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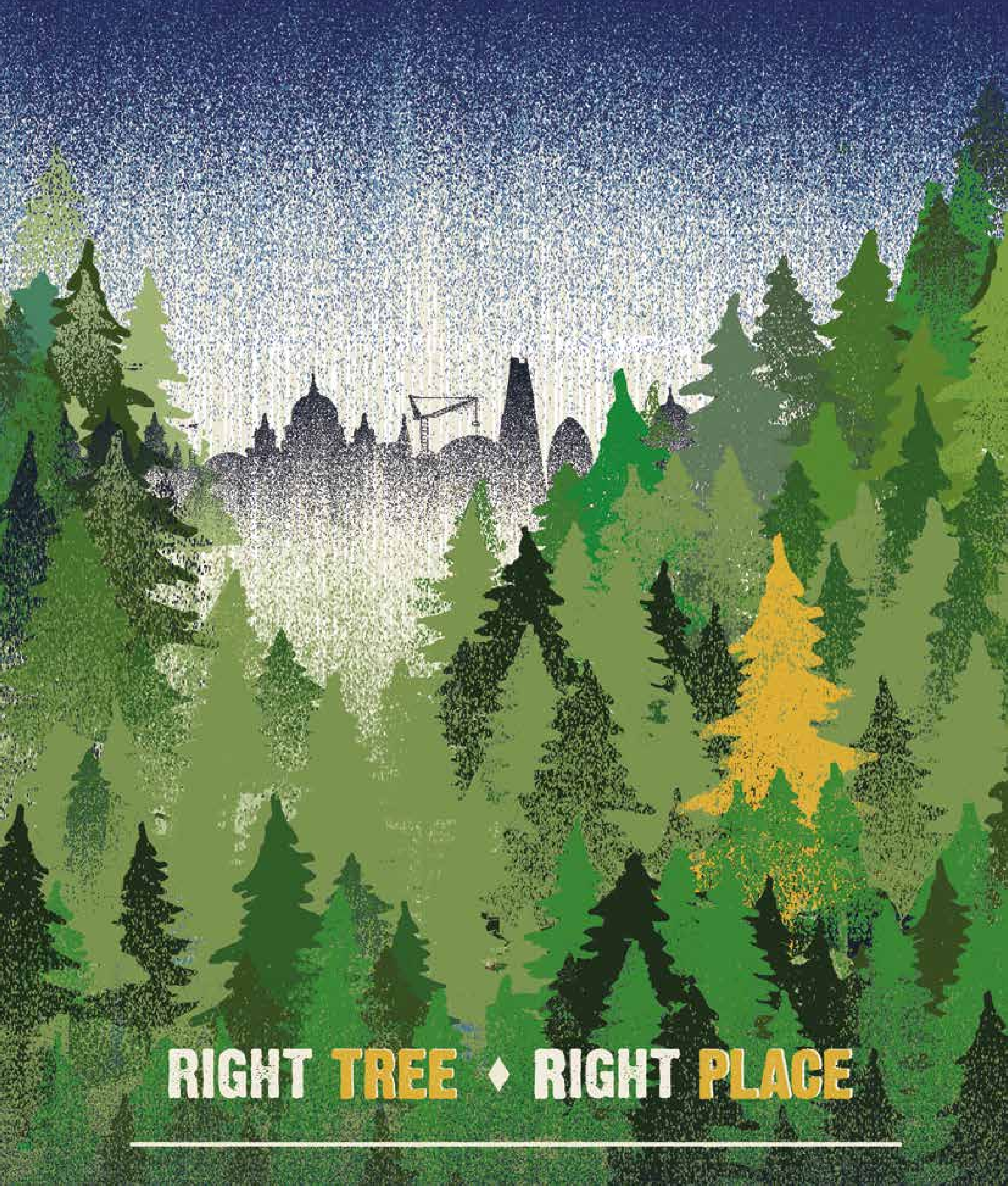

EDITORIAL

The human treescape

In the 1840s, a young Karl Marx pre-empted his later and more infamous theories with an erudite description of how people were becoming disconnected from their place in nature. His observations were later backed up by Friedrich Engels and Francis Bacon, then more recently in 1987 by Norman Moore in his book *The Bird of Time*[1].

I propose that the lack of integration of people in nature is far worse now than it was in their days. Yes, we have numerous studies and clear scientific evidence about endless facets of the environment, but I feel that we do most, if not all, of this thinking from a position of being *outside* of nature. This arms-length attitude results in an approach that leads to policies and decisions couched in the language of externality – saving 'it', protecting 'it' and even divesting ourselves of 'it' – while we focus on other more 'pressing' things such as the economy. What we fail to grasp, as warned by Marx and others, is that we are *part* of 'it'.

Several authors in this edition share evidence that supports my belief that the accommodation of growth should be fully integrated into a tree-rich environment – a treescape. Growth should not be about grey corridors and settlements glued together with tenuous green threads, but instead urban development and nature should be fully integrated, with infinite degrees of light and shade, intensity and density, so that there are always wins for people and nature. Deep inside us all is an instinct that integrates us with nature in all its forms, but there is something about trees that brings this connection to the surface in everybody. People need trees.

Of course our truly wild places and unique trees should be left well alone, but the disconnected, species-poor, unresilient areas can be enhanced for all. Any development, whether newly built or refurbished, should come with associated integrated natural enhancements, rather than 'no net loss' or tenuous attempts at demonstrating 'net gain'. Let's just go for win–win everywhere and every time.

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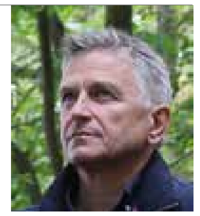

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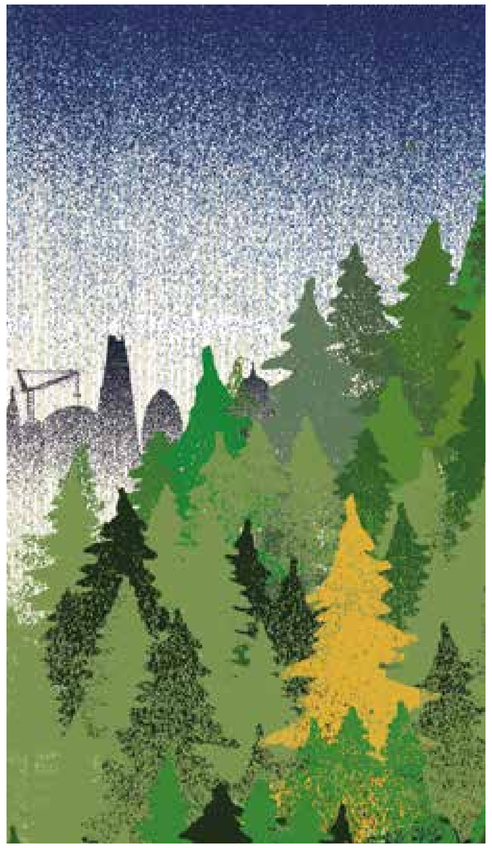

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INTRODUCTION

The need for trees

Sir Harry Studholme reviews the role and future of our trees.

Some of the oldest, largest and longest-lived organisms on Earth are trees. Humanity has formed a deep relationship with trees, not least because they provide many of the raw materials for our lives: pulp for paper, nappies and computer screens, wood for building houses or making furniture and fuel for heating. At the same time, we find trees pleasing to look at, we bask in their shade and our myths are full of the experience of self-discovery in forests. No surprise then that the study of trees – how they grow, what impact they have on our environment and how we can use the materials they provide – is as old as science itself.

The study of trees remains crucially important for understanding our environment and profoundly relevant to finding answers to the question of how we can survive in our resource-limited world. As with so much of science, the more we understand trees, the more we see the limitations of our knowledge. While centuries-old practical knowledge may have been lost, new scientific techniques, such as genetics, computer modelling, remote sensing and microbiology, are opening up new vistas that expose how much more there is to know. The threats of climate change and the increasing incidence of tree diseases have made this need to understand our trees even more urgent.

INTRODUCTION

THE HUMAN CONNECTION

Trees are part of both our urban and our rural habitats. So connected are trees with people that as we moved to cities, we brought trees with us. The study of these urban trees is as old as the study of our forests. Probably the first major paper on urban pollution was *Fumifugium*, published in 1661 by John Evelyn (one of the founders of the Royal Society), who also wrote *Sylva*, the first book in English on forest science. Among the solutions Evelyn proposed in *Fumifugium* to the stench of 17th-century London, for example, was the planting of trees. The recognition of the benefits of trees in cities to human wellbeing so long ago has led to our inheritance, in many British cities, of canopy cover that under some definitions qualifies it as forest.

What is new is that modern science, supported by remote sensing and computer processing, can empirically quantify the values of the urban forest. One approach, i-Tree, calculated in 2015 that the amenity value of the 8.4 million trees in London was £43 billion. This was nearly double the £23 billion natural capital value of the English public forest estate, which covers 250,000 ha and numbers more than a hundred million trees.

Although the methodologies are not directly comparable, the largest components of both valuations come from human access. Forests are more than just trees. They have long been about people, open spaces and wildlife as well. Norman forests, for example, were valued more for hunting than timber and throughout Europe there is a continuing tradition of recreation and managing wildlife in forests. This natural capital value is manifest in the intense public interest shown in trees and explains the importance of social science in forestry.

Virtually all British forests are human made and the plants and other species that depend them on have developed to benefit from this relationship. Even woodland described in Britain as 'ancient' was managed for fuel and timber in past centuries, thus differing fundamentally from old-growth forests elsewhere in the world. Understanding the social and environmental significance of Britain's veteran trees and historic landscapes is not an optional extra to our forest scientists. How we manage and maintain these now-uneconomic human-made habitats without the expertise of the poorly paid rural workers of pre-Victorian times remains a huge conundrum.

THE FORESTRY INDUSTRY

One partial solution to this question is the progress made over the last century in building a viable forest industry in Britain. This has been significantly led by the Forestry Commission, which from its creation in 1919 understood the importance of science. One of the first commissioners' six initial objectives was the endowment of research. The Commission began to plant new forests at a time when British knowledge of forestry was at a low ebb: by the end of the 19th century over 95 per cent of Britain was deforested, because by then farming was more profitable than forestry and timber was easy to source from around the world.

However, the First World War exposed the limitations of an assumption that timber could always be imported. So, when in 1919, a year after the end of the war, the Forestry Act set in motion a process of reforestation of the British Isles, with little home-grown science in place, the process built heavily on the experience of the management of forests in of India, then part of the British Empire. This in turn had built on German experience: in 1713 Hans Carl von Carlowitz had formulated the idea of sustainability in forest management in his treatise *Sylvicultura Oeconomica*. In the 1860s, Dr Cleghorn, who founded forest science and conservation in India, turned to von Carlowitz's intellectual successors.

When the Forestry Commission began to plant its forests, research started with straightforward and practical applied science: how to grow trees most effectively for timber, which species would grow best in British conditions, how to maximise soil conditions for planting, and the impact of factors such as rainfall and altitude. However, the scale of afforestation, increasing forest cover from about 4 per cent to 13 per cent over the last century, exposed the danger of oversimplifying afforestation. A wider perspective was encouraged by public concern in the 1930s over the proposed planting of the open landscapes of the Lake District and in the 1970s over destruction of ancient woodland, because of its historic value and complex ecology. New challenges such as changing climate have emerged, and more emphasis is placed on previously hidden worlds in the canopy or the roots, the latter with their relationship with the fungal networks that provide trees with nutrients. Each advance exposes another layer of complexity. None of this is to say that past research into plantation

forestry was not important. In Britain we created, from a forestry devastated by two world wars, a forest industry employing tens of thousands of people and producing 14 million tonnes of timber a year.

THE GLOBALISATION OF PESTS AND DISEASES

For at least 100 years plant pests, diseases and plant health have been a major component of forest science. The very first Forestry Commission leaflet provided guidance to forest owners and its own staff about pine weevils. Trees, like all lifeforms, exist in a complex web of organisms. This web survives with attack and defence in balance. It is very rare that these systems break down, but these breakdowns are becoming more frequent and the consequences can be devastating. The globalisation of trade has provided pathways for pathogens to move around the world. A changing climate may weaken the defences of hosts and reduce the protection of a climate inhospitable to incoming pathogens. This is the stuff of evolution and over centuries or millennia nature would find a new balance. However, on human timescales, with people dependent on their human-made habitats, these imbalances are a problem.

Each breakdown is different, and while most are not serious, some, such as ash dieback (*Hymenoscyphus fraxineus*) or Dutch elm disease (*Ophiostoma* spp.), can be devastating. Scientists can use the growing understanding of genetics and propagation to identify and propagate disease-tolerant varieties. Unfortunately, in Britain we only have about 35 native tree species, the few that were able migrate onto the former tundra of the British Isles in the period after the last ice age ended nearly 12,000 years ago and before the Channel created a barrier. Few of these are large forest trees. There is particular value in trees that grow to significant heights, such as oak, ash or elm, and whose timber can be harvested to provide an income to manage the forest. Additionally, and this is especially true of oak, these larger, older trees are home to complex ecosystems. Losing these larger trees would leave us without high forest and a less biodiverse countryside that is also impoverished in economic viability and social meaning. This increases the pressure to develop resistant varieties and evaluate alternative species for our future forests.

ARCHITECTS OF CLIMATE CHANGE

The nature of trees is to convert carbon dioxide into timber, which provides one possible and partial antidote to a warming climate. The power of trees in this regard is shown by the fact that at least twice in our geological history, during the Carboniferous period and the Eocene epoch, forests have so dominated the planet as to be probable drivers of global cooling. This is a clear benefit, but the interaction of trees with the environment is not always that simple. In far northern latitudes, white snow reflects solar radiation much more effectively than dark trees – this is the albedo effect. The consequential warming from these forests may be greater than the cooling impact of the carbon absorbed by their trees growing slowly in a cold climate. Another example of the interaction of trees with their environment is the volume of volatile organic compounds (VOCs) emitted by the trees around the world – these dwarf anthropogenic emissions. Trees use these emissions to manage their own environment in ways we have only started to understand. Isoprene, the chemical emitted in greatest quantities, probably protects leaves against heat stress. However, in the presence of nitric oxides, isoprene contributes to the formation of lower-atmosphere ozone, a major pollutant in many countries.

Not only is it desirable to plant more trees, it is also government policy. Science has an important role in unpacking the complexity of this apparently simple proposal. Which tree species should we plant to best absorb carbon? Where should we plant them? How do we ensure they will be managed so as to thrive in future? Above all, how do we ensure they provide the other multiple functions we ask of our trees? These are not simple questions.

At a practical level much has been incorporated into the UK Forest Standard, which ensures that international agreements on areas such as sustainable forest management, climate change, biodiversity and the protection of water resources are robustly applied in the UK. The Forest Standard also provides guidelines around the historic environment, landscape, soils and people in forests. This reflects the multipurpose nature of forests and the need to meet competing interests while delivering a viable forest. Social science is also important: experience of planting over the last century has shown that increasing forest area, especially with the commercial species best suited to absorb carbon or provide medium-term employment, is not always as popular as one would intuitively imagine it to be. Public support is not inevitable and concerns can be exaggerated and misrepresented in social media. Plans to plant future forests need to learn from both past experience and modern communication skills.

