RHS

Frank P Matthews

# Ecosystem services of garden trees

**A guide to selected garden trees and the benefits they provide for people and the environment**

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# Case study taxa (species and cultivars)

*Acer rubrum* 'Brandywine'
*Betula utilis* subsp. *jacquemontii* 'Doorenbos'
*Cercis canadensis* 'Vanilla Twist'
*Corylus avellana* 'Red Majestic'
*Crataegus* × *media* 'Crimson Cloud'
*Crataegus persimilis* 'Prunifolia Splendens'
*Cupressus sempervirens* 'Garda'
*Ilex aquifolium* 'Alaska'
*Ilex aquifolium* 'J.C. van Tol'
*Magnolia* 'Galaxy'
*Malus* 'Comtesse de Paris'
*Malus* 'Scarlett'
*Picea pungens* 'Erich Frahm'
*Picea pungens* (Glauca Group) 'Oldenburg'
*Prunus* 'Fugenzō'
*Prunus lusitanica* 'Myrtifolia'
*Pyrus calleryana* 'Chanticleer'
*Sorbus ulleungensis* 'Olympic Flame'
*Thuja plicata* 'Cole's Variety'

# 1. Who is this guide for?

This guide is for anyone looking for information on environmental benefits provided by garden trees. Garden trees can be differentiated from landscape trees in that they are smaller in stature – typically not taller than 8–12 metres. This guide aims to provide further insight into which taxa provide certain environmental benefits, or **ecosystem services** (ES), and which have the best chance of thriving under changing and challenging climates. It presents background information and key practical findings from a five-year science research project (2020–2025), jointly funded by the Royal Horticultural Society (RHS) and Frank P Matthews tree nursery. The project aimed to understand the benefits of garden trees beyond aesthetic value and food provision. The focus of the field experiments within the project included the study of physical and physiological traits associated with cooling provision, canopy rainfall storage, mitigating soil saturation, and carbon sequestration rates.

**Below. Assessing ecosystem services might seem like a reductive way of looking at trees, whose wonder and beauty have their own intrinsic value. However, by showing how essential trees are in creating liveable environments, an assessment of ecosystem services can help justify the need for more trees and for taking care of those already growing.**



***Crataegus persimilis***

**Right. *Betula utilis* subsp. *jacquemontii* 'Doorenbos'. This rated high to medium for cooling through shading, in the RHS study. *B. utilis* is known as Himalayan birch; the cultivar 'Doorenbos' is also sold as 'Snow Queen'.**



***Betula utilis* subsp. *jacquemontii* 'Doorenbos'**

## 2. What are ecosystem services?

**"With cultivated garden landscapes amounting to approximately 30% of the urban landscape, garden trees can play a key role in delivering their associated services."**

Ecosystem services in the broadest sense are benefits provided to society by nature (Millennium Ecosystem Assessment, 2005). In the context of trees, this ranges from timber supply and temperature regulation to support for human wellbeing. Services are commonly divided into four categories: **provisioning**, **supporting**, **cultural** and **regulating** services. Provisioning services encompass food, timber, genetic resources as well as medicine derived from trees and forest ecosystems. Supporting services include the production of oxygen and the provision of wildlife habitat and pollinator resources. Cultural services incorporate the recreational value of trees, as well as their support for wellbeing and cultural heritage, while regulating services are linked to climate and include carbon sequestration, temperature regulation and flood mitigation (IPBES, 2019). These examples are not an extensive list, but show some of the crucial services provided to us by trees. In the last few decades, and increasingly with a high percentage of

the world's population now living in urban areas, these services have been quantified to highlight the importance of trees in cities. With cultivated garden landscapes amounting to approximately 30% of the urban landscape in the UK (National Ecosystem Assessment, 2011), garden trees can play a key role in delivering their associated services.

Quantification of ecosystem services might seem like a reductive way of looking at trees, whose wonder and beauty have their own intrinsic value. However, by showing how essential trees are in creating liveable environments, quantification of ecosystem services can help justify the need for more trees where they are most needed. It might be a good reminder of how dependent we are on trees to survive as a society, where we are often removed from the living organisms so essential to our life, health and wellbeing.

**Below. The trial at the RHS Field Research Facility, Wisley. The study ran from August 2020 to July 2025, and was a collaboration between the RHS and Frank P Matthews tree nursery. Its aim was to make gardeners aware of the contribution they can make in tackling some specific environmental concerns through tree planting. Specifically, rainfall attenuation, cooling potential and carbon uptake were quantified for a range of garden tree species to better understand how tree species selection can be optimised for the delivery of these ecosystem services.**





**Above. The leaves of *Acer rubrum* (red or Canadian maple) turn bright red in autumn. 'Brandywine', the cultivar in the trial, rated high for cooling through shading and cooling through transpiration, and high to medium for canopy rain storage, carbon sequestration and wind shelter.**

**"Tree taxa in this study were purposely selected to represent common garden trees with a diverse range of leaf and growth characteristics, combined with evidence of moderate drought tolerance."**

# 3. Selection of taxa

Tree taxa in this study were purposely selected to represent common garden trees with a diverse range of leaf and growth characteristics, combined with evidence of moderate drought tolerance. The final list included evergreen, deciduous, needle-leaved, scale-leaved and broadleaved trees. We also avoided trees with many known disservices (e.g. significant allergenicity, emission of volatile organic compounds, or high susceptibility to invasive pests and diseases known at the time of selection), according to peer-reviewed literature and inhouse expertise at the RHS. An online tool (My Garden), managed by the RHS, held the data on more than 5,000 plant taxa (at project initiation) growing in UK domestic gardens and registered by garden owners. This was used to obtain an overview of frequently planted tree taxa. Advice on taxa was also sought from tree expert Nick Dunn at the Frank P Matthews nursery.

The specific effects of root conditions and rootstock were beyond the scope of this study. Once a rootstock is selected for a particular cultivar or variety, it is typically considered the most suitable option, and future grafts of that taxon are likely to use the same rootstock. That said, there may be exceptions, and the rootstock–taxon combinations used in this guide may not always reflect those used elsewhere. Opposite is an overview of the taxa and associated rootstocks used in the experiments within this project, which provide the basis for this guide (Table 1).



***Pyrus calleryana* 'Chanticleer'**

**Table 1. Overview of the taxa studied in outdoor field experiments.**

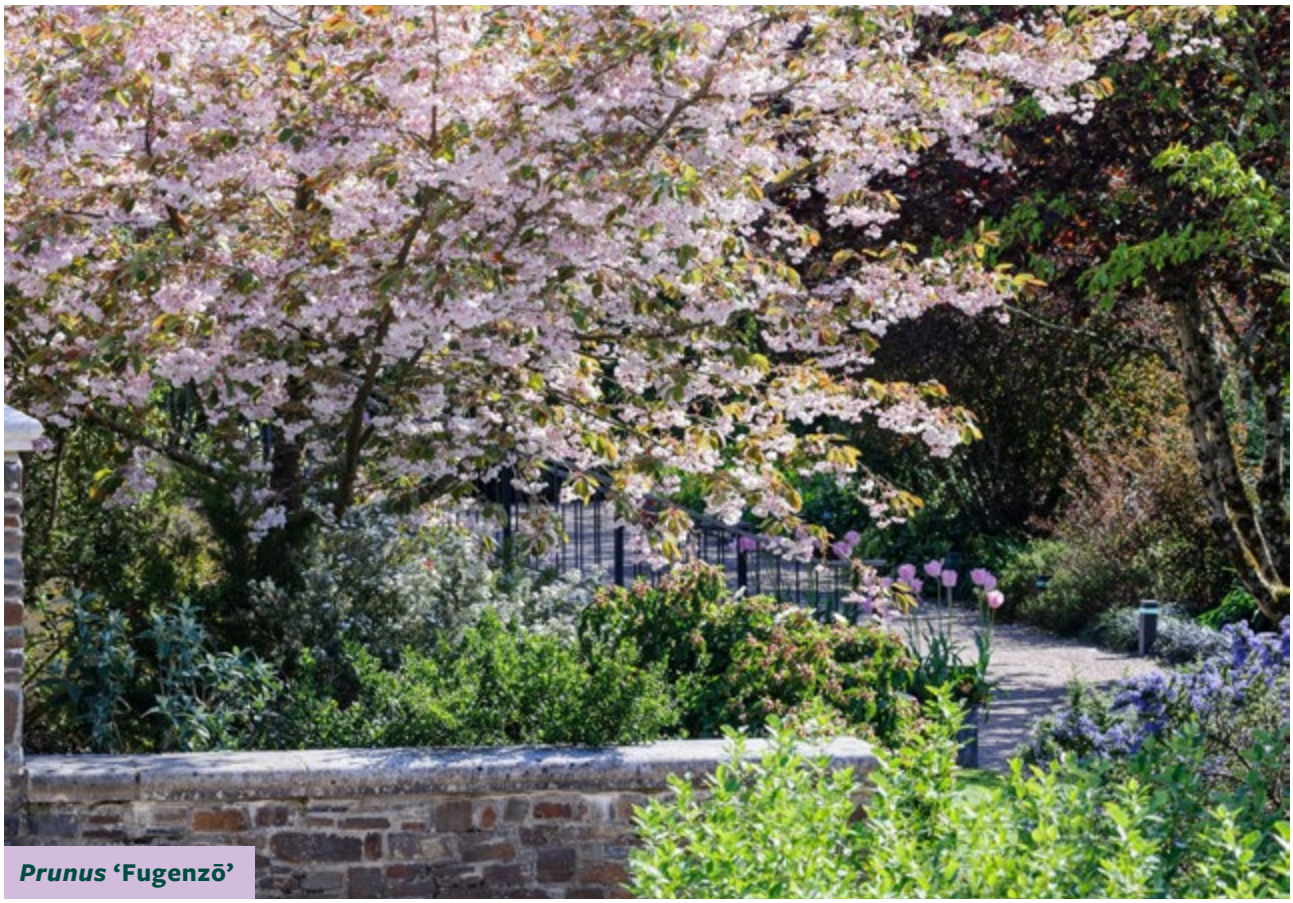
| Genus / species | Cultivar | Rootstock |
|---|---|---|
| *Acer rubrum* | 'Brandywine' | *Acer rubrum* |
| *Betula utilis* subsp. *jacquemontii* | 'Doorenbos' | Not grafted |
| *Cercis canadensis* | 'Vanilla Twist' | *Cercis canadensis* |
| *Corylus avellana* | 'Red Majestic' | *Corylus avellana* |
| *Crataegus* × *media* | 'Crimson Cloud' | *Crataegus monogyna* |
| *Crataegus persimilis* | 'Prunifolia Splendens' | *Crataegus monogyna* |
| *Cupressus sempervirens* | 'Garda' | Not grafted |
| *Ilex aquifolium* | 'Alaska' | Not grafted |
| *Ilex aquifolium* | 'J.C. van Tol' | Not grafted |
| *Magnolia* | 'Galaxy' | Not grafted |
| *Malus* | 'Comtesse de Paris' | 'MM106' |
| *Malus* | 'Scarlett' | 'MM106' |
| *Picea pungens* | 'Erich Frahm' | Not grafted |
| *Picea pungens* (Glauca Group) | 'Oldenburg' | Not grafted |
| *Prunus* | 'Fugenzō' | 'Colt' |
| *Prunus lusitanica* | 'Myrtifolia' | Not grafted |
| *Pyrus calleryana* | 'Chanticleer' | *Pyrus* 'Kirchensaller' |
| *Sorbus ulleungensis* | 'Olympic Flame' | *Sorbus aucuparia* |
| *Thuja plicata* | 'Cole's Variety' | Not grafted |



