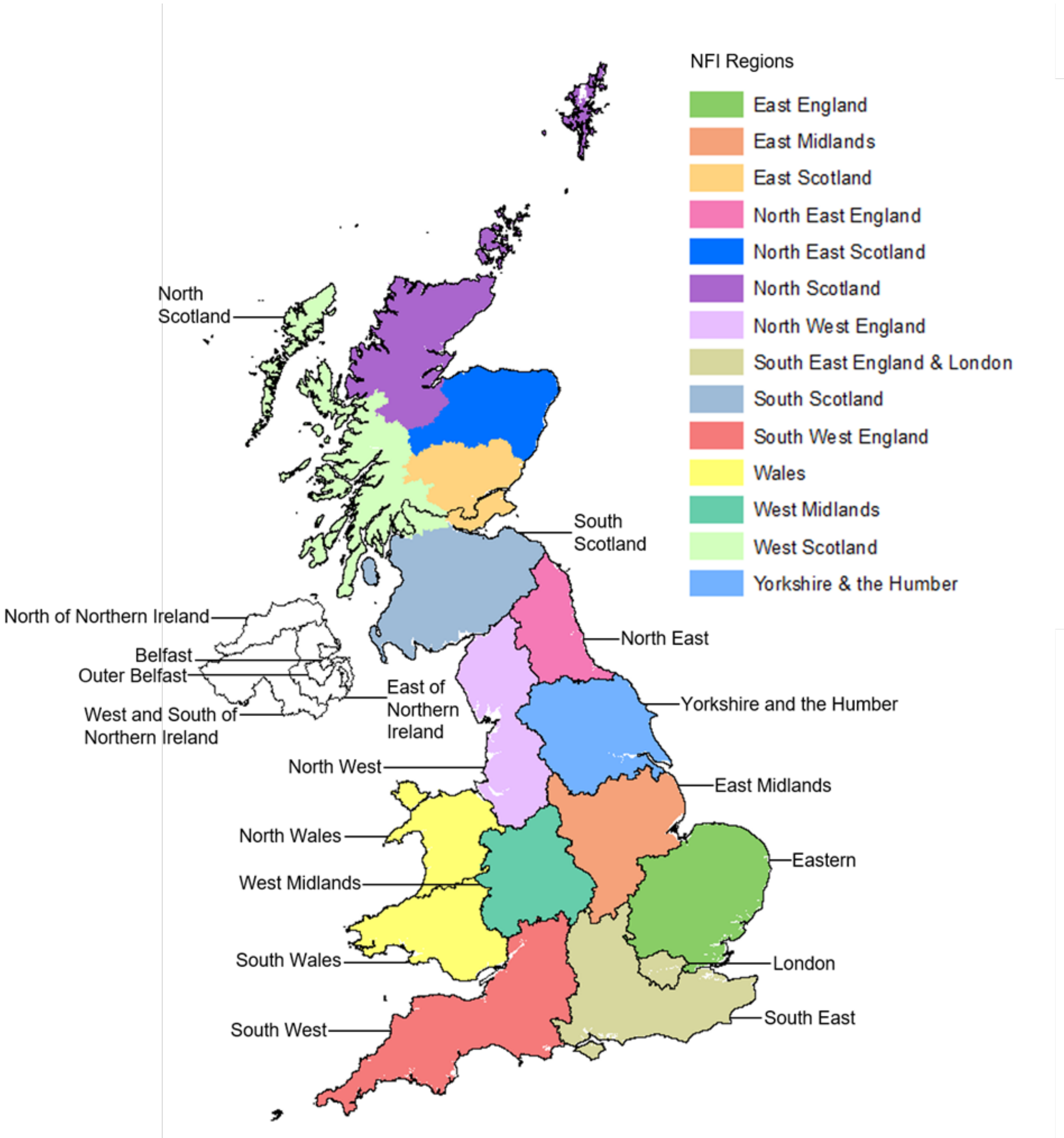

Figure D1. Map of i-Tree Canopy secondary partitions (black boundaries with text labels) and corresponding NFI regions (coloured shading). Note that the North Scotland secondary partition encompasses four NFI regions, and that there are no NFI regions in Northern Ireland.