The fate of humanity and forests have long been intertwined. Our forests provide important raw materials and are part of our very identity as social animals. They are essential habitat for our wildlife. We increasingly understand the critical links of our forests to the climate itself. Forest science is at the heart of providing practical answers to how we can sustainably manage the forests that we need to survive on our crowded planet **ES**

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FEATURE

Edible dormice, bodgers and lasers: Ancient woodland in the Chilterns

John Morris explores the environmental archaeology and current challenges of these important ecosystems.

The Chiltern Hills stretch across four counties, from Goring in Oxfordshire, across Buckinghamshire and Bedfordshire to Hitchin in Hertfordshire, with the River Thames on their southern edge. This iconic landscape, designated as an area of outstanding natural beauty (AONB), is well known for its beech *(Fagus sylvatica)* woodlands with carpets of bluebells *(Hyacinthoides non-scripta)*, rare orchids, prehistoric trails and wooded commons. The Chiltern Hills are one of the most heavily wooded areas in England, with over 22 per cent woodland cover, of which nearly 60 per cent is ancient woodland[1] (see **Box 1**). Which tree grows where depends on a combination of natural environmental and cultural factors, with the soil type and moisture levels being important, along with management history and the source of seeds. Most of the ancient woodlands here are now found on the clay with flint soils that cap the Cretaceous chalk hilltops. Much of the plateau is overlain by Tertiary clays and sand deposits, which result in acidic habitats and the formation of oak–beech woodlands on heavier soils.

A characteristic indicator feature of lowland ancient woodlands is the presence of a wood bank, which consists of an earth bank, with an associated ditch, constructed at the boundary of a woodland or bordering internal compartments. These banks were used to keep out both grazing animals and human intruders as well as to demarcate ownership. In many cases they would have been topped by a hedge or a fence. Sometimes in the Chilterns the ditch is on the woodland side of the bank, but woods bordering commons usually have a wide ditch on the commons side.[2]

◀ **Mature beech wood in autumn. (© John Morris).**

The boundaries of intact older woods are rarely straight and often follow natural features and topography. Surviving fragments of historically larger woods may have straight margins where boundaries were moved by clearance for agriculture, a process known as assarting. This was common from the medieval period onwards, and evidence of it can be seen around the edges and within larger woods.

WOODLANDS IN USE

The River Thames was historically an important waterway supplying London with raw materials, including wood for fuel, building and other uses. Towns such as Henley on Thames and Marlow developed as riverside ports and wood including beech, oak and hornbeam was delivered to London in barges. Chiltern woods were an important resource throughout the medieval period and their former economic importance is why they have survived to the present day.

Woodland clearance for agriculture, in the Chilterns as well as elsewhere, declined in the 13^{th} century following the Black Death. In 1610 William Camden described the area as 'beset with thicke woods'[3] and in 1768 Arthur Young described the 'perpetual woods of beech'.[4] But the fuel provided by woodlands was in high demand. This led to the active management and maintenance of existing woodland stocks. Beech woods in the past did not look like the ones we see today, as the young trees were repeatedly cut down (coppiced or selectively thinned) for poles or fuel and allowed to regrow (given enough light and protection from animals). This was a sustainable method of managing broadleaved woodland species such as ash *(Fraxinus excelsior)*, field maple *(Acer campestre)*, hazel *(Corylus avellana)*, hornbeam *(Carpinus betulus)* and sweet chestnut *(Castanea sativa)*. In a few places in the Chilterns, such as Low Scrubs, there is still old beech coppice, which may be hundreds of years old.

By the end of the 18^{th} century, the demand for wood declined because it was replaced by coal as the preferred fuel in London. Many woods in the Chilterns were left to grow into stands of tall beech trees. This then became the resource for bodgers (those who turned chair parts on pole lathes), with chairmaking and other woodworking industries centred on High Wycombe and Chesham. By 1877 there were almost 100 factories in High Wycombe making 4,700 chairs a day,[5] and by 1911 2 million chairs were being made annually.

WOODLAND ARCHAEOLOGY

Woods are an important part of the historic landscape, with many cultural associations. The archaeological evidence that survives under the trees in the form of lumps and bumps, pits and banks, can be interpreted to explain the history of land use, although some features have been damaged by machinery or changes of use.

◀ **A fine hornbeam in Pigotts Wood. (© John Morris).**

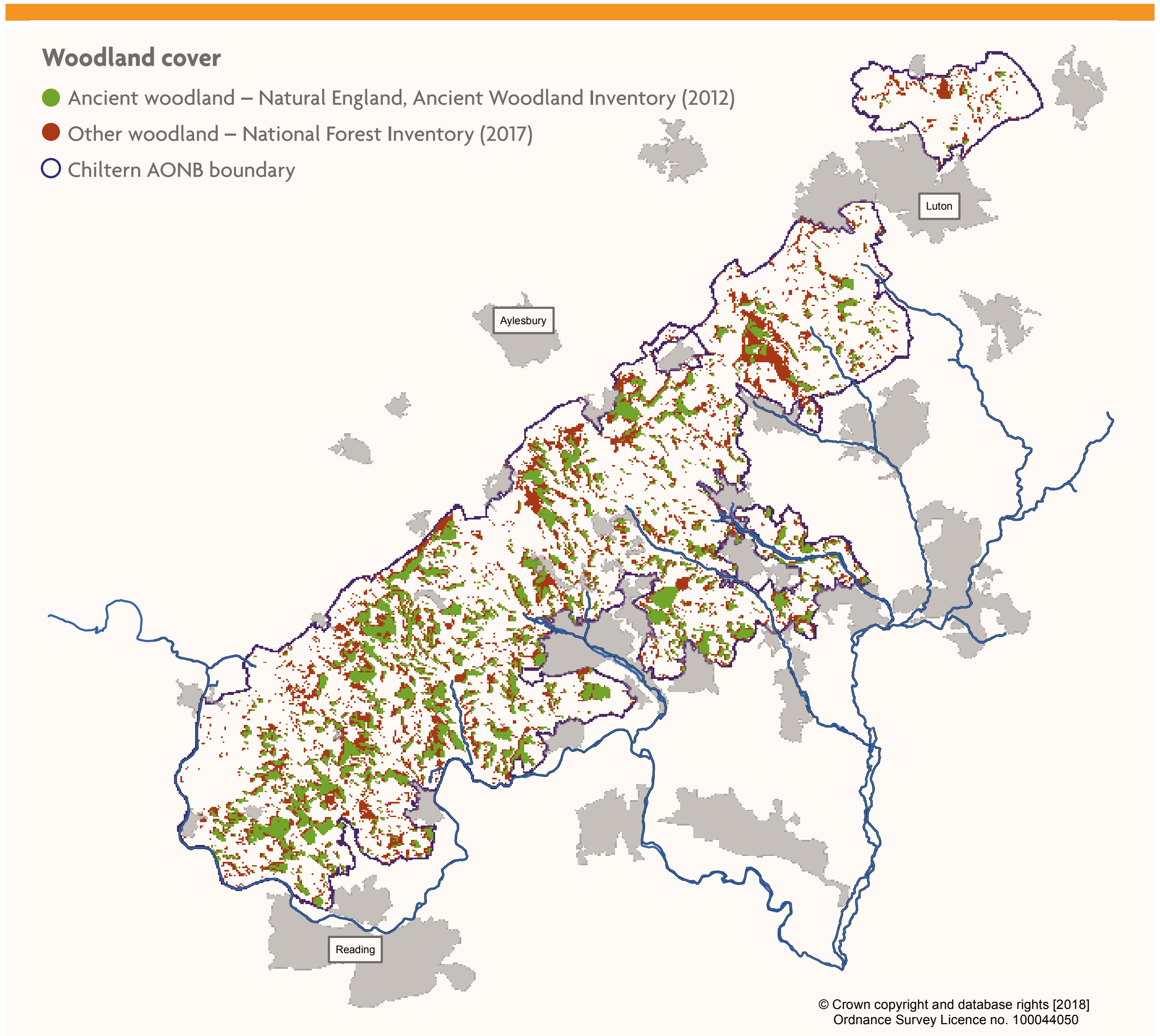
Many historic features have been found in woods, and there is still much to identify, survey and record:

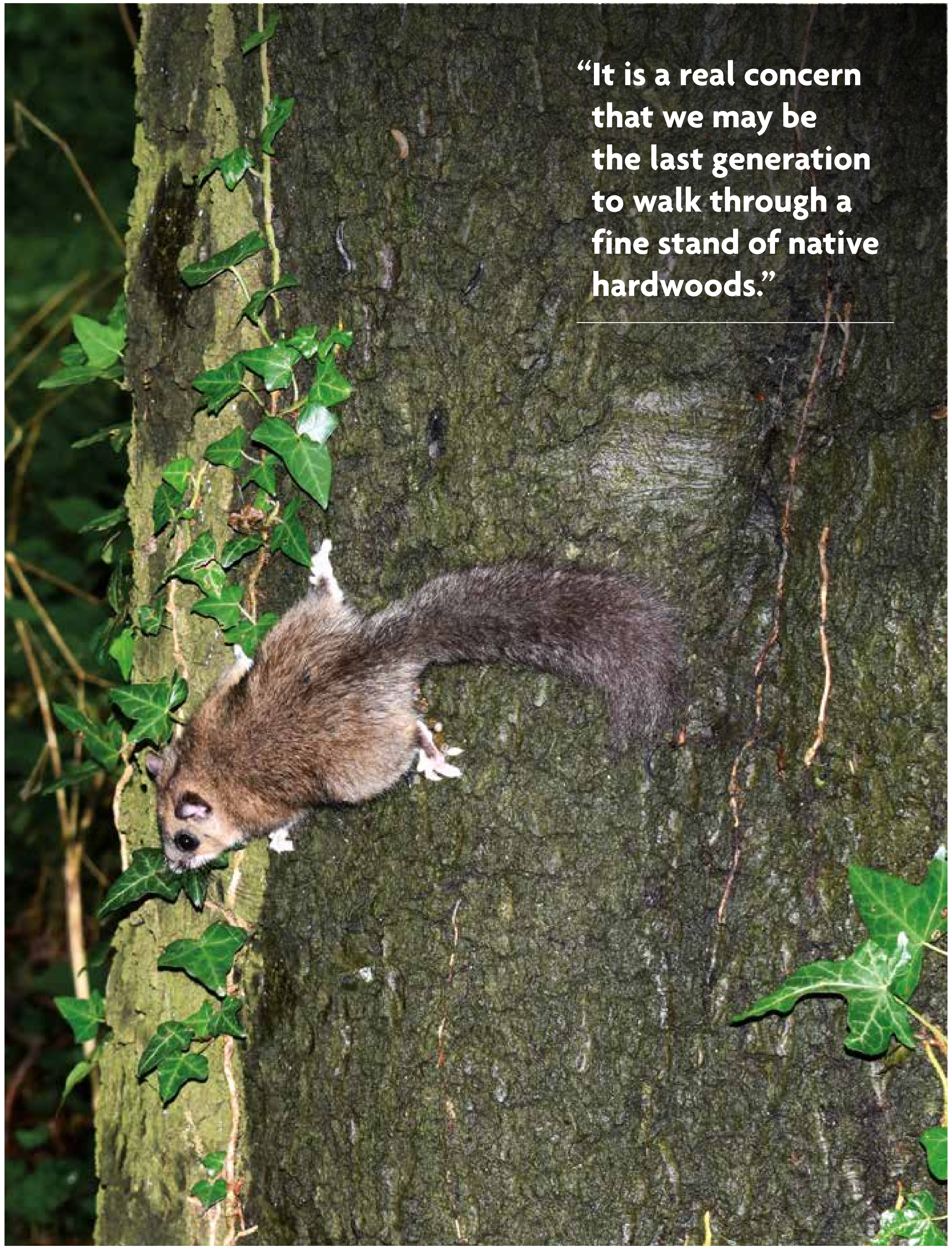
- Living evidence relating to the past management of a wood, for example, coppice structure, aged coppice stools, veteran trees or pollards;
- Archaeological evidence relating to the past management of the site such as saw pits, charcoal hearths, drainage systems, old banks, tracks, mineral diggings;
- Physical features indicating a previous agricultural land use, such as ridge-and-furrow plough markings and lynchets (ploughed terraces); and
- Historical boundary features, such as wood banks, stubbed trees and outgrown laid hedges.

Some of the earliest evidence of woodland management is the discovery of iron slag from smelting in the Iron Age and Roman period. The iron workers would have used charcoal made in the woodland itself. Smelting and charcoal-making sites have been discovered in several woods in the Chilterns.

A later example is the existence of saw pits, which are frequent in ancient woods in the Chilterns because the woods were high forest (i.e. the trees were tall) rather than coppice, and the ground conditions were suitable for pit construction. Most sawpits in the woods are a little over 4 m long (dug along the contour) by a couple of metres wide. There is a mound on the lower edge. A wooden frame supported the log to be cut. Some were backfilled after use, so the depth is variable. As everyone locally knew what they were, the information was rarely

▼ **Distribution of woodland cover in the Chiltern Area of Natural Beauty.**





▲ **Fat dormouse, Glis glis, on beech. (© John Morris).**

FEATURE

▲ **Moss covered woodland boundary bank leaf filled ditch. (© John Morris).**

written down – so it took a visitor from Sweden to record their use in detail. Pehr Kalm stayed at Little Gaddesden, on the Hertfordshire–Buckinghamshire border, in 1748. In his diaries he described the use of saw pits:[6]

"When the tree is felled, they do not go to the expense of taking the whole tree away but saw it into pieces where it grew, digging a pit, where the tree can be sawn into boards or whatever is needed. While in Sweden we have sawyers' trestles, onto which logs must be lifted with considerable difficulty before they are sawn. Here, it is the practice to dig a saw pit. One man stands down in the pit and the other above it, each holding his end of the saw. If they wish to saw across them the logs are rolled across the pit, if they wish to saw them into boards, they are placed lengthways along the pit. In this way, the need to hoist the logs onto a sawing bench or higher structure is avoided."

New survey techniques include lidar (an aerial technique using lasers), which can reveal the landform beneath the trees. The Chilterns AONB is being flown to produce a high-resolution lidar survey as part of a Heritage Lottery Funded Hillforts Project.[7] There are more than 20 hillforts across the Chilterns, most date from the Iron Age and these must have been created in a less-wooded landscape.

CURRENT PROBLEMS

Current threats to trees in Chilterns include diseases and pests, climate change and changing management practices.

Sadly the health of trees across the Chilterns continues to deteriorate. Ash dieback *(Hymenoscyphus fraxineus)* is now found widely. All ages of ash are starting to suffer from this fungal disease, although it is most noticeable on ash saplings in the summer. It is likely to kill millions of ash trees across England, with those along roads and in hedges being harder to replace. Some mature (but not old) oaks are affected by acute oak decline. Pines (*Pinus* spp.), horse chestnuts *(Aesculus hippocastaneum)* and elms (*Ulmus* spp.) also have disease problems. There is also the potential for some serious insect pests to harm woods in the future, such as oak processionary moth *(Thaumetopoea processionea)*, currently not far away in west London.