***Pyrus calleryana* 'Chanticleer'**



**Left and opposite. *Pyrus calleryana* 'Chanticleer', Callery pear, rated high for cooling, carbon sequestration, soil saturation mitigation and pollinator support. Above. The aspects of canopy rainfall storage which we measured in these experiments were canopy volume and leaf area index.**



***Prunus* 'Fugenzō'**

***Prunus* 'Fugenzō' (above; also sold as 'Shirofugen' and 'Alborosea') scored high for cooling through shading and transpiration, and also carbon sequestration and wind shelter/ screening. Its young leaves are a deep coppery brown, turning orange in autumn (below).**



# 4. Ecosystem services

## Cooling

Trees can provide cooling in summer and shelter in winter, regulating the microclimate of a garden year-round. Plants mainly cool their surroundings through plant transpiration and through shading. Transpirational cooling occurs when water in its liquid form within the plant exits the leaf and evaporates into the atmosphere. The process of vaporisation uses solar energy at a rate of 2.45 kJ per gram of water, which makes it possible to calculate the cooling effect (Taiz *et al.*, 2025). A plant's transpiration rate, or water use, is therefore directly linked to how much a tree can cool its surroundings.

Another aspect is cooling through shading, which occurs when leaves intercept and absorb solar radiation. This is linked to traits such as canopy size, leaf area index and even leaf thickness (Monteith & Unsworth, 2013; Zhang *et al.*, 2019). The physiological and morphological traits of plants are therefore important determinants when deciding which trees are best equipped to grow in urban environments and to reduce ambient temperatures. In these experiments, we

assessed cooling potential through the measurement of four key traits: **transpiration rate**, **leaf area index** (total leaf area divided by ground area beneath canopy), **canopy volume**, and **tree height**.

## Canopy rainfall storage

Trees intercept rainfall, with water collecting on leaves, branches and trunks, where it is either retained and evaporates, or reaches the ground from the canopy (throughfall) or by running down the stem (stemflow). Tree canopies slow down rainfall and reduce the size of droplets, both of which help reduce surface flooding and runoff (Carlyle-Moses & Gash, 2011). The extent to which rainfall is captured within a canopy depends on the length, volume and intensity of the rain, but also characteristics of trees such as canopy volume, density, branch angle and leaf size. The aspects of canopy rainfall storage which we measured in these experiments were **canopy volume** and **leaf area index**.

## Soil saturation mitigation

Trees also mitigate flood risk by removing water from the soil through transpiration, especially in summer, thereby reducing soil moisture levels and freeing up space for the soil to absorb additional amounts of rainfall. It allows for more water to filter into the ground during intense and long rainfall, while roots encourage the water to find a way down into the soil (Berland *et al.*, 2017). The root system improves the water infiltration rate into the ground by improving soil structure, increasing soil porosity and water-holding capacity, which mitigates soil erosion and the risk of surface runoff and flooding. Having more trees, especially trees with high water use in the landscape, helps prevent surface flooding.

It's important to note that this does not include flash flooding, which can create enormous damage in a matter of minutes or hours, but rather a level of heavy rainfall that can be absorbed in time by the canopy and the soil beneath to reduce any long-term or surface flooding. The aspect of soil saturation mitigation which we measured in these experiments was the **transpiration rate of trees**.



***Crataegus* × *media* 'Crimson Cloud'.**

**Left. *Crataegus* × *media* 'Crimson Cloud'. The study showed that this cultivar rated high for pollinator support and soil saturation mitigation, and high to medium for carbon sequestration. Most *Crataegus* (hawthorn) cultivars provide support for a range of wildlife. The parents of *Crataegus* × *media* are *Crataegus monogyna* (common hawthorn), which is native across Great Britain and Ireland, and *Crataegus laevigata* (Midland hawthorn), which is native to ancient woodlands in Britain.**



***Malus* 'Scarlett'**

**Above. *Malus* 'Scarlett' scored high for pollinator support, and high to medium for cooling through shading or transpiration, carbon sequestration and wind protection. Below. The plant under test conditions.**



## Carbon capture and storage

Carbon is captured by plants through photosynthesis and stored in various organs, including leaves, stem, branches, and roots. The total amount of carbon stored in a tree is therefore closely related to its size, with roughly half of the dry weight of the wood (after water content of the wood has been removed) consisting of carbon (Taiz *et al.*, 2015). Consequently, the faster a tree grows, the faster it will capture and store carbon. Another key factor is wood density; trees with denser wood store more carbon per unit of wood (Chave *et al.*, 2005). This makes them valuable as longer-term carbon storage holders. Another factor is a tree's longevity, because most of the carbon stored in the aboveground biomass of trees will be released when the tree decomposes (Greenwood *et al.*, 2017; Zanne *et al.*, 2020). It is much harder to know how much carbon is deposited into the soil from the roots. However, the contribution trees make in the form of soil organic matter is substantial for long-term storage of carbon. In a garden context, trees also protect the soil's organic carbon by preventing soil disturbance, while roots improve the structure and stability of the soil. Traits measured in these experiments which relate to this service include **wood density**, **growth rate** and **size**.

## Wind protection / screening

Trees can also act as windbreaks for humans, animals, buildings and other plants. This service will be very different in winter than in summer for deciduous trees. Strategic planting which takes into account the prevailing winds will also improve the effectiveness of this service. Dense canopies and trees with branches towards the ground will provide better shelter than sparse canopies with bare stems. However, wind can place substantial stress on trees, so it's important that a species can withstand exposure to high winds, and newly planted trees should be staked in a wind-prone area. Traits measured in these experiments relating to wind protection and screening include **canopy volume**, **leaf area index** and **tree height**. In addition, growth characteristics such as **multi-stems vs single-stem** trees and **deciduous vs evergreen** were considered.



**Above and bottom right. 'J.C. van Tol' scored high on pollinator support, high to medium for soil saturation mitigation, and low for other services. A second holly cultivar in the experiment, *Ilex aquifolium* 'Alaska' (bottom left), scored low on all services except pollinator support.**

**"The total amount of carbon stored in a tree is closely related to its size. The faster a tree grows, the faster it will capture and store carbon."**



***Ilex aquifolium* 'Alaska'**



***Ilex aquifolium* 'J.C. van Tol'**



***Prunus padus* 'Watereri'**

**Many *Prunus* species are good for pollinators and suitable for garden spaces, including native *Prunus padus* (bird cherry). Its cultivar 'Watereri' is an RHS Plant for Pollinators, and has also been awarded the RHS Recommended: Award of Garden Merit.**

**"Non-native and exotic tree species are increasingly recognised for their complementary value, especially in urban and climate-challenged landscapes."**

## Pollution capture

The air pollutants with the highest threat to human health in UK cities are nitrogen oxide, ozone and microscopic particulate matter (Health Effects of Climate Change, 2023). Trees can also release biogenic volatile organic compounds (BVOC), which can contribute to ozone production and in some circumstances cause a deterioration in air quality of urban landscapes. However, benefits exceed disservices. By and large, trees with large surface areas in the urban landscape mitigate air pollution via the deposition of particles to a greater extent than smaller trees.