Table D2. i-Tree Secondary Partitions without avoided runoff unit values, and the secondary partitions used. Where more than one secondary partition is listed, the mean unit factor was used.

Secondary partition without avoided runoff unit factor	Secondary partition used as substitute
North Scotland	North Wales
South Scotland	North Wales
North East	Yorkshire and the Humber
North West	North Wales
London	South East
Belfast	North of Northern Ireland; West and South of Northern Ireland (mean)
Outer Belfast	North of Northern Ireland; West and South of Northern Ireland (mean)
North of Northern Ireland	North of Northern Ireland; West and South of Northern Ireland (mean)

i-Tree Canopy provides a unit factor for removal of PM_{10}* (PM_{10} minus $PM_{2.5}$). UK air quality damage costs are used to calculate the value of pollution removal by NWTs. The PM_{10} UKSDC is calculated by multiplying $PM_{2.5}$ emission by a conversion factor and then applying the appropriate $PM_{2.5}$ UKSDC. Conversion factors vary with emission source. This study used the mean of all emission source conversion factors (0.711)[1] to convert removal of PM_{10}* to removal of $PM_{2.5}$.

Table D3 gives i-Tree Canopy unit factors for i-Tree Secondary partitions, from which were calculated unit factors for NFI regions.

[1] Department for Environment Food & Rural Affairs (2021). Air quality appraisal: damage cost guidance. Annex A, Table 10. Available at: https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance#annex-a-updated-2020-damage-costs.

Table D3. i-Tree Canopy unit factors for ecosystem service stocks and flows.

	i-Tree Canopy unit factors#						
Region (i-Tree secondary partition)	**Carbon storage (stock) (tonne CO_2e per ha)**	**Carbon sequestration (tonne CO_2e per ha per year)**	**NO_2 removal (kg per ha per year)**	**PM_{10}* removal (g per ha per year)**	**$PM_{2.5}$ removal (g per ha per year)**	**SO_2 removal (kg per ha per year)**	**Avoided runoff (m^3 per ha per year)**
North Scotland	281.8	11.2	43.4	2.4	122.7	5.4	301.4
South Scotland	281.8	11.2	31.5	1.7	99.9	4.4	301.4
North East	281.8	11.2	28.2	1.8	45.0	7.6	222.9
North West	281.8	11.2	33.3	2.4	47.2	3.9	301.4
Yorkshire and the Humber	281.8	11.2	28.6	2.2	5,850.7	5.1	222.9
East Midlands	281.8	11.2	24.3	2.1	5,040.9	3.6	195.7
West Midlands	281.8	11.2	28.2	1.4	6,719.6	1.6	284.6
Eastern	281.8	11.2	25.7	1.6	9,794.9	3.3	312.5
London	281.8	11.2	48.1	3.1	1.2	7.9	194.5
South East	281.8	11.2	19.6	1.7	3,572.1	2.1	194.5
South West	281.8	11.2	20.4	2.0	5,669.7	2.5	260.9
North Wales	281.8	11.2	16.0	2.3	7,327.3	8.1	301.4
South Wales	281.8	11.2	38.7	3.1	29,716.4	5.4	470.9
Belfast	281.8	11.2	68.3	3.9	134.8	2.9	360.5
Outer Belfast	281.8	11.2	92.1	5.6	139.0	2.8	360.5
East of Northern Ireland	281.8	11.2	79.4	5.5	13,439.5	2.4	360.5
North of Northern Ireland	281.8	11.2	22.7	1.8	463.6	3.6	360.5
West and South of Northern Ireland	281.8	11.2	36.5	1.2	10,732.0	0.1	360.5

i-Tree Canopy unit factors provided in personal communication from i-Tree Support on 21st May 2021.

Monetary account: Unit values

Carbon stock and sequestration were valued using the UK non-traded cost of carbon central estimate (DEFRA, 2021a).

Air pollution removal was valued using UK air quality damage costs (DEFRA, 2021b). National central damage costs were applied to all NFI regions.