The cumulative impact of bark stripping year after year on younger 'pole stage' trees by grey squirrels *(Sciurus carolinensis)* on beech, oak *(Quercus* spp.*)*, birch *(Betula* spp.*)* and many others, means it is now difficult to establish the next generation of trees. Increasing numbers of fallow *(Dama dama)*, muntjac *(Muntiacus reevesi)* and roe deer *(Capreolus capreolus)* are browsing down natural regeneration and planted trees and damaging the ground flora. Controlling squirrel and deer numbers is particularly difficult in smaller woods and with multiple woodland owners.

One particular Chilterns problem species is the edible dormouse (also called the fat dormouse; *Glis glis*). This

FEATURE

▲ **Ancient beech coppice at Low Scrubs (National Trust owned). (© John Morris).**

BOX 1: WOODLAND DEFINITIONS

The **wildwood** was more complex and dynamic than today's woods, with areas of open wetland, marsh and clearings maintained by flooding, windblow and large herbivores. The landscape became more fixed during the medieval period with farmland, woodland and commons all more clearly defined as land uses and under various types of land ownership marked by boundary banks and hedges. Today fragments of woodland remain as 'ecological islands' in a largely agricultural landscape.

Ancient woodland is a nationally important and threatened habitat; its existence over hundreds of years has preserved irreplaceable ecological and historical features. It was originally defined for botanical habitat reasons but has now been extended to recognise its importance as part of the historic environment and cultural heritage, and therefore for planning. The government's Keepers of Time policy[8] aims to protect ancient woodland.

Ancient woodland in England is defined as an area that has been wooded continuously since or before 1600 CE. The date used to define ancient woodland for England was chosen by George Peterken because it reflected the point at which maps started to become more common and was prior to the impetus for new woodland planting from the publication of John Evelyn's influential book *Sylva* (1664). Ancient woodland has two sub-categories: ancient semi-natural woodland and plantations on ancient woodland sites.

The trees and shrubs found in **ancient semi-natural woods** may have been felled or cut for coppice at various times since 1600, but provided it has remained as woodland, i.e. the coppice stools have regrown or the stand has regenerated or been replanted soon after felling, then it counts as ancient woodland. Trees may have been cut many times in the past, so ancient woods do not necessarily contain large old trees.

Plantations on ancient woodland sites (PAWS) are areas where the original native tree cover has been replaced by planted stock, for example conifers such as Norway spruce *(Picea abies)*, Douglas fir *(Pseudotsuga menziesii)* or Corsican pine *(Pinus nigra* var. *maritima)*, but also broadleaves such as sycamore *(Acer pseudoplatanus)* or sweet chestnut *(Castanea sativa)*.

Secondary or recent woodland (less than 400 years old) has either been planted or allowed to grow naturally, often on former agricultural land.

nocturnal mammal was introduced from Europe at Tring in 1902. They are now present across much of the Chilterns AONB and can cause serious problems. They damage the tops of trees, including wild cherry *(Prunus avium)* and many species of commercial conifer, adding to the problems caused by bark-stripping grey squirrels. Edible dormice predate woodland birds on their nests, eating adults, eggs or nestlings. There is a real risk that this species will spread from the Chilterns to other parts of England. One potential means of spread is in firewood: edible dormice may hide in log stacks while they are active over the summer months. Firewood is often left to dry in the wood in stacks through the summer for sale in autumn when demand and price is higher. When lorries collect these logs the edible dormice might be moved to new areas.

These tree health problems and a changing climate, with more droughts and storms, mean it is becoming increasingly difficult to know what tree species to grow. The warming climate may lead to some species of tree struggling to survive, particularly if summers become hotter and drier; the prediction is that beech may struggle on some soils. Alternatives might include small-leaved lime *(Tilia cordata)*, English (pedunculate) oak *(Quercus robur)* and perhaps tree species introduced from other countries. The woods are likely to become more varied in composition, with more light coming through the canopy, which will influence the ground vegetation. It is a real concern that we may be the last generation to walk through a fine stand of native hardwoods.

The woods of the Chilterns survived because they were a valuable resource. Veteran trees, ancient coppice and old hedges are all important features of the historic landscape and should be retained where possible. ES

John Morris BSc CBiol MRSB is the Director of the Chiltern Woodlands Project, a registered charity based in the Chilterns AONB office. The Chiltern Woodlands Project offers advice and assistance with woodland management to owners of woods in the Chilterns. It was founded in 1988. John has been working for the project since the start and works with volunteer groups and contractors to implement plans.

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Treezilla: The monster map of trees

Phil Wheeler explains why it is important to map, measure and put a value on urban trees.

FEATURE

Trees are important features of our towns and cities. People see them as significant cultural landmarks and they shape the urban character as much as the buildings around them. What would the Mall in London or the Champs Élysées be without their London plane trees (*Platanus* x *hispanica*)? Trees that have grown with the cities and towns they inhabit change the character of the urban landscape as they grow and are living connections to the past lives of our cities.

ECOSYSTEM SERVICES

Along with their cultural and amenity value, urban trees provide a range of ecosystem services.[1] Of course trees capture and store carbon dioxide, but in an urban context they do much more besides. As air carrying particulate and gaseous pollutants comes into contact with leaves, branches and trunks, some pollutants remain on their surfaces. Although some of these pollutants are re-suspended in the air, some will be broken down on the leaf surface, rain will wash others into the soil and the rest will fall to the ground with the leaves in the autumn. Trees and their roots help to reduce flooding by intercepting rain as it falls, thereby slowing it down, allowing it to evaporate, and providing channels for it to filter into the soil instead of rushing across the soil surface. And because trees contain a lot of water they have substantial capacity to absorb and store heat, thus keeping cities warmer in the cold and cooler in the heat. These cooling effects are further enhanced through evapotranspiration, which removes significant amounts of heat energy, something that is increasingly important for making our cities liveable. All of these services have value to society, and much of this can be estimated and quantified, so how do we go about doing that?

Thinking about how trees deliver pollution-removal services is perhaps easiest to understand. Since air pollution is removed through contact with leaves and bark, the proportion removed should relate to the surface area of the tree, which in most cases is dominated by its leaf area. Through empirical studies, foresters have established relationships between the simple-to-measure properties of trees, such as trunk girth or canopy extent, to the harder-to-measure properties, such as leaf area. These relationships are different for different species. Next, fluid dynamics models of air circulation and pollution deposition can be used to estimate the quantities of pollutants removed from the atmosphere per unit area. Combining the two types of data gives estimates of pollutant removal per tree (or per unit volume of canopy, depending on the approach taken).

◀ **London Mall looking south west towards Buckingham Palace through the London plane trees. (© Tim M | Adobe Stock).**

FEATURE

Air pollution is a known cost to society: it causes respiratory illness and exacerbates other health conditions such as heart disease and stroke, leading to large numbers of premature deaths each year. This leads to lost work days, increased costs for the NHS and reductions in productivity. The UK's Treasury publishes estimates of these social damage costs[2] per tonne of pollutant. Matching the tree data to these costs allows us to quantify the benefits that trees provide in monetary terms.

TREES UNDER THREAT

Despite the benefits they provide, urban trees are contentious assets. The fight over how street trees should be managed in Sheffield has hit the headlines recently, with a vigorous campaign by members of the public against the local authority and their contractors felling important cultural assets. However, it is more common for members of the public to argue *for* the removal of trees. Subsidence claims and disruption to roads and pavements caused by tree roots are major costs to local authorities. There are other less well known dis-benefits of urban trees: some can actually worsen air quality through the release of high volumes of volatile organic compounds and allergens such as pollen. And large trees that form closed canopies over busy city streets lead to a 'canyon effect', when air pollution is trapped at street level.

It is often easier for the public and those responsible for trees to see the costs of urban trees rather than their benefits, and it is for this reason that it is essential that a broad spectrum of values are assessed when making decisions about managing urban trees. As events in Sheffield have shown, it is the cultural, aesthetic and amenity values that are most obvious to people, yet these are hardest to quantify. Nevertheless, approaches do exist. In the UK, CAVAT (Capital Asset Value of Amenity Trees)[3] is a system that is widely used to score the amenity values of urban trees, and these values can overshadow the more physical processes.

INFORMATION GAPS

A major challenge in making the case for urban trees is that we know very little about them. Perhaps surprisingly, we know less about our urban trees – what species there are, how many there are and how they are distributed – than we do about trees in woods and forests. A main reason for this is that local authorities, which are generally responsible for trees on public land, each operate very different systems. There is no coordinated tree database, and even the way that data are collected varies considerably. In addition, with cuts to local authority budgets, many authorities have lost tree officers and therefore have databases that are out of date, patchy or still in hard copy. With hundreds of millions of urban trees across the UK, the scale of the challenge of recording and monitoring them all is beyond the capacity of local authorities alone. However, crowdsourcing data, using a combination of existing datasets and citizen-led efforts, has the potential to go some way towards filling this gap.

MAKING THE MONSTER MAP

A team from the Open University, Forest Research and the social enterprise Treeconomics has established a large citizen science project to do just that. Treezilla: the monster map of trees,[4] is a website with a slightly silly name but a serious purpose: to identify, measure and map as many trees as possible across the UK. We have already collected data for over 830,000 trees, making Treezilla the biggest open tree map in the UK. Anyone can sign up and start adding trees. Some areas are very well covered by the map, but there is a long way to go to get anything like comprehensive coverage.

Treezilla does much more than just allow its users to map and identify trees – it also generates estimates of ecosystem services provision and the monetary value of those services for each tree mapped, identified and measured. It does that using a UK-specific version of a platform called OpenTreeMap. The software is built around a suite of tools developed by the US forestry service under the banner 'i-Tree'.[5] The i-Tree tools have been used in several countries for ecosystem service assessments of trees, and a number of city-wide assessments have been carried out in the UK. Treezilla is based on the same Urban Forest Effects (UFORE) model as these assessments but differs in that it estimates ecosystem services provided by each tree, making it a useful tool for helping people understand the value of trees, starting with those on their street, in their garden or local park. For each tree identified, mapped and measured, the site estimates carbon storage, annual carbon sequestration, pollution removal (and contribution to pollution), flood risk mitigation potential and energy savings from temperature moderation. It does not (yet) include the critically important amenity values, but nevertheless gives a broad spectrum of users an insight into the contribution that trees make to improving the urban environment. It also allows anyone to understand some of the economic benefits from any one tree, and potentially to weigh those against the perceived costs.

PLANS FOR THE FUTURE

Many urban trees are quite small and their individual values modest, but combined they amount to very large numbers. So the 830,000 trees currently in Treezilla are valued, for the limited ecosystem services assessed, at around £77 million. Accounting for all urban trees across the UK would undoubtedly generate values in the billions, several orders of magnitude greater than the resources spent on managing them.

These estimates are necessarily approximations, averaged for typical trees of any one species in typical urban conditions; they are not precise valuations. Nor should

▲ **London Mall in 1910 or 1911 looking west including the London plane trees with supports. (© Leonard Bentley | Flickr (CC BY-SA 2.0)).**

the pound signs associated with trees through tools such as Treezilla be used blindly, without considering the wider range of values we associate with trees. There has been much debate about the wisdom of bringing the language of economics into nature conservation, and some of that debate reflects on urban trees. For example, as the air in our cities gets cleaner and there is less pollution to remove, the pollution removal services that trees can provide decline and so would their economic value. Could we really argue that these trees had become less valuable? But on the other hand, without trees on our streets, society would incur the costs that they mitigate, so their economic value is real and tangible. In the Treezilla project we feel that making people better informed about these values can only increase their understanding of the importance of urban trees to them as individuals and to wider society.

As we continue to work with local authorities, small and large tree-focused NGOs and the several hundred individual citizen scientists who regularly contribute to Treezilla, we hope to reach a million tree records in the coming year and 10 million within five years. We are also looking at ways of incorporating cultural and amenity values into the site's valuations.

Over the past decade we have increased our understanding of the wide range of benefits that trees in our towns and cities provide, and it is clear that in both financial and cultural terms these are very significant. What we must now do is find a way to improve our knowledge of our urban trees, document them properly and engage as many parts of society as we can in looking after them. With the right tools and enough people in the next decade, this monster task might just be achievable. **ES**

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ANALYSIS

The role of trees and other green infrastructure in urban air quality

Emma Ferranti, James Levine and **Rob MacKenzie** explain the role of vegetation for air quality management in our cities.

GREEN INFRASTRUCTURE

'Green infrastructure' (let's shorten that to 'GI' but remember we're talking about trees, not Joes) refers to all vegetation in urban areas, including parks, private gardens, green roofs and walls, grass verges and street trees. GI is 'infrastructure' in the sense that it brings a multitude of environmental benefits to our towns and cities.[1] Some of these benefits are at risk of being underestimated while we lack a means of measuring them, that is, of measuring the natural capital associated with the ecosystem services that GI provides.

Urban practitioners are familiar with the notion that GI provides space and connectivity for nature, providing

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and linking habitats for plants and animals and thereby increasing biodiversity. It is also widely understood that GI can increase urban resilience to extreme weather, such as heavy rainfall events and very hot summers, expected to increase in frequency as a result of climate change.[2] As examples, sustainable urban drainage systems (SUDS) store rainwater and attenuate its release, reducing demands on mains drainage; and trees mitigate the urban heat island effect through the creation of cooler microclimates via the provision of shade and transpiration (the uptake of groundwater and the release of water vapour).

Steps are being taken to quantify these ecosystem services. The Construction Industry Research and Information Association has developed a freely available Benefits of SUDS Tool (B£ST). Meanwhile, a recent study by the Forestry Commission highlighted the monetary value of tree transpiration, estimating an annual saving in air conditioning costs across London ranging from £2.1–84 million.[3] There are also economic benefits: attractive placemaking increases footfall and potential customer numbers increase, benefitting local businesses and stimulating the 'business of serendipity', thus fuelling greater productivity.

Many of the benefits of GI have a direct bearing on human health, translating into health costs saved and working days gained. For urban inhabitants, GI can provide space for recreation and physical activity, and confers benefits for mental health too, including: psychological relaxation, stress alleviation and increased social cohesion.[4] Public Health England recently commented, 'If green infrastructure was a pill, every GP in the country would be prescribing it'.[5]

GI also offers significant physical health benefits via improved air quality, but not as we perhaps expect. Pollutants are deposited to leaf surfaces, but the fraction of pollution removed by this mechanism in the urban environment is typically just a few percent, owing to the small scale of realistic planting schemes[6] and the relatively slow rate of transfer of pollution particles and molecules to (leaf) surfaces. The value of GI for urban air quality lies in its ability, not to remove pollution, but rather to control its distribution by strategically enhancing (or reducing) its dispersion close to its source[7]. For instance, in an open-road environment and under the right wind conditions – blowing from vehicles towards pedestrians – a vegetation barrier can halve the concentrations of pollutants in its immediate wake.[6] As explained below, GI can be of benefit, dis-benefit or of little consequence for air quality. However, used strategically, i.e. with the right vegetation in the right place, GI offers considerable benefits in terms of the public health impact of urban air pollution by altering the public's exposure to it.