In addition, trees can absorb gaseous pollutants through gas exchange via stomata (small openings on the underside of the leaves). Traits measured in these experiments relating to pollution capture were **leaf area index** and **canopy volume**, while known characteristics such as **allergenic pollen** and **high potential for BVOC emissions** were considered.

## Pollinator support

Trees support pollinators by providing essential resources such as nectar, pollen and habitat. Flowering tree species offer a rich food source for bees, butterflies and other insects. In additional to floral resources, trees contribute to structural diversity in landscapes, offering nesting sites, shelter, and habitats. By integrating a variety of tree species into urban and rural landscapes we can significantly bolster pollinator abundance. Native trees often have long-standing ecological relationships with some pollinators, having co-evolved to provide specific resources such as nectar, pollen, and habitat that meet the needs of insect species (Bennett *et al.*, 2020). These symbioses can be critical for maintaining biodiversity and supporting specialist pollinators.

However, non-native and exotic species are increasingly recognised for their complementary value, especially in urban and climate-challenged landscapes. Many non-native trees flower at different times from native species, helping to extend the overall flowering season and provide continuous forage for pollinators (Salisbury *et al.*, 2015; 2025). Additionally, some exotic species are better adapted to harsh environmental conditions, such as drought, poor soils, or urban heat, making them valuable components of resilient green infrastructure. When selected thoughtfully, non-native trees can enhance ecosystem services without displacing native biodiversity.

**Table 2. Parameters linked to high level of ecosystem service delivery. Details of each of these services and how they relate to each trait are described in section 4.**

| Ecosystem services | Traits* | | |
|---|---|---|---|
| **Cooling by shading** | Large crown size / volume | High leaf area index | Taller trees |
| **Cooling through transpiration** | High water use | Large crown size / volume | High leaf area index |
| **Canopy rainfall storage** | High leaf area index | Large crown size / volume | |
| **Soil saturation mitigation** | High water use | | |
| **Carbon sequestration** | Fast growing | Large sized trees | Higher wood density |
| **Heat tolerance** | High water use during heat | Light leaf colour | Higher wood density |
| **Wind protection/ shelter** | High leaf area index | Large crown size / volume | |
| **Air pollution mitigation** | High leaf area index | Coarse leaf surface | |

* The order of traits reflects the importance of their contribution to the service

## Evidence base

The ecosystem services table in this document draws on findings from experiments conducted at RHS Field Research Facility, as well as existing literature, as part of the Ecosystem Services research fellowship/project. Each measurement listed is linked to an ecosystem service, which is described in Table 2. For specification on how each of these traits were measured, see Appendix 1. It is important to note that this trait list is not exhaustive, but rather includes those traits that were considered in the experiments within the project.



***Sorbus ulleungensis* 'Olympic Flame' rated high for pollinator support**



**Measuring sap flow in *Picea pungens* (above) and *Cupressus sempervirens* 'Garda' (below). Sensors inserted into the xylem monitor the speed and volume of water moving upward from the roots. A log was then developed to understand the water use of trees through the summer.**



# 5. Trees and abiotic stress

## Heat tolerance

Heat tolerance in trees refers to their ability to maintain plant function under high air temperatures without experiencing cellular damage or photosynthetic shutdown (Hall, 1992; Porch & Hall, 2013). Some species are more sensitive to heat stress than others, and this sensitivity can be exacerbated by intense solar radiation, particularly in urban environments where surfaces reflect additional heat onto surrounding vegetation. Like humans, trees function best within an optimal temperature range, with the upper physiological limit typically around 45°C. In cities, temperatures often exceed those of surrounding rural areas. These extremes pose risks not only to human health but also to animals and plants.

## Drought tolerance

Drought tolerance can be associated with different physical aspects of a tree; it can be the roots which have the capacity to grow deep and seek water, or the adaptability of changing the growth direction towards moisture (Brunner *et al.*, 2015). It can be a physiological aspect; a 'conservative' approach to water use, meaning that the species / cultivar readily closes its stomata in response to abiotic stresses such as drought or heat (McDowell *et al.*, 2008). Needle-leaved trees such as *Picea* have a smaller leaf area which can provide certain advantages: the small leaf area prevents excessive water loss, while the waxy surface protects the stomata (which are also sunken) from being too exposed to the elements. Another characteristic that can help leaves retain moisture is leaf hairs, as they slow air circulation and therefore help reduce water loss.



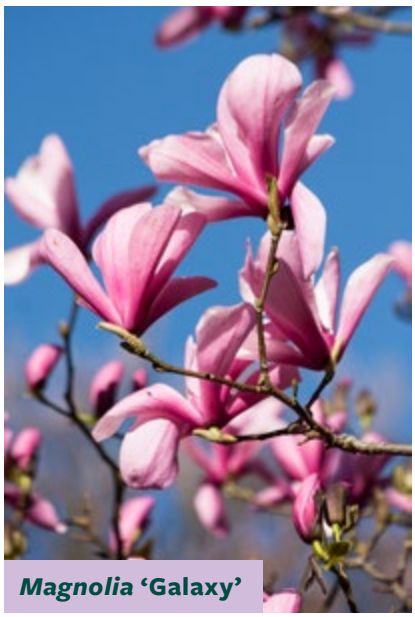
***Picea pungens***

# 6. How were the ecosystem services estimated?

In Table 3, each taxon is listed together with a set of ecosystem services: cooling through shading, cooling through transpiration, canopy rainfall storage, carbon sequestration and wind shelter. Each service is attributed a score with an associated colour, based on the traits measured (Table 2).

A four-tiered colour coding system was developed to describe the delivery of the services: **High**, **High to Medium**, **Medium to Low** and **Low**, following an assessment of how efficiently that specific taxon provides the service, in comparison with the other taxa studied within our project. For cooling through shading, for instance, three traits were measured: tree height, canopy volume and leaf area index (LAI). A taxon was assigned a score for each of these traits, and the sum of the score from all the traits determined which category each was assigned. For example, *Acer* 'Brandywine' scored high on LAI, tree height and canopy volume and was therefore assigned a 'high' score for cooling through shading. However, if a tree scored high in two out of three traits related to cooling through shading, as with *Betula* 'Dorenboos', which has a large crown and considerable height, but a low LAI, it was assigned 'high to medium'.

The cutoff values used to group trees varied depending on the trait being measured. For traits like tree height, the differences between species were statistically significant, making it straightforward to group the trees. For example, *Betula* was significantly taller than *Corylus*. In contrast, traits like water use were more complex to categorise, as they fluctuate with factors such as season and time of day. In these cases, cutoff points were based on visual interpretation of the graphs generated during the experimental trial rather than a statistical threshold. Another aspect, such as whether a tree was evergreen or deciduous – which will affect services such as wind protection and rainfall canopy storage – was added to the score for the measured traits. For instance, *T. plicata* 'Cole's Variety', which had a similar crown volume and LAI to *Magnolia* 'Galaxy', scored higher on wind protection because it is evergreen, and will therefore provide this service when it is more likely to be needed. The underlying data used to determine these scores are provided in Appendix 2. Because we measured a wide range of tree taxa, we were confident that the dataset included trees with



***Magnolia* 'Galaxy'**

**Above. *Magnolia* 'Galaxy', a small tree with slightly fragrant flowers, scored low for pollinator support, but high to medium for cooling through shading or transpiration, carbon sequestration and wind protection. Though similar in crown volume and leaf area index to *Thuja plicata* 'Cole's Variety', it scored lower on wind protection, because 'Cole's Variety' is evergreen and will therefore provide this service in winter.**

**"Because we measured a wide range of tree taxa, we were confident that the dataset included trees with traits spanning both ends of the performance spectrum."**



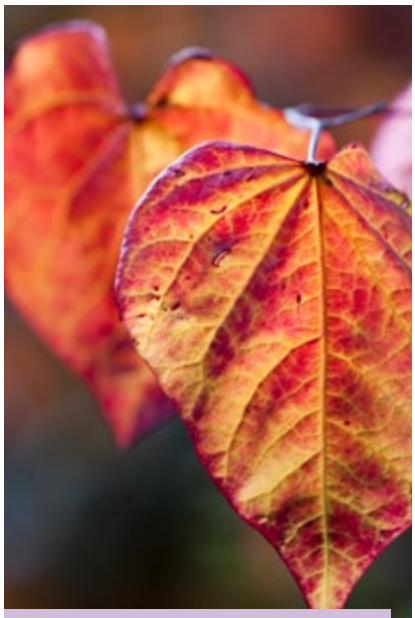
***Malus* 'Comtesse de Paris'**

**Above. *Malus* 'Comtesse de Paris' rated high for pollinator support, and medium to low for cooling through shade or transpiration and soil saturation mitigation. A small rounded crab apple with single white blossom, the small, bright yellow, slightly pointed fruits persist on the tree into winter.**

traits spanning both ends of the performance spectrum. Depending on the ecosystem service being evaluated, each performance category typically included 4–5 taxa. There were around three traits measured per service.