Water providers in different regions take a different approach to charging customers for treatment of runoff. This report followed the approaches taken in published reports from completed i-Tree Eco sample projects. Table D4 gives volumetric waste water charges for the NFI regions, which were used as the unit values for avoided runoff in the calculations. Where more than one volumetric charge was available for a region, the mean was calculated for the unit value.

Table D4. Domestic standard volumetric water charges.

NFI Country	NFI Region	Value per m^3	Source
Wales		£1.5218	Welsh Water 2021-2022 sewerage volumetric rate – foul only[2]
Northern Ireland*	-	£1.868	Northern Ireland Water 2021-2022 sewerage volumetric rate[3]
Scotland	North Scotland	£1.5316	Scottish Water 2021-2022 volumetric waste water charge[4]
	North East Scotland	£1.5316	Scottish Water 2021-2022 volumetric waste water charge
	East Scotland	£1.5316	Scottish Water 2021-2022 volumetric waste water charge
	South Scotland	£1.5316	Scottish Water 2021-2022 volumetric waste water charge
	West Scotland	£1.5316	Scottish Water 2021-2022 volumetric waste water charge
England	North West England	£1.1241	United Utilities 2021-2022 foul drainage volumetric charge[5]
	North East England	£0.7981	Northumbrian Water 2021-2022 metered sewerage volumetric charge[6]

[2] Welsh Water (2021). Scheme of Charges 2021-2022. Available at: https://corporate.dwrcymru.com/en/library/our-charges/scheme-of-charges.
[3] Northern Ireland Water (2021). Scheme of Charges 2021-2022. Available at: https://www.niwater.com/your-bill-and-our-charges/
[4] Scottish Water (2021). Metered Charges 2021-2022. Available at: https://www.scottishwater.co.uk/your-home/your-charges/your-charges-2021-2022/metered-charges-2021-2022
[5] United Utilities (2021). Charges Scheme 2021/2022. Available at: https://www.unitedutilities.com/my-account/your-bill/our-household-charges-20212022/
[6] Northumbrian Water (2021). 2021/2022 metered charges. Available at: https://www.nwl.co.uk/tariffsandcharges

Yorkshire and the Humber	£1.6609	Yorkshire Water 2021-2022 metered sewerage foul charge[7]
East Midlands	£0.9832	Severn Trent Water 2021-2022 metered used water (public sewer) charge[8]
East England	£1.5655	Anglian Water 2021-2022 metered Standard foul water and highway drainage volumetric charge[9]
South East and London	£2.0450	Southern Water 2021-2022 foul water drainage unit volume charge[10]
South West England	£2.2203	Mean of South West Water 2021-2022 measured foul and highway volume charge 11 and Wessex Water 2021-2022 wastewater volumetric charge[12]
West Midlands	£0.9832	Severn Trent Water 2021-2022 metered used water (public sewer) charge

* Note: There are no NFI data for Northern Ireland.

[7] Yorkshire Water (2021). Charges for 2021-2022. Available at https://www.yorkshirewater.com/bill-account/how-we-work-out-your-bill/customers-with-a-meter/
[8] Severn Trent Water (2021). Household Scheme of Charges 2021-2022. Available at: https://www.stwater.co.uk/my-account/our-charges/
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Appendix E: Supporting information for CAVAT

There are two CAVAT methods: Full, and Quick (Doick et al., 2018). The Full method is suited to valuation of individual trees or groups and takes into account:

- Stem diameter
- Population density
- Accessibility
- Functionality
- Contribution to setting
- Life Expectancy.

The Quick method is suited to valuation of tree stock as a whole and takes into account:

- Stem diameter
- Population density
- Functionality
- Life Expectancy.

When used as an additional element in an i-Tree Eco project, either an amended version of the Full method or Quick method has been used.