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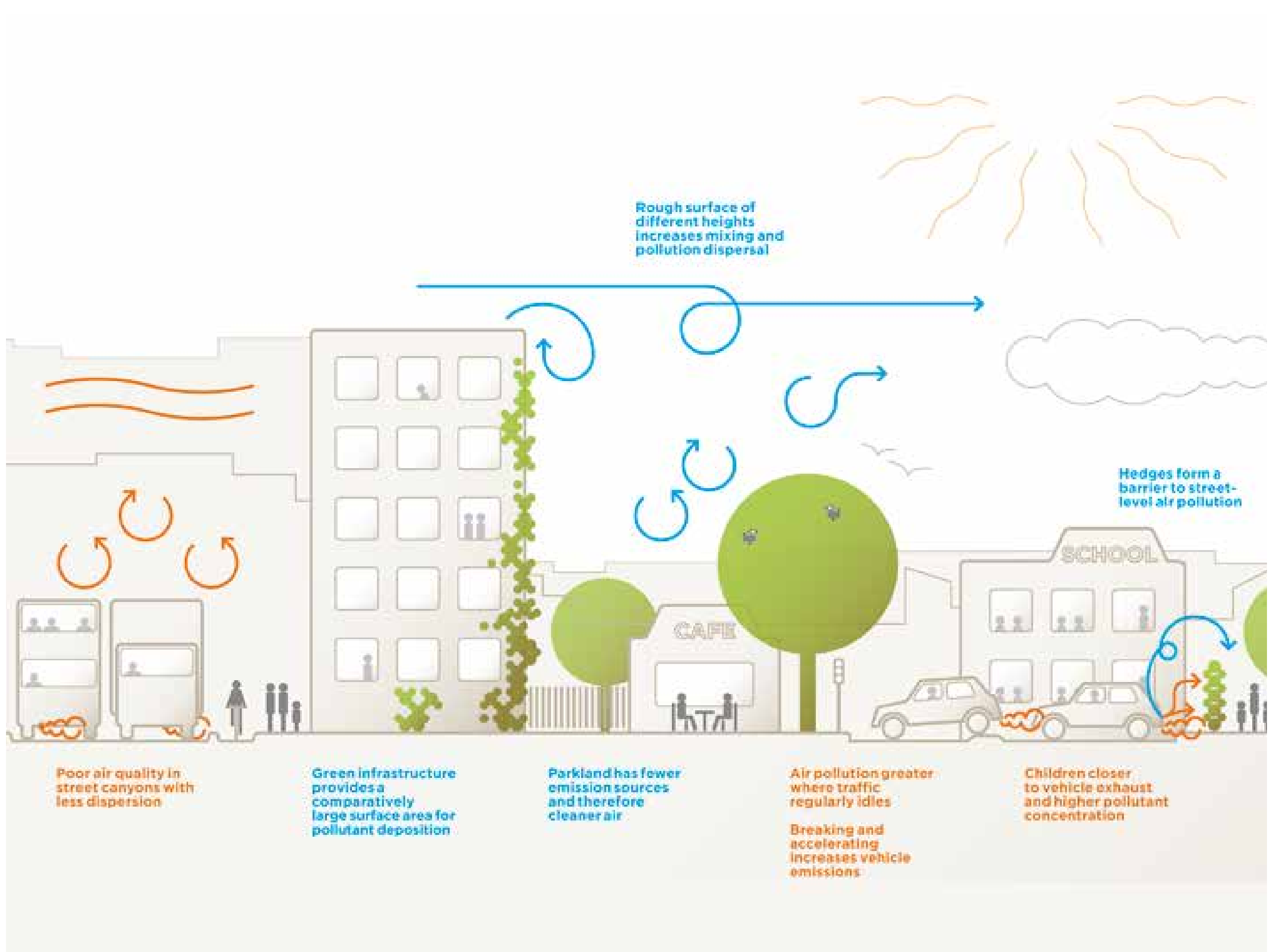


▲ **Figure 1. The role of trees and other green infrastructure in urban air quality.[13] (© Trees and Design Action Group Trust).**

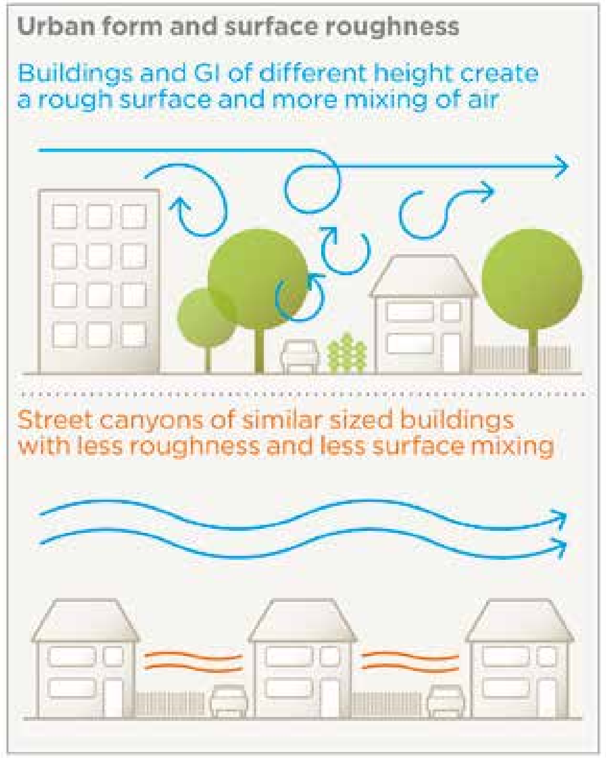
The University of Birmingham is developing a software platform with urban practitioners to enable them to predict quantitatively the impacts of a range of interventions on exposure, on a site-by-site basis. Meanwhile, as outlined below, certain interventions will reliably reduce exposure.

URBAN AIR POLLUTION

The World Health Organization identifies air pollution as the greatest environmental risk to human health:[8] 90 per cent of the world's urban population live in cities exceeding its air quality guidelines, and outdoor air pollution claims roughly 3 million lives each year. In the UK alone, outdoor air pollution contributes to approximately 50,000 deaths each year,[9] and road transport has been identified as the main source of directly emitted emissions in urban areas.[10] Roadside air pollution often exceeds national air quality objectives and has been the subject of litigation against the UK government.[11] In these reports, and in what follows, the key pollutants are microscopic particulate matter (PM) and nitrogen dioxide (NO_2). However, there are some pollutants – notably ozone and secondary PM – where the relationship with emissions is not linear,[12] but we do not consider those here.

Urban form (the size, shape and configuration of our built environment) affects the location and strength of road transport sources of pollution and, importantly, its subsequent dispersion (dispersion refers to the way that air dilutes pollutants and carries them away from their sources). Critically, the impact of road transport pollution on human health depends on the concentration of pollutants at point of exposure – in other words, not only the amount of pollution emitted at source but also how much it has dispersed en route to its human 'receptors'. The total public health impact also depends on the number of people exposed, the length of time for which they are exposed, and their vulnerability; the very young and the elderly are particularly vulnerable, as are people with certain pre-existing medical conditions.

Through its impact on the emission and dispersion of pollution, and hence the extent of exposure, urban design has a significant bearing on the public health impacts



▲ **Figure 2. Green infrastructure can be used to create heterogeneous surfaces that stimulate the mixing, and hence dilution, of relatively polluted air at street level with relatively clean air above it.[13] (© Trees and Design Action Group Trust).**

of pollution emissions. Good urban design provides a tool with which to reduce these impacts and improve health outcomes (and health equality) via the application of three key concepts, listed here in order of priority:[13]

1. **Reduce** emissions, particularly from road transport. This is by far the most effective way to reduce urban air pollution and improve public health outcomes.
2. **Extend** the distance between sources of pollution and human receptors (this is called the source–receptor pathway). Pollutant concentration is highest close to the emissions source but decreases with distance, initially very quickly, as a result of mixing with cleaner ambient air. Increasing the dispersion of pollutants between source and receptor reduces the concentration at the point of exposure.
3. **Protect** the most vulnerable people. Anyone can suffer negative health impacts from air pollution, but children under 14, adults over 65 and those with pre-existing health conditions, such as chronic obstructive pulmonary disease (COPD) or asthma, are most vulnerable.[14]

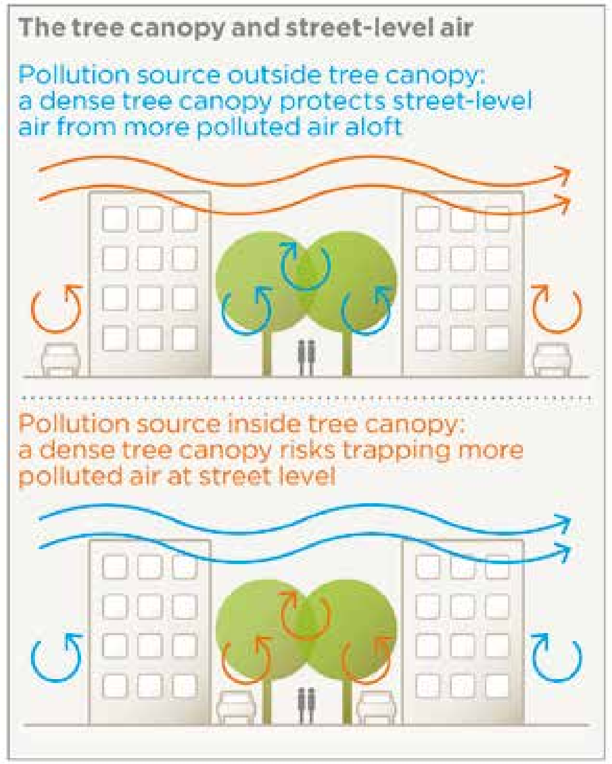
GI – already an ingredient in good urban design – can help to reduce, extend and protect (see **Figure 1**). Green open space often takes the place of what would otherwise include further sources of pollution, implicitly reducing emissions. Parks and tree-lined roads can also create green corridors that encourage active transport, such as walking and cycling, in preference to driving, further reducing emissions. GI, whether it is green open space or trees, hedges and green walls, helps to create an urban form with a more variable topography and texture. This creates more turbulent air flows, stimulating mixing between relatively polluted air at street level and the relatively clean air above it[15,16] (see **Figure 2**) and tending to extend the source–receptor pathway. Parks, meanwhile, tend to draw people, including vulnerable people, away from polluted areas into cleaner ones, and hence have a role to play in protecting people. The strategic use of trees, hedges and green walls as vegetation barriers in urban canyons (i.e., streets bounded by buildings on both sides) to extend the source–receptor pathway, and thereby protect people at the kerbside, is the subject of the next section.

GREEN INFRASTRUCTURE FOR ROADSIDE AIR QUALITY

In the urban environment the value of green infrastructure for roadside air quality – what we are dubbing 'GI4RAQ' – lies in the strategic use of vegetation as physical barriers to extend the source–receptor pathway. At the scale of realistic planting schemes, deposition on leaf surfaces typically removes just a few percent of particulate matter (PM) and a similarly small fraction of nitrogen dioxide (NO_2); what NO_2 is deposited is offset by accompanying soil emissions of nitrogen monoxide (NO) – subsequently converted into NO_2.

Likewise, the emission of volatile organic compounds (VOCs) associated with ozone formation from this scale of vegetation has only a minor impact on air quality.[17] Vegetation is only responsible for a small fraction of total urban VOCs, and as ozone formation takes a certain length of time, their minor impact is predominantly felt at a distance downwind, rather than at the point of VOC emission.[6] Some VOCs, such as isoprene, have greater impact than others– and emissions from vegetation are expected to increase somewhat as the climate warms. It may be prudent to plant fewer trees of species known to be particularly strong isoprene emitters,[18] but simply planting a mixture of species will mitigate any concerns, and species selection[19] must take many other factors into account, not least those governing successful long-term growth. The key to GI4RAQ in urban canyons is controlling the distribution of pollutants, by either enhancing or reducing their dispersion (dependent on the site in question) to reduce their concentrations at point of exposure.

The first consideration in identifying what GI will be beneficial is how the air quality at street level compares with the average air quality above the surrounding



▲ **Figure 3. The effect of a dense avenue of trees in an urban canyon depends on whether the air at street level is cleaner or more polluted than the air above it. By reducing mixing between the two, a dense canopy on a quiet street protects relatively clean air at street level from the import of polluted air from above (top panel). On a busy street, however, a dense canopy risks trapping pollution at street level (bottom panel).[13] (© Trees and Design Action Group Trust).**

buildings. We often first think about options to reduce exposure on highly trafficked roads, where pollutant concentrations are highest. There is potential, however, to reduce the overall public health impact of road transport pollution by protecting roads with little or no traffic from the import of pollution from above. A dense avenue of trees, forming a near-continuous canopy, can provide very effective protection from downward dispersion. Meanwhile, the increased residence time of air beneath the canopy makes the deposition of pollutants to leaf surfaces more effective. The combination of protection from more polluted air above and enhanced deposition below can create a clean, green corridor (see **Figure 3**, top panel).

On highly trafficked roads (i.e., where the air quality at street level is worse than that above them), the vertical dispersion of air is beneficial. A dense avenue of trees could exacerbate the lack of vertical mixing due primarily to the built form and risk trapping pollution at street level (see **Figure 3**, bottom panel). Note, however, that trees spaced more widely have

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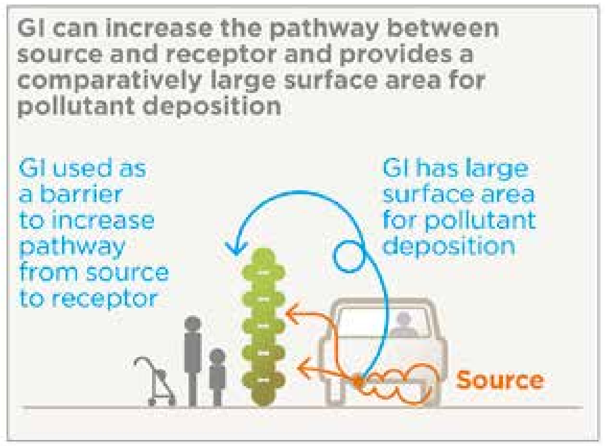
little effect on vertical dispersion but do deliver the many further environmental, health and socio-economic benefits outlined earlier.

Meanwhile, vegetation barriers to the horizontal transport of pollution may be of considerable benefit in reducing public exposure at the kerbside on highly trafficked roads. The addition of a hedge (or green wall) between vehicles and pedestrians in an urban canyon (or on a more open suburban road) may not achieve the 50 per cent reduction in pollutant concentrations achievable under idealised conditions (see above).[6] However, in all but the deepest and/or narrowest canyons, it will reliably extend the source–receptor pathway and thereby reduce concentrations at point of exposure; see **Figure 4**. (In canyons with a height/width ratio >2, the air flow is complex and the addition of barriers is not recommended without fluid dynamic modelling of the specific situation.)