Judgements on pollinator association were made based on the RHS list of plants supporting pollinators in addition to published literature on specific species. Mostly the flowering trees are assigned a 'high' value here, and the non-flowering plants are assigned a 'low'. However, other traits, such as double flowers (*Prunus* 'Fugenzō'), were assigned a 'low' value, since this often means no production of pollen; or if there is any pollen, it's hard for pollinators to access.

Table 4 provides additional insights on the genera included in our experiments, offering a broader overview of ecosystem services beyond those taxa directly measured in this study. It highlights how certain traits or benefits may apply across an entire genus – or, in some cases, may not. This contextual information was compiled through literature reviews conducted during the experimental design phase.



***C. canadensis* 'Forest Pansy'**

***Cercis canadensis* cultivars such as Lavender Twist ('Covey'), right, and 'Forest Pansy' (above) are known for their small pink flowers and autumn colour. The cultivar in the study, 'Vanilla Twist', scored low or medium to low for all ecosystem services.**



***C. canadensis* Lavender Twist ('Covey')**

**Table 3. A four-tiered colour coding system based on the delivery of service: high, high to medium, medium to low and low. Each level is based on the comparison between taxa in the field experiments within the project in the period 2020–2024.**

| Cultivar | Cooling through shading | Cooling through transpiration | Canopy rainfall storage | Soil saturation mitigation | Carbon seqestration | Wind shelter / screening | Pollinator support |
|---|---|---|---|---|---|---|---|
| *Acer rubrum* 'Brandywine' | High | High | High to medium | Medium to low | High to medium | High to medium | Low |
| *Betula utilis* subsp. *jacquemontii* 'Doorenbos' | High to medium | Medium to low | Medium to low | Medium to low | Medium to low | Medium to low | Low |
| *Cercis canadensis* 'Vanilla Twist' | Medium to low | Medium to low | Low | Low | Medium to low | Low | Low |
| *Corylus avellana* 'Red Majestic' | Medium to low | Medium to low | Low | Low | Medium to low | Low | High to medium |
| *Crataegus* × *media* 'Crimson Cloud' | Medium to low | Medium to low | Low | High | High to medium | Low | High |
| *Crataegus persimilis* 'Prunifolia Splendens' | Medium to low | Medium to low | Medium to low | High | Medium to low | Medium to low | High |
| *Cupressus sempervirens* 'Garda' | High to medium | High to medium | High | Low | High to medium | High | Low |
| *Ilex aquifolium* 'Alaska' | Low | Low | Low | Low | Low | Low | High |
| *Ilex aquifolium* 'J.C. van Tol' | Low | Low | Low | High to medium | Low | Low | High |
| *Magnolia* 'Galaxy' | High to medium | High to medium | High to medium | Medium to low | Medium to low | High to medium | Low |
| *Malus* 'Comtesse de Paris' | Medium to low | Medium to low | Low | Medium to low | Low | Low | High |
| *Malus* 'Scarlett' | High to medium | High to medium | Medium to low | Medium to low | High to medium | High to medium | High |
| *Picea pungens* 'Erich Frahm' | Low | Low | Low | High to medium | High to medium | Low | Low |
| *Picea pungens* (Glauca Group) 'Oldenburg' | Medium to low | Medium to low | Medium to low | High to medium | Medium to low | Medium to low | Low |
| *Prunus* 'Fugenzō' | High | High | Medium to low | High to medium | High | High | Low |
| *Prunus lusitanica* 'Myrtifolia' | Medium to low | Medium to low | High to medium | High to medium | High to medium | High to medium | High |
| *Pyrus calleryana* 'Chanticleer' | High | High | High to medium | High | High | High to medium | High |
| *Sorbus ulleungensis* 'Olympic Flame' | Medium to low | Medium to low | Low | Medium to low | High to medium | Low | High |
| *Thuja plicata* 'Cole's Variety' | High to medium | High to medium | High | High | Medium to low | High | Low |

High High to medium Medium to low Low

**Table 4. Judgements on ecosystem services associated with tree genera, based on selected refences and nursery information.**

| Genus | Information and traits |
|---|---|
| *Acer* | One native species, *Acer campestre*. Large number of cultivars, especially appreciated for their leaf shape, size and colour. Largely a temperate genus, though species of *Acer* occur in tropical Asia. Many species/cultivars with flowers and fruit, ranging from drought tolerant to drought sensitive. Large species can give good shading and provide canopy rainfall storage. The cultivar *A. rubrum* 'Brandywine' has been observed to have good adaptability to heat. |
| *Betula* | The genus has two native species: *Betula pendula* and *Betula pubescens*, both considered pioneer species and fast growing and tolerant to exposed conditions and early competition from weeds. *B. pendula*, *B. pubescens* and *B. utilis* are found to be sensitive to drought, though tolerant of cold conditions. However, people with pollen allergies often react strongly to *Betula* species. |
| *Cercis* | *Cercis* need a long, warm growing season to tolerate cold seasons. Edible spring flowers. Some species of the genus are very drought tolerant. No native species. |
| *Corylus* | *Corylus* has 16 species, with one native species, *Corylus avellana*, though all are native to the northern hemisphere. Good for wildlife. Species and cultivars that are not dark-leaved can be heat tolerant. Produces edible nuts. Tolerant of air pollution and good shade tree. |
| *Crataegus* | *Crataegus* has many species and cultivars, most of which provide support to a range of wildlife. Spring flowers and fruit. Some tolerant to drought. *Crataegus monogyna* and *Crataegus laevigata* are native. |
| *Cupressus* | Drought tolerant species and provides good cooling in summer. The dense canopy gives opportunity for birds to nest and take shelter. Can give shelter and rainfall canopy storage in winter months. There are no native species. |
| *Ilex* | *Ilex* has one native species, *Ilex aquifolium*, though other species from this genus belong to temperate and tropical climates. Produces flowers and berries for birds and pollinators. Many garden cultivars available. NB. Only female trees will produce fruit. |
| *Magnolia* | Needs protection, moist and nutrient rich soil. Thrives in the warmer regions of temperate climates. There are no native species. |
| *Malus* | The whole genus is considered good for pollinators and is valuable for biodiversity. Provides flowers and fruits. There is one native, *Malus sylvestris*, which is a very hardy species. Many cultivars available for smaller garden spaces. |
| *Picea* | Many hardy species, both in relation to wind and cold. Prefers acid soils. Can have good wind shelter capacity when established. *Picea* is not generally recommended to plant in the UK due to its susceptibility to the bark beetle *Ips typographus*. There are no native species. |
| *Prunus* | *Prunus* has a large variety of species and cultivars suitable for garden spaces. The genus also has a lot of species with edible fruits. Many *Prunus* species are good for pollinators, except those with cultivated double flowers. Some have high tolerance of cold, drought and windy conditions. *P. avium*, *P. padus* and *P. spinosa* are native. |
| *Pyrus* | *Pyrus* has a large variety of species and cultivars suitable for garden spaces, including domestic edible pear varieties. Fruits and flowers valuable to wildlife. Many with some tolerance to warm and somewhat dry conditions. Some tolerant to heat and drought. *P. cordata* probably native. |
| *Sorbus* | There are many native *Sorbus* species. *Sorbus aucuparia* is our most widespread, which is great for wildlife. Many cultivars available and appreciated for their autumn leaves and smaller size suitable for a garden space. Provides fruits and flowers. |
| *Thuja* | Evergreen and dense. High canopy rainfall storage capacity, good for cooling through shading and can provide shelter for wildlife year-round. Leaves have a pineapple smell when crushed. Useful barrier to wind and pollution. There are no native species. |

Following the Botanical Society of Britain and Ireland, 'native' in this study indicates 'native to Great Britain and / or Ireland'.

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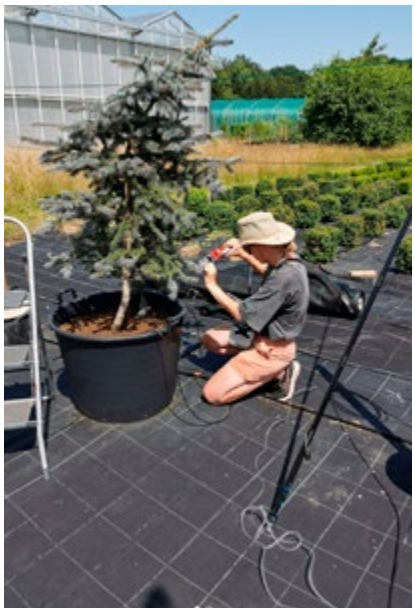
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# Appendix 1

## Measurements

The two large-scale outdoor field experiments were conducted at the RHS field research facility to evaluate 19 tree taxa. The experiments were initiated in February 2021 and 2023 respectively, each running for a duration of two years. Trees were planted in containers, 130 L in the first experiment and 100 L in the second, and placed on geotextile-covered ground with drip irrigation and supporting fencing. Each tree taxon was represented by 5–6 replicates, and moisture probes were installed to monitor substrate moisture content.