The amended Full method makes the following assumptions (Rumble et al., 2015):

- Population density: for studies comprising more than one local planning authority area, density is assumed to be constant across the study area.
- Accessibility: Judged to be 100% for trees in parks, street trees and trees in other open areas. Reduced to 80% for trees on institutional land, 40–60% on vacant land and 40% for trees in residential areas and on agricultural land.
- Functionality: Health and completeness of the crown of the tree are taken from the i-Tree Eco measurements % Crown Condition and/or % Crown Missing. Factors influencing management of individual highway trees are not taken into account. To reflect expected reductions of the crowns of highway trees their functionality factor is reduced to 50%.
- Contribution to setting: Not considered.

The Quick method used in i-Tree Eco reports makes the following assumptions (Moffat et al., 2017):

- Population density: Held constant across the study area.
- Functionality: Crown size estimated from the % Crown Missing i-Tree Eco. Crown condition estimated from the % Crown Condition i-Tree Eco measurement.

Table E1. CAVAT unit values from reported i-Tree Eco studies.

Country	NFI Region	Source study	Total CAVAT value (£million)	CAVAT unit value (£million per ha of tree cover)	CAVAT Method
England	North West England	Greater Manchester[13]	24,600	1.2	Unknown
		Oldham[14]	1,790	1.1	AFM*
	Yorkshire and the Humber	Sheffield[15]	9,345	1.4	AFM
	East England	Cambridge[16]	1,035	1.9	AFM
	South East and London	Ealing Borough[17]	3,400	3.7	AFM
		Greater London[18]	43,400	1.9	AFM
		Oxford[19]	2,500	3.4	Unknown
		Petersfield[20]	498	4.1	Quick Method
		Southampton[21]	3,215	3.5	Quick Method
	South West England	Area 1 Highways[22]	40	0.1	Unknown
		Cranbrook[23]	58	1.2	AFM
	West Midlands	Burton-upon-Trent[24]	1,126	4.2	Quick Method

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Country	NFI Region	Source study	Total CAVAT value (£million)	CAVAT unit value (£million per ha of tree cover)	CAVAT Method
		Shrewsbury[25]	512	1.3	Quick Method
Scotland	South Scotland	Edinburgh[26]	3,066	1.6	AFM
		Glasgow[27]	4,000	1.5	AFM
Wales		Bridgend[28]	686	1.3	AFM
		Cardiff[29]	11,200	4.2	AFM
		Newport[30]	2,100	3.6	Amended QM
		Tawe catchment (Swansea)[31]	816	0.7	AFM
		Wrexham[32]	1,400	2.1	AFM

* AFM = Amended Full Method.

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Appendix F: Alternative representation of the NCA logic chain

Table F1. NCA logic chain – an alternative representation.

Step	General approach to ecosystem service valuation on the basis of UK NCA	Application to air pollution	Application to floods	Method in the report
	Benefit Transfer from UK woodlands NCA	Air Pollution, only PM2.5	Flood regulating service, rural NWT only	2a
1	Identify ES value (£ per year) provided by the UK/GB woodland area (from published NCA) (2018 prices)	£938 million by UK woodlands	£218.5 million by GB woodlands	
2	Identify the relevant UK woodland area, e.g., all, UK or GB, or only rural/urban woodlands	2,887,500 ha UK woods (2007)	2,465,533 ha GB woods (2016)	1a,b
3	Calculate £ per ha value for the chosen ES by the relevant UK/GB woodlands	£325	£89	
4	Assume the same value for the ES (£/ha/year) applies to NWT ES provision (adjust if necessary, e.g., by income level difference between areas)	£325	£89	
5	Identify the relevant NWT area, e.g., all or only rural/urban woodlands	742,266 ha of NWT in GB	546,000 ha of rural NWT in GB	1a,b
6	Apply value in step 4 to the relevant NWT area (2018 prices)	£241 million	£48.3 million	
7	Identify annual flow pattern for NWT ES (same each year or different projections, including affected population changes)	Greenbook discount rate (3.5%), Income uplift (2%) and population growth rates	Greenbook discount rate (3.5%) and population growth rates applied	2b
8	Estimated discounted value of NWT ES over the chosen time horizon (100 years is a current standard for renewable assets, trees, use the Green Book discount rate schedule)	Full series not presented here.	Full series not presented here.	3a
9	Sum discounted values to obtain the stock value (NPV) for the NC for this NWT ES	£12.8 billion	£1.4 billion	3b

Appendix G: Unit factors and unit values

Unit factors

Table G1. UK-wide unit factors used in the i-Tree Canopy tool.