If sufficiently dense and suitably maintained, green walls can be used in place of hedges as effective vegetation barriers between vehicles and pedestrians. They also offer some potential to reduce road transport pollution in highly trafficked urban canyons when mounted to building facades,[20] but further research is needed to quantify their benefits. A computer-modelling study found that they not only provide surfaces for pollutant deposition but interact with air flow (via surface roughness) to alter the average residence time of air in the canyon. The significant modelled reductions in PM_{10} (and NO_2 to a lesser extent) justify further research.[21]



▲ **Figure 4. Green infrastructure barrier to extend the distance between emissions source and receptor, and protect vulnerable people on the roadside.[13] (© Trees and Design Action Group Trust).**

HE WHO PLANTS A TREE PLANTS A HOPE[22]

The world is becoming increasingly urbanised and the United Nations estimates that by 2050, 68 per cent of the global population will live in urban areas. It is imperative that our urban areas are resilient to extreme weather and future climatic change, and are healthy, liveable places for their inhabitants. The importance of GI in creating resilient urban environments is becoming acknowledged nationally and internationally. Cities are leading this green revolution: Birmingham is part of the international biophilic cities network,[23] aspiring to place nature at the heart of all planning decisions; Greater Manchester aims to be the UK's first zero-carbon city by 2038 and is planting a tree for every resident within a generation.[24] In June 2019, London will become a National Park City making the city greener, wilder and healthier for its residents.

Strategic green infrastructure has a role in reducing exposure to urban air pollution. First and foremost, we must reduce road transport emissions at source. Reducing exposure to what is emitted, however, provides a means of further reducing the impact on public health. As part of good urban design, GI can also be used to create cleaner spaces where people prefer to spend time – and choose to walk or cycle instead of hopping in the car. Meanwhile, GI provides a multitude of further benefits, including: increased biodiversity; urban resilience to extreme weather in the form of increased thermal comfort and sustainable urban drainage; mental and physical health benefits; and attractive placemaking for communities and business. There is no need to over-sell the benefits, but there is a need to state them clearly and often. Our most valuable urban infrastructure is green. ES

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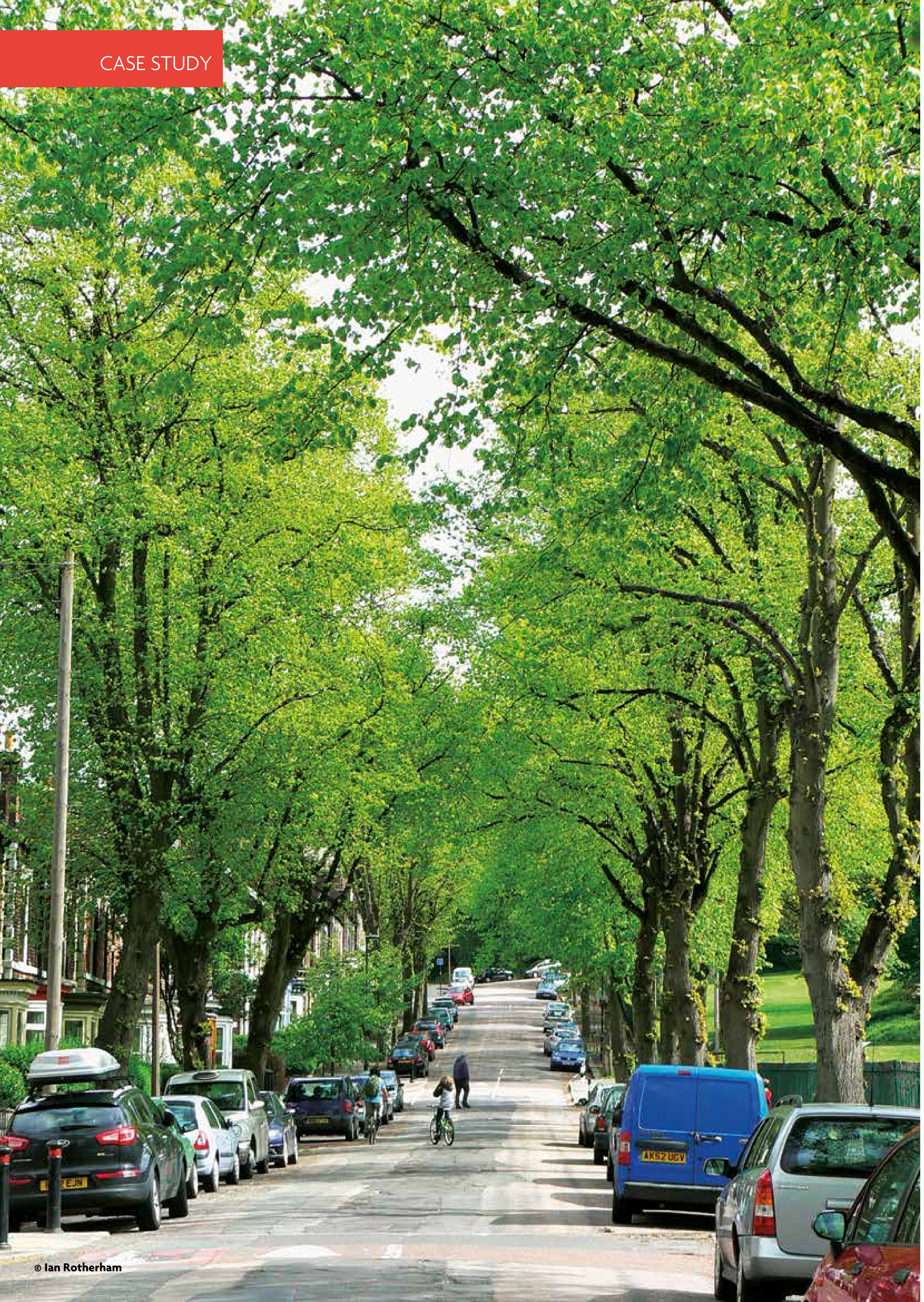

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CASE STUDY

Stumped: Urban street-tree (mis)management

Ian D. Rotherham argues for democracy and transparency in the care of the urban forest.

Sustainable development, liveable cities, green infrastructure and urban ecosystem services have been widely discussed by researchers and decision-makers. Today, the benefits to human wellbeing and health of high-quality open spaces and green areas are undisputed.[1,2,3] However, with increasing pressure on urban landscapes for competing uses such as housing, green spaces are under threat. Furthermore, cuts to local authority budgets mean the loss of core services and skills relating to open-space management and planning,[4,5] and in some cases, local authorities are cutting all expenditure on parks and community spaces.[6]

Within this wider scenario has been the growing importance of public–private partnerships (PPPs) to deliver core environmental and green-space services in many urban areas. These have been seen as possible fixes for the budget cuts, and many local authorities, including Sheffield City Council, have gone down this route. Nevertheless, the real costs of PFIs are now emerging: inflated monetary costs, damage to biodiversity and urban forest infrastructure, eroded local democracy, and reputational damage to the city and the private-sector partner.[7] There are also major issues of public access to information once contracts become commercially sensitive because one of the partners is a private-sector business, and of profit-driven delivery of core public services. It seems these changes also threaten local environmental democracy and are part of a wider shift in democratic processes.[8,9]

THE CASE OF SHEFFIELD

Sheffield's Streets Ahead project was set up in 2012 as a 25-year private finance initiative (PFI) to undertake transformation works on Sheffield's roads, pavements and bridges following a major review of the highways in 2007. It was noted that this was the result of long-term neglect in the city dating back to the 1980s. The review also suggested that three per cent of the city's street trees (about a thousand of the 35,000 highway trees) might need to be removed.

However, people began to notice that large numbers of street trees in their neighbourhoods were earmarked for felling, and in some cases replacement by saplings, but without consultation. Public meetings were held at which local communities were told what was to be done but there was no opportunity to influence the process or the outcome. This situation quickly led to widespread anxiety and alarm about damage to the local environment, and ultimately to city-wide meetings and protests. Disputes and direct conflicts over the management of the street trees between the local communities on the one side and the contractor (Amey plc) and the City Council on the other emerged in 2012–2013.

In 2013, ways to address the issues were proposed to Amey by the author on behalf of local community groups and individuals but were flatly rejected. Suggestions included more effective consultation with communities prior to felling plans being finalised, a telephone hotline for concerned citizens, and that the proposals and plans should take heed of established and agreed City Council environmental strategies and the like.

Following this attempt to resolve the emerging issues, public-facing meetings with expert and stakeholder presentations and panels were held in 2013 and 2014, followed by Action for Woods and Trees workshops in 2015 and 2016. These events were organised by South Yorkshire Biodiversity Research Group, Sheffield Hallam University, the Woodland Trust, the Green Party and local community groups. The events involved local councillors, environmental and tree experts and campaigners; they served the dual purpose of informing local people and helping to coordinate actions and networking across the city. By then city-wide protests were taking place and the Sheffield Trees Action Group (STAG) had formed.

In spite of all of this, around 7,000 street trees had been felled by 2017. Furthermore, it was confirmed that in Sheffield removal was without effective consultation and frequently by stealth, which raised major concerns about both community engagement and local environmental democracy. There were also reports that up to 17,500 street trees (i.e. 50 per cent of the original total) were to go. Most of these trees were completely healthy.

By 2018, following long-running demonstrations and peaceful protests, the City Council was pressing for custodial sentences for its own unhappy citizens objecting to tree removal. Furthermore, the costs to the local authority and the community were spiralling upwards, with over a million pounds' additional expenditure associated with demonstrations, legal processes and compensation to the private-sector partner.

Concerns had already been raised about street trees as disputed environmental resources nationally,[10] before the Sheffield situation developed. Indeed, the management and conservation of urban street trees is well-documented,[11] but the political ramifications and issues of democratic processes have been largely ignored. However, the dispute in Sheffield has now grown into a globally recognised environmental campaign with the almost-complete breakdown of established processes and protocols of green-space and community engagement and 'ownership'. The Sheffield-based PFI project with Amey plc is perhaps best-known, but only one of many around the country. This project is explored specifically by the current paper but the principles apply more widely.[12]

STREET TREES AND THEIR IMPACTS

In urban environments and with the impacts of climate change, trees are stressed and require on-going care and maintenance, but clearly these needs are increasingly threatened by long-term underfunding of essential maintenance and harsh cuts to local government services.[4] The likely escalation of this threat to urban street trees was predicted.[10]

In this context, it is unsurprising that local government may prefer the short-term tree removal 'solution' to expensive, ongoing and long-term maintenance. It is generally accepted that the costs of inspection, care, maintenance, and where necessary, remediation or removal of urban trees are relatively high. Councillors see older and bigger trees with higher maintenance costs, potential damage to pavements and other perceived issues as especially problematic: they may present significant insurance risks, with ongoing professional and legal debates about what may be considered reasonable professional competence for tree condition survey and assessment.

Whilst in recent years approaches to risk have become more pragmatic (addressed by nationally agreed standards), individual urban householders with big street trees close to buildings can be concerned about damage to pavements, clay movement affecting building foundations (though tree removal may exacerbate damage), branch fall in high winds, liability and, if failure occurs, collateral damage to adjacent properties. Other problems include droppings and noise from nesting or roosting birds, leaf fall and shade. With many trees on private land adjacent to highways, this can become significant, and increasingly so with society developing a culture of blame, litigation and compensation. For landowners and local authorities with big trees, despite the recognised significance of big urban trees in mitigating climate change and flood risk, the focus turns to the risks rather than the benefits.

Public concerns lead to local politicians under pressure to '*do something*', which joins with the view that big trees are somehow inappropriate for urban residential roads. With onerous maintenance costs and responsibilities for local authorities, demand grows for removal rather than maintenance.[6,10,12]

THE VALUE OF STREET TREES

However, despite these issues, research with local community stakeholders indicated that most people value their trees very highly, and long-term ecosystem benefits outweigh costs many-fold. Especially in urban situations, street trees, and especially mature trees, deliver important services to people and places:[11,13]

1. A sense of urban seasonality;
2. Visual enhancement in terms of a green and high-quality environment;

CASE STUDY

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3. Enhanced community and individual health – physical, mental and spiritual – leading to major financial savings for the healthcare services and others;[14]
4. Enhanced property values and desire to live and work in a location;
5. History, heritage and connection to the past – a sense of place, local distinctiveness and cultural identity;
6. Moderation of extreme weather (street trees lower peak summer temperatures by several degrees centigrade) and climate-proofing of urban areas;[15,16]
7. Reduction in the costs or expected costs of air-conditioning;
8. Moderation of precipitation runoff and flood-risk through interception at canopy level; root-pits act as soakaways to take surface runoff into groundwater;[15,17]
9. Removal of particulate pollution;[18,19] noise reduction; capture of carbon dioxide and release of oxygen; and
10. Enhanced urban ecology, biodiversity, habitat continuity, and connectivity of urban green spaces, thus creating 'habitat volume' – a large, three-dimensional habitat as compared to a two-dimensional area of, for example, a wildflower meadow or garden. Street trees, especially those such as European lime (*Tilia x europea*), provide a huge volume of nectar- and pollen-rich feeding habitat to support pollinators such as bees, which are currently under threat.

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PROBLEMS WITH PFI PARTNERSHIPS

Contractual issues that are normally subject to scrutiny and public transparency become confidential, in spite of being publicly financed. This means even the public who pay for the work and in this case, whose street trees are affected, cannot obtain details. Furthermore, in the Sheffield study, even elected local councillors were unable to access them. And with environment projects such as the Sheffield–Amey street trees, it has been suggested that partners failed to do due diligence in negotiating environmental aspects of the street-trees programme contract Streets Ahead.[6,12]

Outsourcing publicly funded services resulted in dramatic deterioration in public relations, local community engagement, long-term financial debts and significantly compromised urban street-tree resources. It now seems other local authorities, such as Birmingham and Newcastle, that have gone down this route have similar problems. In addition, Birmingham has lost 9,200 street trees, Newcastle-upon-Tyne 8,414 and the London boroughs 47,000 trees in total.

Additionally, despite big metropolitan districts being areas where the community need for good-quality green space is highest, cuts to local authority budgets hit those areas disproportionately hard. Consequences include the dissipation of countryside, woodland, tree, and environmental services, and the disempowerment of communities.

THE LEGACY OF SHEFFIELD

Research suggested that street trees are strongly motivational for local communities and provide a focus for local environmental action when people feel marginalised by political processes. The case study of Sheffield has dramatically challenged aspects of current urban planning and green-space management and has triggered relevant policy responses from national government.[20,21]

In the Sheffield situation, inputs to the original contract from tree specialists within the Council were overruled and many of the subsequent issues stem from that decision. Despite the warnings, the contract was signed as it was and the work then went ahead. For several years, Sheffield City Council and Amey dismissed all attempts to provide specialist external advice or indeed to compromise on either the process or the product of the Streets Ahead programme.

However, by late 2018, there was a significant change in political emphasis in Sheffield City Council. This was alongside changes in UK central government policy and practice – with the appointment of a Tree Champion nationally,[21] and a major consultation document launched in December 2018, which included proposals for local authorities to have to consult on proposals for tree felling.[20] These are all positive moves and stem directly from the Sheffield street-tree campaigns.

© Sheffield Tree Action Groups

Clearly there are questions about how we balance political, professional and community views and judgements on trees in the urban forest. In this particular case study, it is clear from any balanced perspective that the process went badly wrong and the ultimate cost to the environment, the city, the private-sector partner and the community has been colossal. Hopefully, despite the unnecessary damage done, some good may have emerged in changing national policy to deliver sustainable urban treescapes in towns and cities – essentially, the right trees in the right places. ES

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FEATURE

Military woodland

Steven Holdsworth outlines the functions and management of the MOD's trees and forests.