**Above. The field experiment at the RHS Field Research Facility, Wisley, July 2021.**

## Leaf area assessment

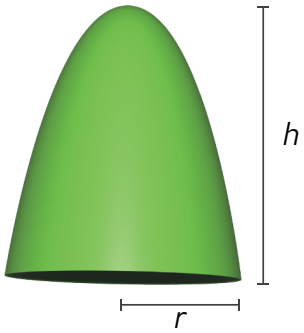
To assess leaf area, a minimum of 3 branches of varying length were selected from each taxon. All leaves were then removed from these branches and their surface area measured with a WinDias 3, Leaf Image Analysis System (Delta-T Devices Ltd, UK). We then obtained a correlation between branch length and leaf area (increasing the number of branches if necessary to achieve a correlation/$R^2$ of 0.8 or more); to extrapolate the measurements to the whole plant, we measured the length of all branches (thicker than 5 mm) on all trees and estimated the total leaf area per branch using the correlation. For each tree, total leaf area was calculated as the sum of the leaf areas of all its branches

## Leaf area index

Leaf area index (LAI) represents leaf area per unit of projected ground surface. To assess LAI, we measured the crown width and breadth of each individual tree. Assuming a circular crown shape, we then calculated the projected crown area for each tree. Total leaf area was then divided on total projected crown area to obtain the LAI.

## Crown volume

Crown width and depth were used to estimate crown volume, along with canopy height, which was defined as the vertical distance from the lowest branch to the top of the tree. Total tree height was also recorded, as it is a key trait associated with several ecosystem services, including carbon sequestration and microclimate regulation through shading. Crown volume was estimated using the formula for the volume of a paraboloid ($V = \frac{1}{2}\pi r^2 h$), where $r$ is the crown radius (half the crown width) and $h$ is the crown height. To




Volume of crown estimated using formula for volume of paraboloid ($\frac{1}{2}\pi r^2 h$)



**Measuring the diameter of individual branches on a tree. The branch volumes are calculated and then summed, together with that of the stem, to estimate the total woody biomass.**

approximate crown density, total leaf area was divided by the estimated crown volume.

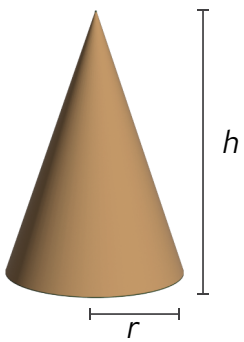
## Woody biomass

Total tree height was measured using a measuring tape, from the base of the stem to the top of the tree. For trees with a drooping growth habit, such as *Corylus avellana* 'Red Majestic', height was measured to the tip of the longest branch to accurately reflect the full extent of vertical growth. This approach was necessary because stem volume was estimated using the cone volume ($V$) equation ($V = \frac{1}{3}\pi r^2 h$), where $r$ is the stem radius and $h$ is the total stem height. In cases of multi-stemmed trees, each stem was measured individually, and the volumes were summed to estimate total woody biomass. Each branch was also treated as a cone, with volume calculated using branch length and width as input parameters.

During the first trial and the first year of the second trial, total biomass was estimated by summing the calculated volumes of stems and branches. At the end of the second trial, a destructive harvest was conducted: all trees were cut down and separated into stems, branches, and, where applicable, leaves (for evergreen species). This allowed for a direct and accurate assessment of total biomass through weighing.

## Wood density and water content

For wood density, 3 fresh cores (5 mm diameter) were extracted using a stem corer, from the main stems while the trees were still growing. Each core was then weighed directly, using a high precision scale and dimensions measured for volume estimations. Cores were then dried in the oven for three days at 70°C, before dry weight was assessed. Wood density was calculated dividing the dry weight by the fresh volume. Water content of the wood was assessed taking the fresh weight minus the dry weight, divided by the dry weight.




Volume of stem estimated using formula for volume of cone ($\frac{1}{3}\pi r^2 h$)

## Sapwood area and Huber value

Sapwood is the wood beneath the bark and cambium, where water and nutrients are transported from roots to shoot. There is usually an active part of the sapwood and an inner non-active heartwood, whereas in young trees most of the wood will be active sapwood. Therefore, sapwood can be measured by estimating the area of a circle and discounting for the depth of bark and cambium. The Huber

value is a ratio between sapwood cross-sectional area and leaf area (sapwood $cm^2$ / leaf area $cm^2$). It can be used as an indication of the relationship between hydraulic supply capacity (sapwood area available to transport water) and transpirational demand (water use per unit leaf area). The higher the ratio, the higher the hydraulic capacity and drought tolerance, although it is often used as one indicator among several indicators, due to the many factors that can affect both the sapwood growth and the leaf area. Sapwood area was measured during the first spring, and the second summer and again during the second autumn for both experiments to see how the growth had evolved. However, leaf area measurements, being very time-intensive, were not measured frequently. The Huber value was calculated in those instances where this was applicable, i.e. where leaf area and sapwood area were measured during the same season.



**Above. A higher ratio of sapwood area to leaf area indicates advantages in the relationship between water supply (through sapwood) and water demand (by leaves), enhancing resilience to water and heat stresses. *Prunus avium* (wild cherry, above) is a native example.**

## Substrate measurements

Twenty moisture probes were used in the first trial (SM150, Delta-T Devices Ltd.), with one probe installed approximately 20 cm deep in the substrate of two trees per taxon. In addition, point measurements were conducted to assess whether trees needed additional watering. Custom-made holes were drilled 5 cm from the bottom of the containers, where an SM150 probe was inserted to assess substrate moisture content. In the second trial this was done weekly in the summer, whereas fewer measurements were conducted for the first trial. A log was developed to understand the water use of the trees throughout the summer and to assess it together with sap flow measurements.

**Below. Taking stomatal conductance measurements, using a handheld infrared gas analyser.**



## Stomatal conductance

Stomatal conductance was measured using a handheld Infrared gas analyser (LCi, ADC Bioscientific). Three mature leaves were selected to be measured on three trees per taxon for replicates. Due to the size of the trees, a ladder was used to access the crown of the tallest trees. This was repeated on two days of full sun, to understand the leaf level photosynthesis, stomatal conductance as well as leaf temperature and solar radiation for the trees. It was repeated in summer for both experiments. Each measurement day took from four to five hours.

## Water use

In the first trial, three out of six replicate trees per taxon were installed with sap flow sensors, using the Heat Pulse



**Above and bottom. Sap flow sensors were inserted into three holes drilled in the stem and wired to customised solar panels. Hourly heat pulses were used as a tracer to calculate how fast sap moved up the stem. This, combined with estimates of sapwood area, allowed the total transpiration value to be calculated.**

Velocity (heat ratio) method (SFM1, ICT, Australia). Three holes of 5 mm were drilled into the stem about 20–30 cm from the ground. Then, the sensors were installed and wired up to customised solar panels. The sensors were programmed to record the ratio of the heat pulse every hour. Data were downloaded monthly, and raw data were post-processed following Burgess *et al.* (2001). To calculate how fast the heat pulse was travelling from the middle heat probe to the upper and lower thermocouple, equations were used to account for wound correction and misalignment (Burgess *et al.* 2001). The last step included using wood density and stem water content values to convert it into how fast sap was moving up the stem per area of sapwood ($cm^3\ cm^{-2}\ h^{-1}$). For total transpiration values, these values were upscaled by multiplying this value with total sapwood area of a given taxon.

## Water use in response to radiation, relative humidity and air temperature

To understand the dynamic of the water use, how each taxon transpired in response to increasing temperatures, RH or radiation, a linear mixed model was developed. The statistical analysis was done in RStudio. The model selected was a Bayesian method, which gives a posterior distribution and a 95% confidence interval for estimated outputs. To predict sap flux at any given time, each taxon and its interaction with the various meteorological drivers were used as predictors. Because of the high autocorrelation in the data, three time points, at 08:00, 13:00 and 18:00 BST in July, were used in



the first experiment, to understand the influence of peak air temperature, peak solar radiation and peak air dryness (low RH). A model was developed for each hour selected, with taxa and block included as random effects. The fixed effects included air temperature, squared expression of air temperature, relative humidity, soil temperature and year (2021 and 2022). Square expressions were included because of the nonlinearity between air temperature and solar radiation with sap flux.

## Rainfall interception by tree crowns

An outdoor 'rainfall simulator' was used to investigate the potential for a taxon to hold rainfall in the crown and thus reduce the rainfall reaching the ground below. Two values were obtained: rainfall collected directly under each crown and rainfall collected in the catchment area of the rainfall simulator. The height of the emitter nozzle was adjustable, and depending on the height of the trees, the nozzle was placed at a similar distance to the tip of each tree crown for easier comparison. The trial was done on days when the wind speed was less than 5 mph.