Ecosystem service	i-Tree Canopy unit factors
Carbon storage (tonne CO_2e per ha)	281.776
Carbon sequestration (tonne CO_2e per ha per year)	11.2

Table G2. Regional unit factors used in the i-Tree Canopy tool.

Country	Region	NO_2 removal (tonnes per ha per year)	SO_2 removal (tonnes per ha per year)	$PM_{2.5}$ removal (tonnes per ha per year)	PM_{10}* removal (tonnes per ha per year)	Avoided runoff (m^3 per ha per year)
England	N.W. England	0.033	0.004	0.00005	0.024	301
	N.E. England	0.028	0.008	0.00005	0.018	223
	Yorkshire & Humber	0.029	0.005	0.006	0.022	223
	E. Midlands	0.024	0.004	0.005	0.021	196
	E. England	0.026	0.003	0.010	0.016	313
	S.E. & London	0.034	0.005	0.002	0.024	195
	S.W. England	0.020	0.003	0.006	0.020	261
	W. Midlands	0.028	0.002	0.007	0.014	285
Scotland	N. Scotland	0.043	0.005	0.0001	0.024	301
	N.E. Scotland	0.043	0.005	0.0001	0.024	301
	E. Scotland	0.043	0.005	0.0001	0.024	301
	S. Scotland	0.032	0.004	0.0001	0.017	301
	W. Scotland	0.043	0.005	0.0001	0.024	301
Wales		0.027	0.007	0.019	0.027	386
Northern Ireland		0.060	0.002	0.005	0.036	361

Table G3. UK-wide unit factors used in the woodland NCA Benefit Transfer approach.

Ecosystem Service	Unit Factor (per ha, per year)
Carbon sequestration	5.08 tCO_2e
Air pollution removal	0.093 tonnes
Temperature regulation	0.00000058 degrees Celsius
Noise reduction	1.68 buildings
Flood mitigation	10.53 flood storage (m^3)

Unit values

Table G4. UK-wide unit values used in the i-Tree Canopy tool.

Ecosystem service	i-Tree Canopy unit values (£ per tonne)
Carbon storage (stock) and sequestration (as CO_2e)	241
NO_2 removal	6,385
SO_2 removal	13,026
$PM_{2.5}$ removal	73,403
PM_{10}* removal	52,176

Table G5. Regional unit values used in the i-Tree Canopy tool.

Country	Region	Avoided runoff unit value (£ per m^3 avoided wastewater)
England	N.W. England	1.12
	N.E. England	0.80
	Yorkshire & Humber	1.66
	E. Midlands	0.98
	E. England	1.57
	S.E. & London	2.05
	S.W. England	2.22
	W. Midlands	0.98
Scotland	N. Scotland	1.53
	N.E. Scotland	1.53

	E. Scotland	1.53
	S. Scotland	1.53
	W. Scotland	1.53
Wales		1.52
Northern Ireland		1.87

Table G6. Unit values used in the CAVAT tool.

Country	Region	CAVAT unit value (£ million per ha canopy cover)
England	North West England	1.2
	North East England	2.2
	Yorkshire & Humber	1.4
	E. Midlands	2.2
	East England	1.9
	SE. & London	3.3
	South West England	0.7
	W. Midlands	2.8
Scotland	North Scotland	1.5
	North East Scotland	1.5
	East Scotland	1.5
	South Scotland	1.5
	West Scotland	1.5
Wales		2.4

Table G7. UK-wide unit values used in the woodland NCA Benefit Transfer approach.

Ecosystem Service (physical unit)	Unit value (£ per physical unit, per year)
Carbon sequestration (tCO_2e)	241*
Air pollution removal (tonnes)	3,778
Temperature regulation (degree Celsius)	1,023,800,000
Noise reduction (buildings)	99
Flood mitigation (flood storage m^3)	9.1

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