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The Ministry of Defence (MOD) owns approximately 19,500 hectares of woodland – this equates to some 40 million trees. In addition to the rural forest cover, there are large areas of urban woodland, small group plantings and individual amenity trees across 600 sites. Although currently difficult to quantify, a desk-top exercise has established that those add up to around 270,000 individual amenity trees.

So why does the MOD own woodland and amenity trees at all? The answer is that it forms part of the defence training estate – land that is used for training the armed forces. Most of the woodland was established after the Second World War and through the Cold War to provide a European training scenario, hence the fact that the forest cover is around 56 per cent conifer and 44 per cent broadleaf – the planting of large areas of conifer woodland was to replicate an Eastern European landscape. In some cases existing MOD land was planted up, while in others adjacent Forestry Commission plantations were purchased, including Sennybridge and Thetford.

A team of four foresters manages all the forests, woods and trees. A mix of thinning and clear-felling is carried out to produce an average of 40,000 m^3 timber per year, which is sold through standing sales to the UK roundwood markets (for standing sales, timber is sold as standing trees that buyers arrange to fell and extract themselves; roundwood consists of small logs). On average we replant 50 ha per year, but due to disease, restoration of windblow sites (where trees have been uprooted by the wind), etc., the restocked figure for 2018 was 115 ha.

The primary objective for woodland management has always been to facilitate military training, and sound silvicultural management was therefore often ignored. Many training areas have now reached the point of needing significant intervention. Due to lack of management, in many areas of the forest the trees are now reaching terminal height and a large proportion of them will start to blow down in storms. In this situation there is little option but to fell whole coupes (groups) of trees, as thinning out a proportion of them will make the remainder even more susceptible to damage. The other main reason for enforced intervention is the disease situation we have with larch in Wales (see below). Fortuitously, the mature forests that have developed are providing us with an opportunity to provide a more robust, diverse and climate-change-resilient woodland resource, one that will also meet evolving military needs.

FOREST RESILIENCE – TREE HEALTH CHALLENGE

In 2017, as part of the UK Climate Change Risk Assessment, the Adaptation Sub-Committee conducted an independent review of evidence.[1] Hot and dry summers (which favour insects) along with mild and wet winters (which favour fungi) may lead to conditions that could easily make the country more suitable for the establishment of new pests and pathogens, or more susceptible to their impacts.

It seems increasingly likely that the combination of globalisation (increases in international trade) and climate change has seen UK tree pest and disease introductions increase progressively over recent years[2] and the increasing number of them attacking trees in the UK is having a significant impact on the MOD woodland resource. Although there are a host

FEATURE

▲ **Harvesting work at one of the MOD forests in Wales. The matchsticks in the middle ground are in fact 4.8m sawlogs. (© Steven Holdsworth).**

of diseases affecting our trees, the most significant current threats are *Phytophthora ramorum* and ash dieback (*Hymenoscyphus fraxineus*).

PHYTOPHTHORA RAMORUM

Unfortunately, larch trees (*Larix* spp.), which are widely grown in the UK for the timber market, are particularly susceptible to this disease, and large numbers have been affected. *P. ramorum* is detected by a combination of visual inspection, using both interpretation of aerial photography and field visits, followed by field tests of bark and needles. Currently 38 per cent of larch has had a Statutory Plant Health Notice (SPHN), which is issued to owners of diseased trees and means that infected trees in the area must be felled. Across the MOD estate in Wales, four SPHNs have been issued to date. If we add areas where there has been no confirmation, but which look to be clearly infected, then around 70 ha might have the disease. Timber from infected larch can still be used, and a programme is currently underway to ensure that the income from timber sales is reinvested into the estate to establish new woodlands.

As well as felling operations, additional biosecurity requirements are needed to reduce the risk of further infection. These have been put in place through collaboration with Defence Infrastructure Organisation (DIO) Foresters, Landmarc, Natural Resources Wales and the Forestry Commission Plant Health Team. As *P. ramorum* can be spread through water, soil, timber harvesting products (logs at the roadside) and residue (branches, bark, woodchip and sawdust), it is important to keep access routes clear so that machinery and vehicles avoid becoming contaminated and spreading the disease to other forests. Portable test kits have recently been used in the larch areas and the vehicle wash-downs. The results so far have been negative, but the practical challenge of working with the outbreak is likely to be an ongoing issue.

ASH DIEBACK

Once an ash *(Fraxinus excelsior)* is infected, it rapidly starts to lose condition, with small trees dying within a season. Larger trees can withstand the disease for longer but are structurally weakened and soon start shedding limbs once infected. Unlike many trees, ash timber becomes inherently weak once dead and therefore cannot be used.

Due to the large number of ash trees across the MOD estate (approximately 10 per cent of the MOD woodland resource of approximately 3.5 million trees), there will be a massive impact across our estate from the loss of training cover and the health and safety implications resulting from the dead and dying trees.

The most significant impact of ash dieback on MOD land to date is in Kent, where the disease was first identified five years ago. Most the trees are either dead or dying, resulting in large areas of the training facility being placed out of bounds.

A recent assessment of replacement species for ash[3] shows there is no single species that can substitute for the wide range of site conditions associated with the good growth of ash. In deciding to replace ash with another tree species, selection decisions will have to be made based on particular site conditions and woodland objectives.

FUTURE PLANS

DIO foresters and ecologists are working together with the military to redesign the forest resource across the MOD estate. We need a comprehensive rationale to address resilience through forest plans to ensure that woodlands are better suited to training requirements and better prepared to deal with climate change and new pests and diseases. The redesign will also create new woodlands and restore some ex-plantation areas to open habitat. Fundamentally all this means moving away from plantation silviculture to more naturalistic forestry and towards forest stands composed of more than one species, with innovative species chosen or encouraged.

The good news here is that there is little conflict between military requirements in terms of woodland structure and where we want to be in terms of more resilient woodlands. The move towards more continuous cover silviculture will provide a more natural woodland setting, and breaking away from even-aged stands of trees has other benefits. For example, one of the problems with a well-thinned, uniform plantation is that you can see right down the extraction routes and planting lines.

Managing light levels within a forest is a big part of growing quality timber for future markets, but it is also an important factor in terms of military training. If we remove too many dominant trees in a single operation, this could lead to a resurgence of dense ground cover, such as bramble. Whilst this is a perfectly natural part of a forest ecosystem, it can make areas impassable on foot, especially when trainees are carrying heavy kit and taking part in exercises at night.

In future, the suggestion is to use appropriately mixed stands; accept and use regeneration and regrowth; and enhance stands with additional species where required in all locations – including within ancient woodland sites – in continuous cover forest systems, coppice woodlands and high forest.

Where should we be looking for these additional species? While we think of UK as being cold and wet as compared with most of western Europe, what is absent in mainland Europe are trees of cold, wet oceanic conditions. These were squeezed out in the distant past as areas were covered in ice or became warmer and drier. However, in North America they survived to become the north-west forests we know today, with species such as giant Douglas fir *(Pseudotsuga menziesii)*, noble fir *(Abies procera)*, Sitka spruce *(Picea sitchensis)* and Western hemlock *(Tsuga heterophylla)*. In western Europe their ecological place is occupied only by oak *(Quercus* spp.*)* and minor associated species.[4]

In future, the suggestion is to adopt two models: a native western European warm temperate forest model for woods in south and east England, and a north-west American cool temperate forest model for upland production forests, particularly for upland northern and western areas of the UK, which will deliver in terms of the objectives for MOD woodland: future resilience and military training. ES

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The role of trees in sustainable urban drainage systems

Charlotte Markey outlines the issues and advances in using trees to deal with surface water in urban areas.


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The need to incorporate multifunctional constructed ecosystems and sustainable urban drainage systems (SUDS) into the hard landscape has increasingly moved up the political agenda, and more recent planning policy documents across the country reflect this change. This is because more impervious surfaces across existing and new sites impact on the transport of pollutants into receiving water and therefore the increased risk of degradation of our waterways.[1] The installation of stormwater control measures can take a variety of forms and a general understanding across the industry of the efficacy of such measures in urban catchments has increased significantly over the last five years across the UK.

SUDS are designed to reduce the impact of development through the management of surface water by replicating the drainage pattern of natural systems in a cost-effective way. Common features include swales, filter strips, permeable paving, raingardens and bioretention tree pits. A raingarden is generally a planted area on a natural slope designed to temporarily hold rainwater runoff. A bioretention tree pit is an engineered environment beneath the paved surface that is designed to attenuate and treat water from the highway. Bioretention tree pits can be constructed from sand or structural soil systems that are crated (in structural, modular cell matrices) or rafted (in shallow, modular units). As well as being low maintenance, well-designed SUDS can reduce pollution and the contamination of groundwater sources.

Bioretention is the process by which contaminants and sediments are removed from stormwater runoff; this is achieved by the movement of the water across and storage within a treatment area. Bioretention facilities have underdrain systems, while bioinfiltration facilities allow runoff to infiltrate into existing site soils. Bioretention and bioinfiltration facilities are typically small – footprints are generally 5 per cent of the impervious area that they receive drainage from, which is usually less than 2 acres. Where space is available, a forested or multi-zone filter strip may be used as pre-treatment for bioretention and bioinfiltration facilities.

Nutrients have been identified as key pollutants in stormwater, particularly nitrogen and phosphorus. The nutrient removal efficiency of SUDS is related to the root structure and density of the plants within the system. It is important that dense vegetation cover is established at an early stage, so that extensive root penetration prevents compaction or surface sealing. However, some bioretention tree pits are designed without understorey vegetation, and in these instances, it is likely that additional maintenance will be required to maintain the porosity of the surface of the filter media (e.g. physical removal of any fine sediments accumulating on the surface).

THE ROLES OF URBAN TREES

While numerous benefits of urban trees are understood, such as heat island mitigation and air quality improvement, knowledge of their potential contributions to stormwater management as a component of bioretention is minimal. Critical to tree function in these systems is the trees' ability to maintain health in the unique substrate and hydrologic regime found in the bioretention environment.

There is ample research to suggest that increasing the urban forest by providing optimal growing conditions for street trees will result in higher growth rates and ecosystem service benefits, but urban trees can be negatively impacted by detrimental rooting conditions and other associated stresses that are a direct result of their being grown in the urban environment. For example, limited access to water is one of these most common stresses.[2] Providing suitable soil water conditions is one of the contributing factors for success that precipitated the development of the SUDS tree pit concept that this article addresses.

ANALYSIS

Due to stresses such as compacted soil, development, air pollution, increased temperatures, insects and disease,[2] urban trees have an average life expectancy of only 10–25 years. Finding ways of prolonging the life of urban trees and decreasing the amount of maintenance required is critical in an era in which resources across local authorities are subject to conflicting pressures. Multifunctionality and the merging of budgets to deliver green infrastructure and SUDS solutions fit for highways is therefore an important step forward for urban environments.

Parameters relating to bioretention media composition, media chemistry tree species selection and planting location (upslope, mid-slope, or at the bottom of the bioretention system) were found to have the most influence on tree health. Results from our 25 years in practice suggest that tree health may be improved if species selection is based on bioretention media analysis and consideration of species compatibility with the growing conditions found in bioretention. The most suitable trees share certain characteristics. They are:

- Street trees that can tolerate urban environments;
- Trees with appropriate root volume provision, and designed for long-term tree health;
- Trees with a 2.5 m clear stem to ensure establishment and deter vandalism; and
- Generally deciduous so that natural light is maximised during the winter.

THE INTEGRATION OF TREES AND SUDS

One of the challenges that commonly faces planners and those who endeavour to bring SUDS to the market place are the constraints below the pavements of towns and cities in the forms of services, utilities and the need to retrofit into existing streets and highways. How can we connect into existing drainage networks and how do we respond when infiltration is poor?

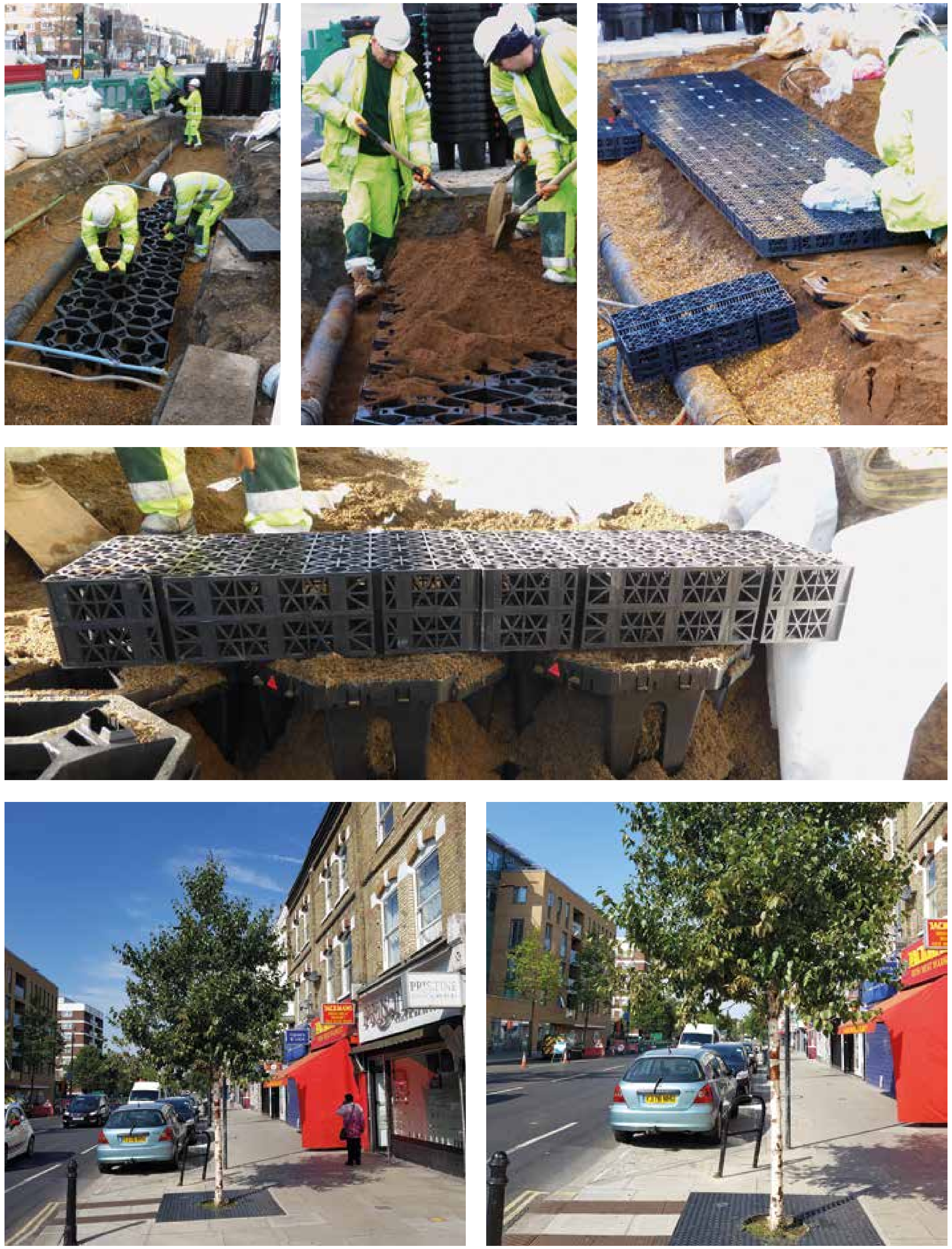
When we began to develop a tree pit bioretention feature for use in complex hard landscapes, we had to consider the urban environment in the round and to understand how interventions create new and often unexpected changes to the urban ecosystem. For example, integrating retrofit solutions into the hard landscape that include geocellular storage crates filled with specific soil mixes will have an impact on the root systems and the way water flows through the tree pit and into the drainage systems to which the pit is connected. We have to be constantly mindful that when we integrate a retrofit solution into a specific locale that we consider all the impacts and feedbacks. Soil cell systems (which are open structured, modular polypropylene crates) can be connected to existing drainage systems or combined with other SUDS features, such as swales and permeable paving, to create larger-scale systems. Tree pits have to be conceptualised as part of a wider nexus of solutions.