**The rainfall simulator. 'Rain' was emitted through the nozzle at a similar distance to the tip of each tree's crown. Rainfall was then collected directly under each crown and also in the catchment area of the simulator.**

# Appendix 2

## Research data used to quantify delivery of ecosystem services

Figures 1–10 visualise the data behind the parameters listed in Table 2. The first field experiment (2021–2022) included nine taxa, represented here by their genus (*Crataegus*, *Cupressus*, *Ilex*, *Magnolia*, *Malus*, *Picea*, *Prunus*, *Pyrus* and *Sorbus*), and the second field experiment (2023–2024) included ten (*Acer*, *Betula*, *Cercis*, *Corylus*, *Crataegus*, *Ilex*, *Malus*, *Picea*, *Prunus* and *Thuja*).

### Total tree height per taxon for each experiment

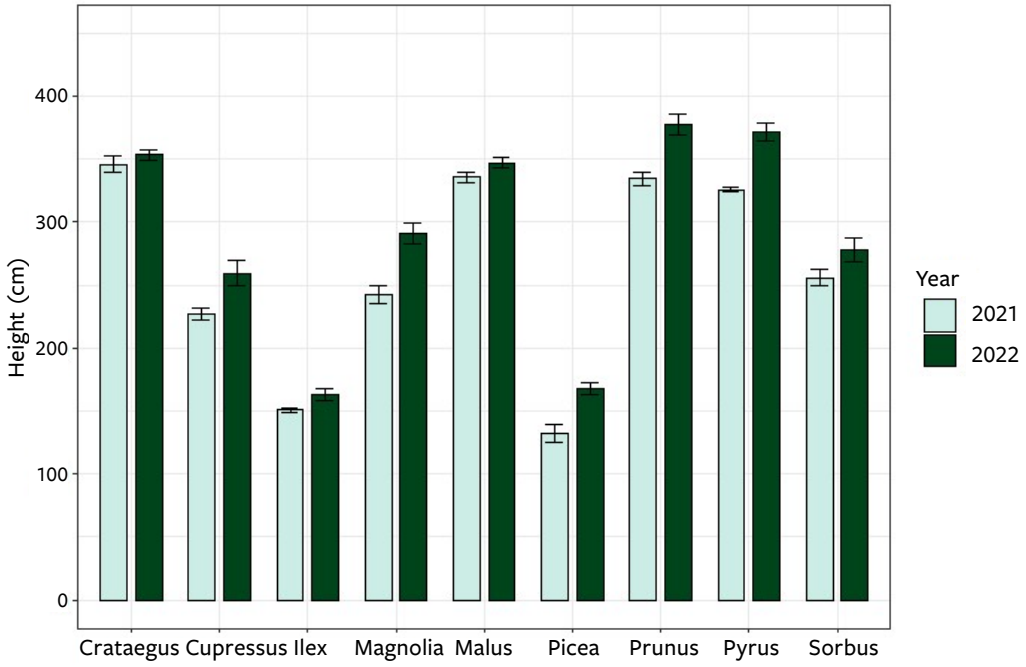



**Figure 1. Total tree height per taxon, average taken from six trees in 2021 and 2022. This parameter was used in estimation of cooling capacity and carbon capture and storage.**

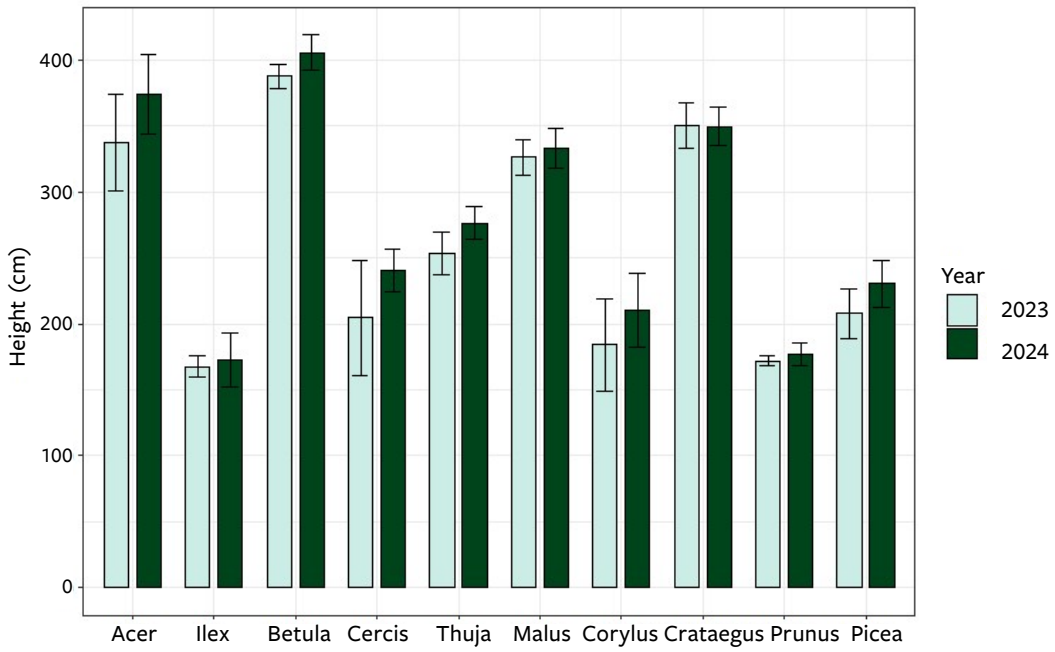



**Figure 2. Total tree height per taxon, average taken from five trees in 2023 and 2024. This parameter was used in estimation of cooling capacity and carbon capture and storage.**

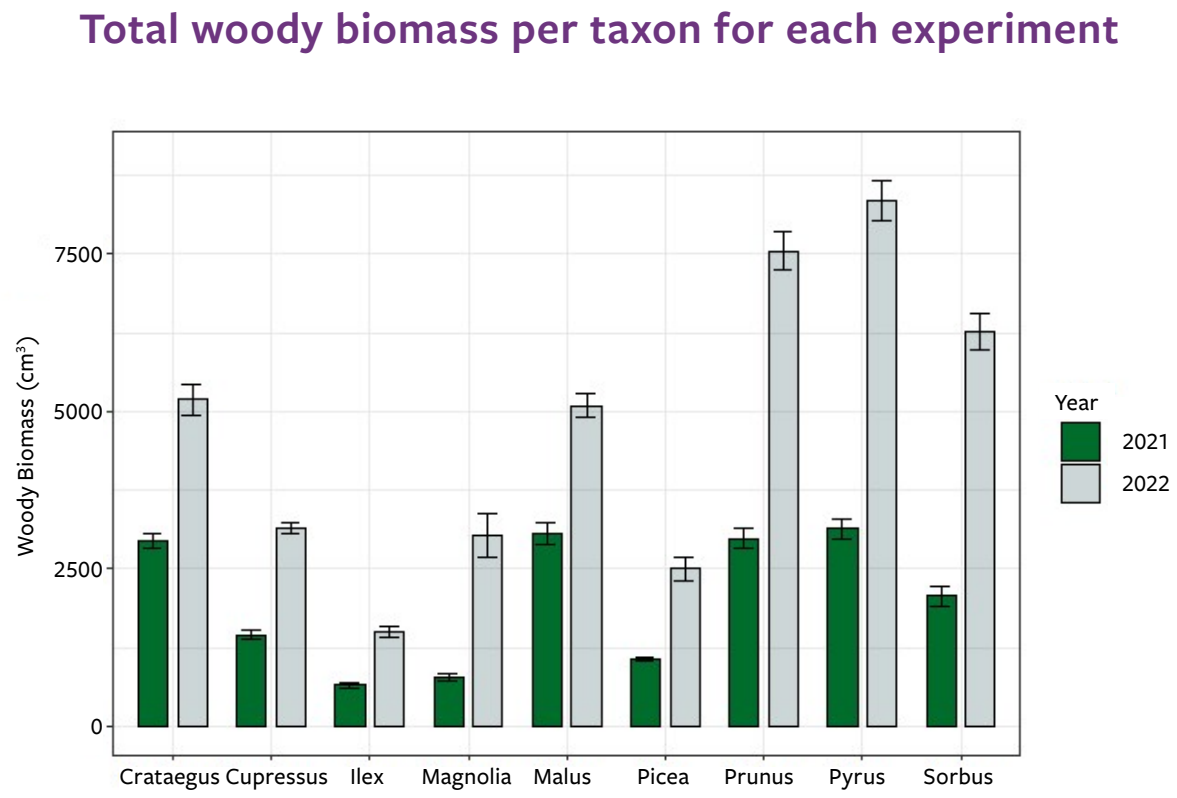



**Figure 3. Total woody biomass per taxon, average taken from six trees in 2021 and 2022. This parameter was used in estimation of carbon capture and storage.**