Peerenbom[3] considered different categories of interdependency, of which physical and geographical interdependencies are the most pertinent. In terms of physical interdependencies, when we integrate a SUDS tree pit we have to be aware that by using specific soil cell systems, how we underdrain the tree pit and the scale of our intervention will affect, and be affected by, the material output of other SUDS and non-SUDS drainage plans for the site. In terms of geographical interdependencies, when critical infrastructures are located on the same site, we have to design in and accommodate the sometimes-competing requirements. These competing requirements can often include the need to work around underground services and utilities, and sites where infiltration is poor or the topography creates a challenge to integrating the combination of natural solutions to managing water.

We have to recognise the complex nature of the relationship between urban flooding and green infrastructure (the network of multifunctional natural and semi-natural solutions for the natural mitigation of climate change and pollution).[4] We also need to highlight the need to assess flood return and design return approaches for each component to critically evaluate where we are best placed to integrate specific SUDS interventions. (A return period, also called a recurrence interval, relates to the likelihood of an event, in this instance a flood; design return relates to the period for which a product or solution is intended to last.) These are imperative when considering the role of urban trees in soil support systems used as bioretention features.

RESEARCH AND COLLABORATION

The importance of underground solutions that integrate treatment and attenuation has been expedited by the need to plan utilities systems that are compliant with the structural and engineering requirements of local authorities across the UK. Sand-based planting mediums are not suitable for highways schemes and for the treatment of runoff; also, there was a need to create a solution that provided an optimised rooting environment more specifically tailored to water management. Trials undertaken by Tom Smiley provided evidence to suggest that the use of structural soils would not provide the canopy cover required for interception in the event of heavy rainfall.[5] Structural soils are mediums that can be compacted to pavement designs, and they are made from either sand or gravel-based mixes that a tree's rooting systems grow through. Structural soils do have an increased loading capacity in comparison to sand-based solutions and, depending on design, there is the potential to absorb larger amounts of water due to relatively high porosity. However, we have relatively few case studies that demonstrate the ability of a structural soil to retain critical nutrient levels when under the increased pressures of water attenuation and managing surface water runoff.



▲ **Installation and completed works at Goldhawk road. (© GreenBlue Urban).**

▲ **Installation and completed works at Greener Grangetown. (© ARUP).**

Working with the University of Abertay, the team at GreenBlue incorporated soil cell technology to amalgamate the requirements of tree rooting systems below the paved surface and a unique system of treating and attenuating surface water in the event of heavy rainfall. It was with these considerations in mind that the development of two critical tree pit components was conceived: the treatment panel removes hydrocarbons and pollutants, and disperses salts from the highway, while the tree pit cells serve as geocellular storage for increased attenuation.

The following case studies connect the SUDS tree pit solution from its inception to its current status in the UK. The first is a hybrid tree pit that combines two different configurations of soil cell. The others provide the ultimate SUDS features that encapsulate the four pillars of SUDS: amenity, biodiversity, quality and quantity.

GOLDHAWK ROAD, LONDON

In Goldhawk Road, we were required to work with complex below-ground service configurations, so this was a unique opportunity to showcase what could be achieved by a combination of our soil cells and our treatment panels to form a bespoke bioretention feature. The need to position the tree pits around the existing gullies and to use a mixture of soil cell sizes to accommodate the varying depths at which we encountered services provided valuable learning.

Traditional highway gullies were removed from the location and kerb inlets were installed. These inlets were linked directly to the tree pits (beneath the tree grille) and directed surface water from the carriageway into the tree pits over the surface of the tree pit soil. This ensures that the trees receive rainwater every time it rains (even in short summer rainfall events), and that litter and silt are managed in an accessible location – the surface of the tree pit beneath the tree grille. Once the tree pit has filled with the polluted first flush of runoff, it passes over a weir surrounding the tree pit and through a layer of geocellular sub-base replacement beneath the pavement bedding layer. Geocellular sub-base is a shallow matrix of polypropylene cells varying in depth beneath the paved surface. This allows the flow of runoff to spread over the whole root zone and infiltrate into the soil. A perforated pipe at the base of the root zone collects the runoff as it reaches the base of the installation and directs it to a Controflow orifice flow control chamber, thus restricting discharge to the combined sewer. A second pipe connected to the upper level of the tree pit allows free overflow to the sewer once the storage capacity of the installation is exceeded.

The tree pits are designed to cope with a one in 30-year event discharging at 2 litres per second. This means that this system installed at the small scale can cope for a one-in-30 rainfall event; if scaled up and combined with other SUDS interventions, it could be designed to cope with much larger storms. A tree pit in isolation is therefore an effective measure but when integrated at scale into the design process can be optimised for stormwater management.

GREENER GRANGETOWN, CARDIFF

Greener Grangetown's raingardens are planted areas that mimic the natural environment, providing a more sustainable method for catching and cleaning rainwater. When it rains, water flows into the raingardens, where hardy plants and trees soak it up and filter it, capturing and breaking down some pollutants along the way. During heavy storms, water that cannot be absorbed by soil and vegetation travels through pipes at the base of each raingarden and is conveyed to the nearby River Taff. The scheme has resulted in:

- 42,480 m² of surface water being removed from the combined waste water network (the equivalent of 10 football pitches); and
- An additional 1,600 m² of green space (the equivalent of two-and-a-half football pitches).

BLETCHLEY ROUNDABOUT

The project was an excellent opportunity to combine tree planting with best practice in water-sensitive urban design. Careful consideration was given to the daily burden to the environment, including the movement of vehicles, people, stormwater and road gritting, along with the practicality of maintenance over the long term without affecting the quality and visual features.

One of the key success criteria for allowing long-term water attenuation within soil is to maintain uncompacted soil structure. This means that the macro pores as well as the micro pores, so critical to water and air transport and storage within the soil, are protected. They are fundamental to both tree health and SUDS performance. The design of the tree pit allowed large volumes of uncompacted soil to be provided, with a high-strength air deck support allowing flood dispersion and air replenishment to the soil zone. In addition, the modular, scalable root zone construction allowed tree pits to be linked below ground and thus accommodate a large volume of stormwater. The project has eight trees and a minimum combined stormwater capacity of 19,511 litres. That is 2,438 litres of attenuation per tree. The actual water capacity is likely to be significantly more, but current calculating methodology ensures a baseline figure that engineers can rely on. The figure does not include tree canopy interception (which can account for 70 per cent of the rain in the first hour of a rain event) or ground percolation and recharge, which varies by site.

LINKING SUDS AND GREEN INFRASTRUCTURE

Many types of urban infrastructure are able to provide a range of hydrological, ecological and built environmental functions and for multifunctional components. Particularly for SUDS-enabled tree pits in engineered below-ground solutions, it is clear that the so-called dominant function can oscillate depending on the conditions. For example, under flood conditions, various components facilitate the hydrological function via storage or infiltration, but in other scenarios, as more components become inundated, their ecological function can become compromised. Using an innovative solution that connects to existing drainage networks and adapts to sites with varying levels of infiltration, we could reduce and mitigate the potential impacts on this interdependent network of SUDS and grey infrastructure components. (Grey infrastructure includes the more conventional engineering solutions and infrastructure based on concrete or steel.) These bioretention solutions are able to reconnect the hydrological cycle through the contribution to groundwater recharge and to have a positive impact upon urban ecology.

Historically, green infrastructure planning is focused on a desire to extend the function of urban tree pit interventions to facilitate connectivity and multifunctionality, in contrast with SUDS planning, which was often governed by more site-specific approaches. An enduring modular solution can be used to bridge the divide between these competing yet interdependent objectives. **ES**

Charlotte Markey is a qualified urban planner for GreenBlue Urban and has an abiding interest in the development of SUDS, with a particular emphasis on retrofit solutions.

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New members and re-grades

Member

is for those individuals who have substantial academic and work experience within environmental science.

Pedro Abreu – Air Quality Officer
Paul Adamczyk – Environmental Consultant
Richard Ambrose – Director Environmental Services
Nicole Asante – Environmental Consultant
Paul Aujla – Environmental Manager
Roma Back – Environmental Coordinator
Paul Bentley – Air Quality Consultant
Jonathan Bladon – Laboratory Manager
Kenneth Bucke – Forestry Inspector Grade II
Kate Burrows – Principal Environmental Consultant
Scott Chambers – Principal Environmental Consultant
Lynsey Coles – Environmental Consultant
James Collins – Environmental Engineer
Phillip Colyer – Senior Environmental Consultant
Ami Cooper – Senior Engineer
Daniel Cox – Associate Director
Julie Coxon – Senior Scientific Officer
Verity Curtis – Environmental Scientist
Alistair Dick – Environmental Lead
Cheryl Donohoe – Technical Manager
Helen Embleton – Principal Ecologist
David Emmott – Geo-Environmental Consultant
Steven Fitch – Associate Director Environmental & Sustainability
Richard Foster – Wastewater Scientist
Stephen Franey – Senior Geo-Environmental Engineer
Loren Franklin – Senior Scientist and Project Manager
Sarah Freeman – Graduate Air Quality Consultant
Philip Garvey – Environmental Consultant (Land Quality)
Asha Ghowry – Environmental Scientist
Christopher Gilbert – Associate/Environmental Scientist
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Ka Po Ho – Environmental Consultant
Satbir Jandu – Principal Air Quality Consultant
Lisa Jobling – Principal Environmental Consultant
Caroline Jooste – Senior Environmental Engineer
Fiona Keates – Project Environmental Manager
Elaine Keenan – Environmental Consultant
Anil Kolapkar – Assistant General Manager
Alexander Koscielski – Environmental Manager
Kieran Laxen – Principal Air Quality Consultant
Mark Leatherland – Pan Alliance Enabling Programme Manager
Malachy McAlister – Senior Environmentalist
Susan McAuley – Environmental Consultant
John Millar – Air Quality Specialist
Charlotte Murray – Senior Geo-Environmental Engineer
Christopher Naick – Project Environmental Manager/Director
Oliver Nofal – Environmental Consultant
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Michael Sheard – Associate Director
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Hannah Smith – Senior Air Quality Consultant
Adam Steele – Geo-Environmental Consultant
James Thiaine – Environment, Health & Safety Specialist
Mark Thistlethwaite – Senior Geo-Environmental Consultant
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Astrid Tishler – Principal Environmental Consultant
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Anne Vergette-Hollingworth – Environmental Consultant
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Victoria Ward – Director
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Craig Watson – Remediation Project Manager
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is for individuals beginning their environmental career or those working on the periphery of environmental science.

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FEATURE

The 21st century wood-stock

Chloe Fletcher gives an overview of how the carbon storage capacity of forests is measured, given their vital role in regulating atmospheric carbon dioxide levels.

Forests are intrinsically important, covering more than 31 per cent of the global land surface[1] and hosting over 75 per cent of terrestrial flora and fauna.[2] These highly productive regions provide vital ecosystem services that we depend on for survival. Photosynthetic activity in leaves helps to regulate the levels of oxygen in the atmosphere. Forest soil anchorage and porosity increases the rate of groundwater recharge, providing approximately 75 per cent of usable water for drinking and bathing.[3] In addition, the timber trade historically laid the foundations of globalisation, providing resources for transport, energy and manufacturable goods. At a local level, forests reduce the erosion of soil and coastal land by wind and water. At a larger scale, they reduce the impact of natural disasters and, due to their essential role in the carbon cycle, contribute hugely to the modulation of climate and mitigation of climate change.

THE IMPACTS OF DEFORESTATION

Over the last three decades, deforestation, degradation and afforestation are estimated to have caused a net 1.3 million km^2 reduction in forestland, contributing to approximately 12 per cent of anthropogenic CO_2 emissions.[4] Land use changes have primarily occurred across the tropics to make way for commercial agriculture, increased urbanisation and large-scale (sometimes illegal) logging. Whilst the rate of deforestation had, on average, declined by 20 per cent between 2000 and 2010 against the previous decade, the rate of loss, at 33,000 km^2 per year, remains high.[1] Model projections indicate that perpetual losses at this present rate will result in changes in precipitation and global increases in CO_2 and temperature. As a result of feedback loops, these may lead to increased risk of regional drought, wildfires and flooding.

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FEATURE

A recent example of this can be seen in the heatwave that swept across most of Europe throughout the summer of 2018. Modellers at the University of Oxford indicated that climate change more than doubled the likelihood of this particular weather event across many regions of Europe.[5] By July 2018, there had been 42 per cent more wildfires across Europe since January than the average for the same period between 2008 and 2017.[6] Fires are natural phenomena that ecosystems rely on for cycling nutrients, promoting new growth and increasing species richness, as well as enabling the growth of serotinous tree species. However, the increased frequency and duration of wildfires can exacerbate environmental hazards such as increased atmospheric CO_2, ozone and particulate matter, which can in turn affect cardiovascular and respiratory health, along with the economic and social impacts of human displacement, climate change mitigation and suppression.

A warmer climate will also have considerable impact on tree phenology, potentially extending the length of growing seasons and, for deciduous species, causing shifts in leaf emergence, senescence and abscission. For example, a 1 °C increase in March temperatures in the north west of the UK is correlated with an earlier budburst of English oak *(Quercus robur)* by 4.3 days.[7] Species acclimation is not always possible, resulting in geographical shifts of tree species or, in worst cases, loss of forest biodiversity. With forests playing such an integral role in the climate system, effective mitigation of climate change is dependent on their sustainable management, primarily through reducing deforestation and preserving, or even increasing, forest biomass.

HALTING DEFORESTATION

Whilst it may appear that the simple answer is to stop deforestation, the issue is a complex one. A growing global population reliant on forests for basic resources means that demands on industries such as the timber trade will continue to rise, with estimates pitched to double by 2030 and potentially treble or quadruple by 2050.[3] Increasing demand for food and goods will also raise pressure to increase available land, often leading to large clearances of forestland. As younger trees absorb CO_2 at a faster rates than mature trees, deforestation can partially be compensated by afforestation and reforestation programmes, estimated to have covered half a million km² over the last decade.[3] However, this is often at the expense of forest biodiversity and genetic variation.