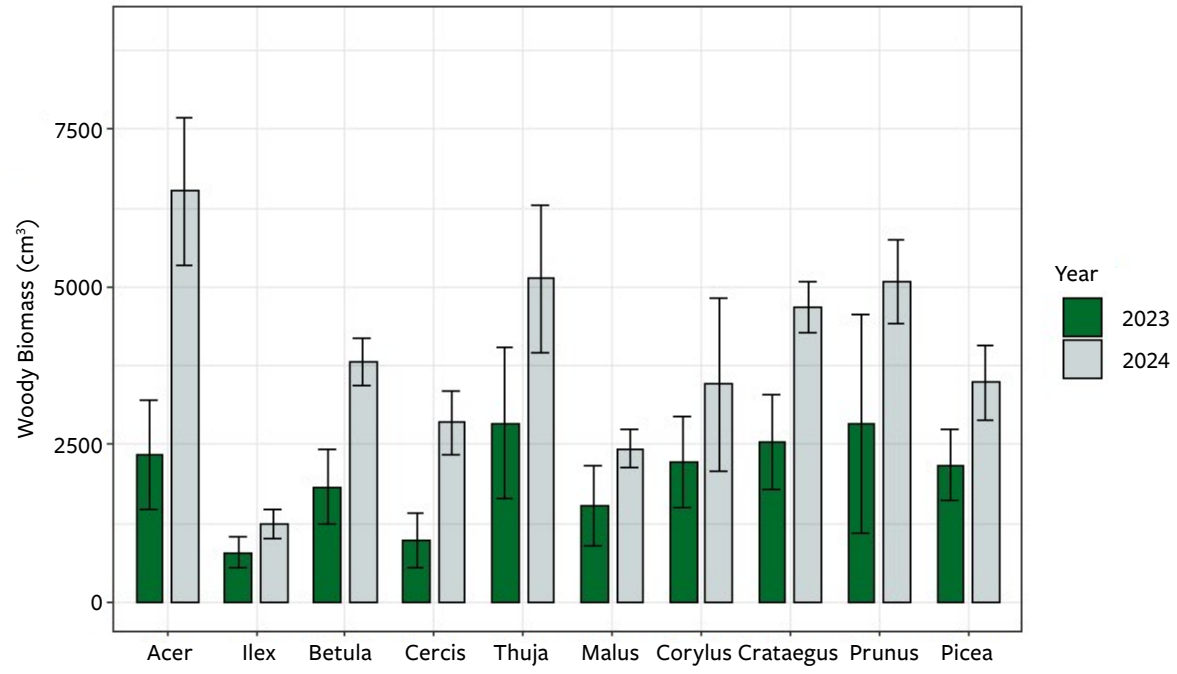



**Figure 4. Total woody biomass per taxon, average taken from five trees in 2023 and 2024. This parameter was used in estimation of carbon capture and storage.**

## Total crown volume per taxon for each experiment

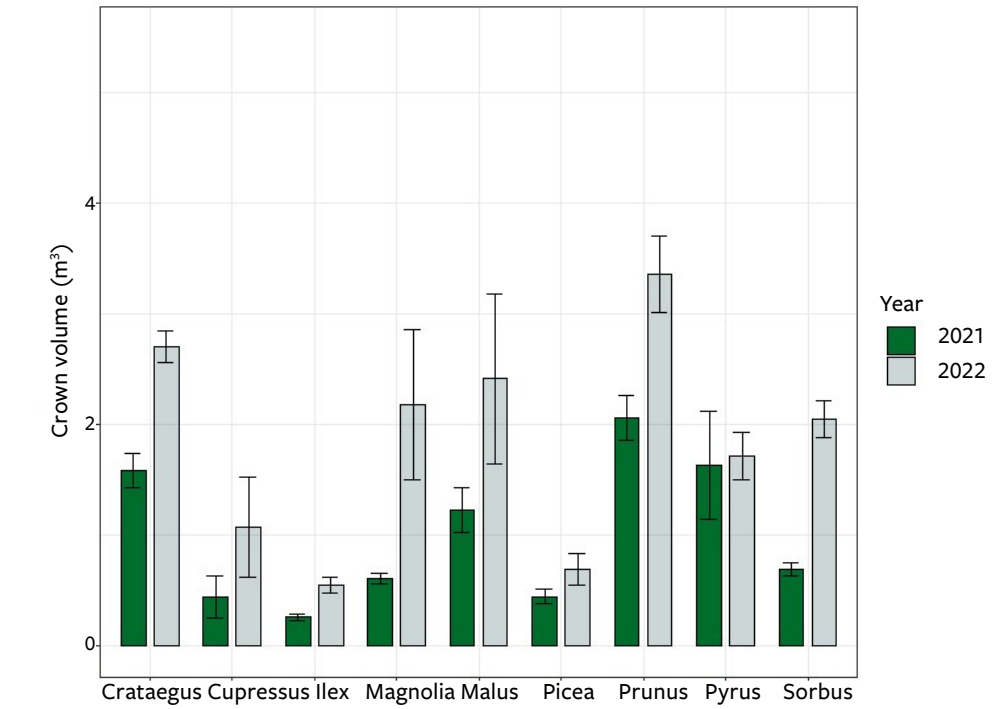



**Figure 5. Total crown volume per taxon, average taken from six trees in 2021 and 2022. This parameter was used to estimate canopy rainfall storage and cooling through shading.**

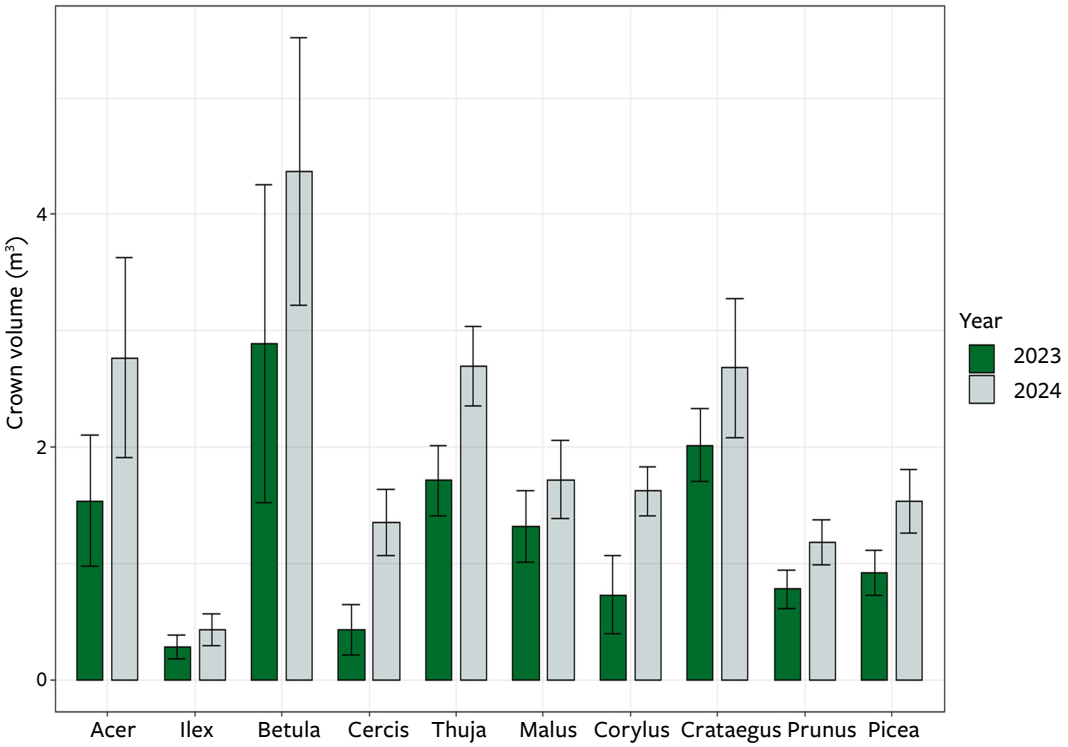



**Figure 6. Total crown volume per taxon, average taken from five trees in 2023 and 2024. This parameter was used to estimate canopy rainfall storage and cooling through shading.**

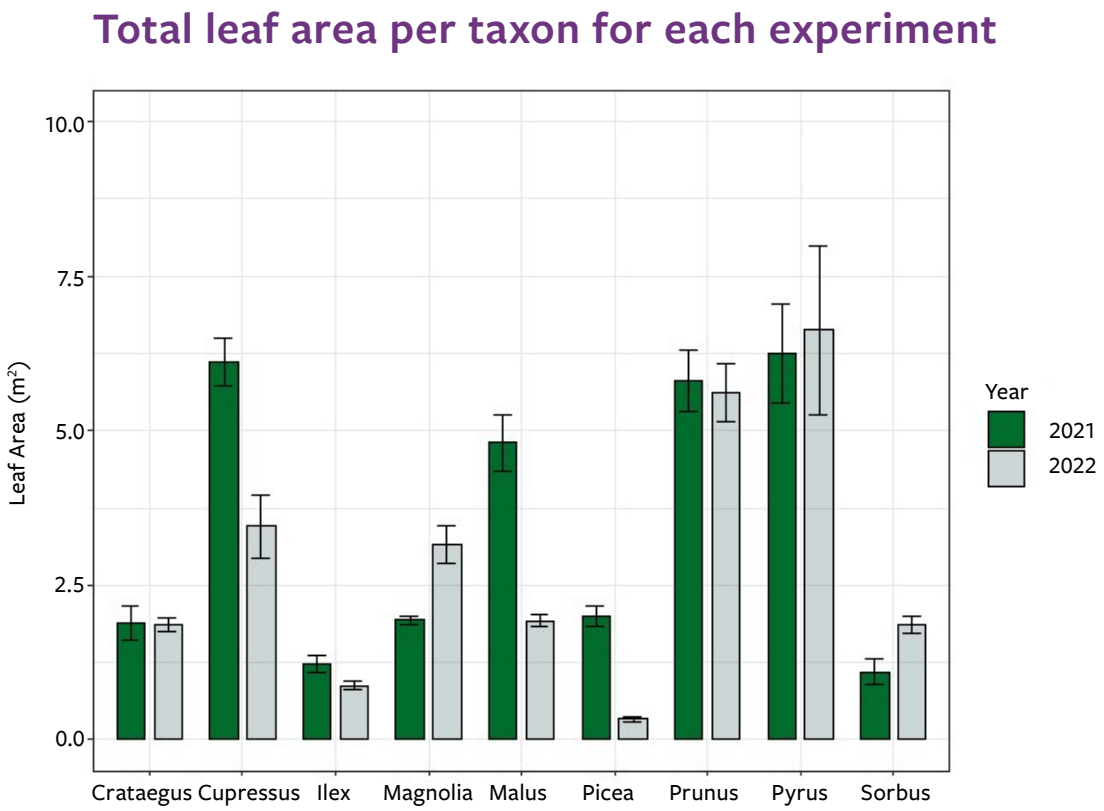



**Figure 7. Total leaf area per taxon, average taken from six trees in 2021 and 2022. This parameter was used to estimate canopy rainfall storage and cooling through shading.**

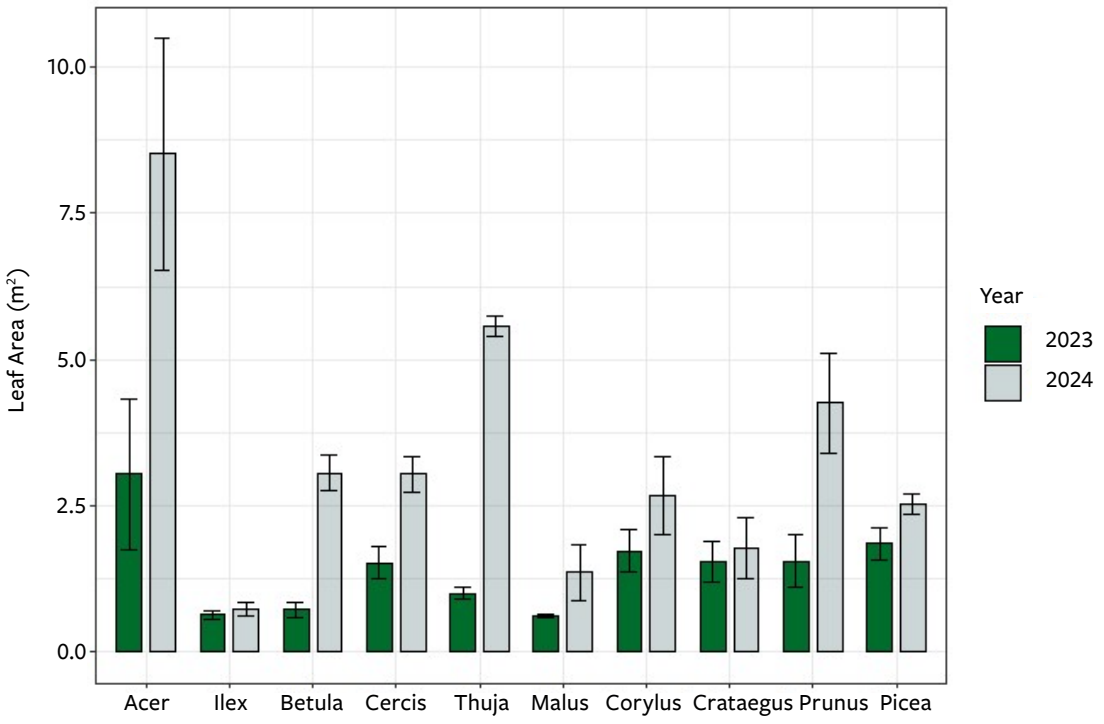



**Figure 8. Total leaf area per taxon, average taken from six trees in 2023 and 2024. This parameter was used to estimate canopy rainfall storage and cooling through shading.**

## Sap flux density for each experiment

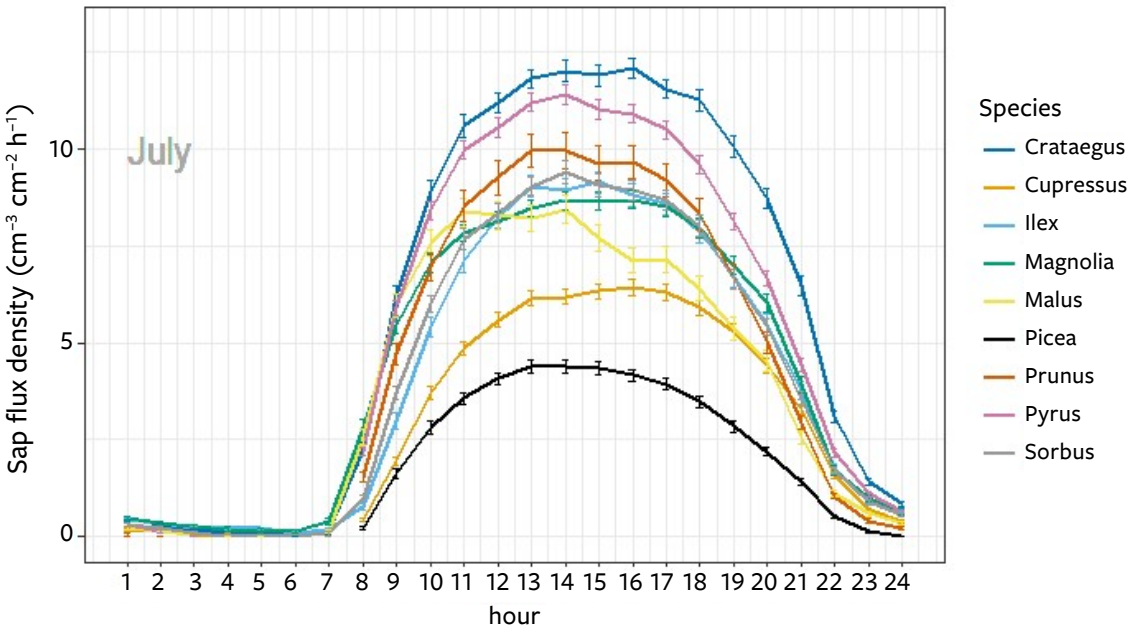



**Figure 9. Sap flux density as a proxy for water use relative to wood area. Each line is an average taken from 2–4 trees in July 2021–2022. This parameter was used to estimate cooling through transpiration and heat tolerance.**

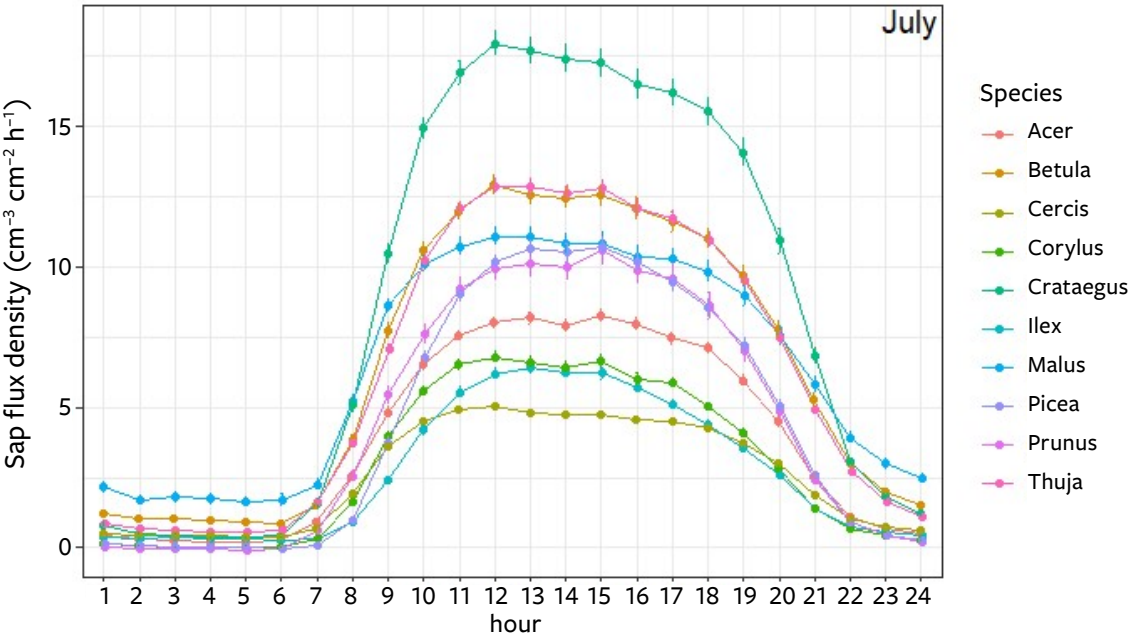



**Figure 10. Sap flux density as a proxy for water use relative to wood area. Each line is an average taken from 2–4 trees in July 2023–2024. This parameter was used to estimate cooling through transpiration and heat tolerance.**

# Find out more

The following papers are available:


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