A key dimension to this issue is that forests are not international assets – they are partitioned by national boundaries that are controlled by seperate governments. For example, the Amazon rainforest crosses the boundaries of nine nations, with its largest regions in Brazil, Peru and Colombia. Therefore, forest management and sustainable logging practices implemented by one country could unintentionally be undermined by the inaction of another. For developing nations, the issue can be further compounded by a lack of resources and pressure to increase short-term wealth and preserve the livelihood of inhabitants. The duality of these circumstances led to the development of the United Nations Framework Convention on Climate Change's REDD+ programme (Reducing Emissions from Deforestation and Forest Degradation).

REDD+ is an initiative that incentivises developing nations to reduce emissions from deforestation and forest degradation, and increase reforestation and conservation efforts, by attributing financial value to carbon stocks.[8] Evidence of actions to preserve or enhance the carbon sink capacity results in financial reward. The ratification of the Paris Agreement since the United Nations Conference of the Parties 21 (COP 21) in 2015 has given prominence to REDD+ as a critical tool for mitigating climate change, particularly for ensuring warming does not exceed the threshold of 2 °C – or preferably 1.5 °C – above pre-industrial levels. The effective implementation of REDD+ relies on accurate quantification and distribution of carbon stored within forests. However, estimations vary wildly, with some researchers judging that forests act as net sinks and others as net sources. In the tropics, estimates of the carbon sink capacity have been found to vary by up to 42.5 billion tonnes, leading to uncertainty in climate projections.[9] As there are no unified data acquisition standards for measuring forest carbon stocks, this variation can often be attributed to differences in methodology, which typically focus on measuring forest biomass.

ABOVEGROUND BIOMASS

Forest biomass, the total dry mass of organic matter, reflects the cumulative productivity of carbon. Aboveground biomass (AGB) primarily comprises tree components such as leaves, branches, trunks and bark. Whilst AGB does not provide the whole picture of forest carbon productivity, its relative accessibility makes it a suitable determinant for forest inventory carbon estimations and one of over 50 essential climate variables established by the Global Climate Observing System programme.[10] In the context of REDD+ and the Paris Agreement, AGB compromises the largest pool of carbon most vulnerable to deforestation, fire, drought and disturbance. Therefore, carbon fluxes in forests as a result of these processes can be most accurately quantified by measuring AGB. There are several approaches to calculating tree AGB, either directly or indirectly, with the most commonly used methods described below.

DESTRUCTIVE SAMPLING

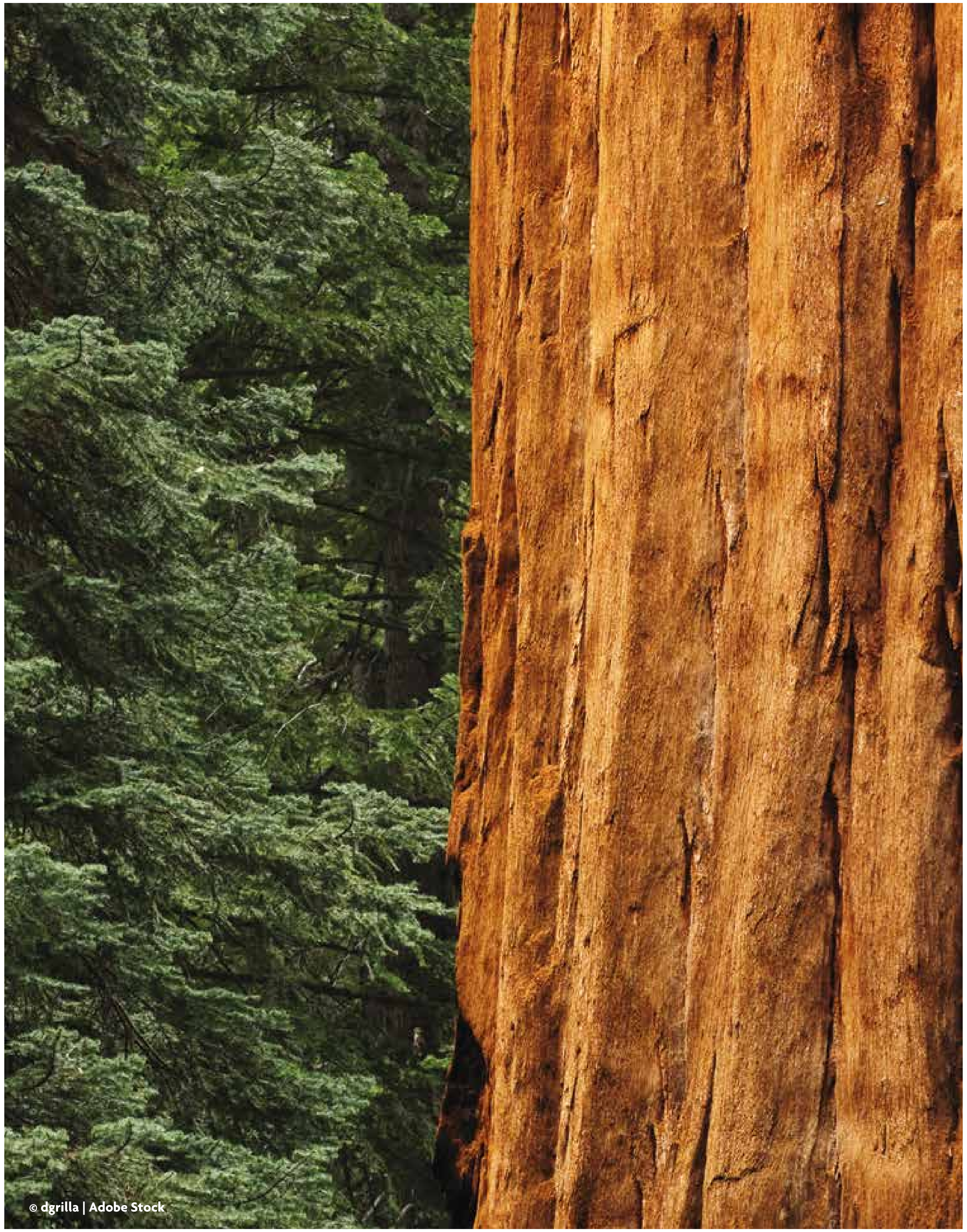
Destructive sampling is a direct method that yields the most accurate measurement of carbon. The process involves felling and harvesting a candidate tree, cutting it into smaller pieces, drying them in an oven to remove the water content, weighing the dry pieces and calculating the carbon content. Depending on the species, approximately 50 per cent of the biomass is carbon.

Whilst this method is a highly accurate and direct means of measuring carbon stocks at the individual tree level, it is impractical for determining large-scale carbon in forests due to its fundamentally destructive nature, which contributes to the specific problem it seeks to remedy. The process is also time-consuming and expensive, requiring a team of technicians and researchers using costly equipment. Furthermore, destructive sampling does not permit repeat measurement as trees are removed in the process, therefore changes in forest dynamics and carbon stocks cannot be observed over time.

Extrapolation over larger areas can also skew carbon estimates due to the small number of trees sampled and a necessarily biased selection process: old, endangered or otherwise protected trees are rightly excluded, as well as trees that are particularly large, deformed or buttressed. However, despite these limitations, destructive sampling works exceptionally well to permit calibration for other indirect methods that can be performed at larger scales.

ALLOMETRIC EQUATIONS

Tree allometry involves finding mathematical relationships between characteristics of trees. It uses *in-situ* field measurements that are easy to obtain, such as trunk diameter, tree height or wood density, to derive measurements for properties that are harder to measure, such as tree volume or AGB. This permits non-intrusive estimations of AGB that can be extrapolated to quantify carbon over large areas with relative ease and is therefore, at present, the most commonly used method for estimating forest carbon stocks. However, as relationships are empirically determined from carefully selected samples through destructive harvesting, relationships can be oversimplified and inherently biased, leading to inaccurate estimates, particularly for large tropical trees. Furthermore, this method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assumes regional homogeneity compared to sample measurements which, due to dynamism and frequently high biodiversity, is often unrealistic.

LIDAR

Over the last two decades, light detection and ranging (lidar) sensors have been increasingly deployed for their ability to capture the structure and shape of forests. These can be used to derive various biophysical properties, such as AGB, leaf-area index and canopy height, which inform changes in climate and forest productivity.

Lidar instruments fire laser pulses at target objects and measure the energy reflected back to the sensor as a function of time. This information is used to calculate the distance of objects and then translated into a digital 3D map that reveals a relatively clear picture of forest structure. Lidar uses lasers in either the infrared or visible spectra, depending on the parameter being measured and the location of the sensor. Sensors can be mounted on ground-based stands, mobile devices, aircraft, drones and satellites; each location provides different spatial resolution and detail.

TERRESTRIAL LASER SCANNING

Terrestrial lidar, most frequently referred to as terrestrial laser scanning (TLS), has received particular acclaim among forestry and climate researchers for its exceptional ability to capture high-quality 3D structural detail of forests. Multiple TLS scans can be combined to provide coverage of plots of 10,000 m^2 or more in size. From these combined datasets, individual trees can be extracted, identified and catalogued, with the tree structure then derived via a quantitative structure model. Once the architecture of the tree has been established, the total volume is calculated. With the tree species identified, the average wood density is used to determine AGB and subsequently the mass of carbon stored in the tree.

Whilst the process may sound arduous, many of the computational steps are becoming increasingly automated. Scans themselves can be completed in minutes, and 10,000 m^2 plots covered by over 250 scans can take between three and six days, depending on the understory density. In addition to AGB calculations, these measurements can determine tree height, tree diameter and other key metrics found in forest inventories, meaning this technology has the potential to replace field-based measurements. The accuracy in deriving AGB has been demonstrated in countless forest environments when compared with destructive samples, making TLS a worthwhile investment for aiding forest inventory.

However, a few issues arise from TLS measurements of AGB. Firstly, TLS instruments are predominantly effective for capturing understory vegetation, meaning that upper canopy layers are not always well represented,

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leading to underestimation of carbon stocks. This is because, in the presence of branches and leaf cover, laser pulses can become progressively intercepted up through the canopy, which leads to tree components being hidden from the scanner. Additionally, the high-quality detail of TLS means that there are computational constraints, including memory storage and processing time. Furthermore, whilst this technology permits rapid acquisition of forest structure, datasets are insufficient as a sole means for quantifying carbon stocks globally due to the time and resources needed to capture large areas of forest. However, if used to calibrate airborne or spaceborne lidar measurements, these highly detailed datasets can provide broader forest coverage and aid extrapolation of AGB estimates globally.

AIRBORNE AND SPACEBORNE LASER SCANNING

Airborne lidar instruments use the same technology as TLS but are mounted on aerial vehicles, such as aircrafts or drones, which are then flown over a target region. Spaceborne sensors are mounted on satellites. Due to the bird's-eye perspective, instruments are required to penetrate through the upper canopy layer to effectively measure AGB and maintain visibility in various weather conditions, which is virtually impossible using visible light. Therefore, airborne and spaceborne lidar sensors typically operate in the infrared spectrum.

Contrary to TLS, airborne and spaceborne laser scanning is most effective for capturing the upper canopy layers, with limited representation of the understory. This is particularly true in the tropics, which host the densest areas of vegetation that obscures visibility of the forest floor and increases the frequency of laser interception by foliage. When combined with TLS, these instruments permit a more detailed picture of all canopy layers.

One advantage airborne and spaceborne instruments have over TLS is that they capture much larger areas of forest with a single scan, making the measurement of AGB regionally and globally a more manageable task. However, the trade-off with area is the amount of detail acquired as well as additional costs associated with scheduling flights or satellite launches. It is therefore likely that TLS would be best used to calibrate and validate airborne datasets, and similarly airborne to calibrate spaceborne lidar, to strike a balance between spatial coverage, structural detail and necessary expenditure.

DATA QUALITY CONSIDERATIONS

Data quality in this context refers to the comprehensiveness with which laser scanners reproduce the 3D structure of forests. Factors that may impair quality include campaign design and scanner configuration, such as the position and density of sensors and angular resolution used, as well as atmospheric conditions such as wind or rain, which can move foliage and increase scattering of laser pulses. Additionally, quality may be affected by human invention or automated post-processing, including noise reduction, co-registration of multiple scans and interoperability between different platforms such as TLS with airborne lidar or airborne with spaceborne. This, along with variability in instrument configuration and retrieval methods, can lead to incomplete capturing of structural detail, which impacts data quality.

Minimum data standards and quality assurance protocols are necessary if laser scanning is to replace traditional forest inventory, but at present no formal consensus on these standards exists. It is well understood that trade-offs between efficiency and accuracy are ubiquitous in lidar data acquisition, as increased precision requires greater temporal, computational and financial expenditure. However, the effects of these trade-offs have not been fully realised, with different user groups relying on independent trial and error to optimise their results.

The implementation of REDD+ is becoming increasingly critical for meeting the needs of the Paris Agreement. Because of this, researchers are giving greater prominence to developing standards to increase the viability of lidar instruments for measuring carbon stocks, both regionally and globally. This will be necessary if laser scanning is ever to replace traditional methods, such as field measurement and allometry. With greater data interoperability and technological development, laser scanning truly holds the potential to further our understanding of terrestrial carbon (and the global carbon cycle), aid in more robust forest inventory, and inform effective mitigation against inevitable changes to the climate. ES

Chloe Fletcher is the Operations and Business Development Officer at the Institution of Environmental Sciences. Chloe recently completed an MSc in Environmental Modelling at University College London (UCL) for which she achieved recognition through the UCL Dean's List. Her specialisms include earth observation and remote sensing in support of ecological and climate change science. She also holds a BSc in Mathematics from UCL.

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ANALYSIS

Ash dieback in Britain – planning for a resilient treescape

Jon Stokes discusses the present and future of the disease affecting the UK's third most common broadleaved tree.

Ash dieback disease will lead to the decline and death of the majority of ash trees in Britain. It is the most significant tree disease to affect the UK since Dutch elm disease, which claimed 30 million British elms. Ash dieback has the potential to infect over 2 billion ash trees, from 1.8 billon saplings and seedlings to more than 200 million mature trees.

The disease spread from Asia into Europe during the 1990s and was first officially recorded in the UK in 2012, although evidence now suggests it arrived here as early as 2004. An outbreak in a nursery in Buckinghamshire in February 2012 was followed by the infection of a newly planted tree in a car park in Leicestershire in May. In autumn 2012, it was detected on young trees in Ashwellthorpe Woods in Norfolk. Ash dieback can now be found in 49 per cent of the UK's 10 km squares and over 66 per cent of England's 10 km squares. It may be even more widespread than officially reported, as the symptoms can be difficult to detect, especially in large trees.

Sometimes known as 'chalara', ash dieback affects ash *(Fraxinus excelsior)* and other *Fraxinus* species and is caused by a fungal pathogen. Scientists originally thought that its sexual and asexual phases were different fungi, and therefore gave them different scientific names. However, once they realised that the two were simply different phases of the same organism, they used the name *Hymenoscyphus fraxineus*.

▲ **Figure 1. Fruiting bodies on the central stem of the previous year's leaves. (© Jon Stokes).**

▲ **Figure 2. An example of a basal lesion. (© Jon Stokes).**

THE SCIENCE OF ASH DIEBACK INFECTION

The invasive fungus causes a range of symptoms from leaf spots to branch dieback. The majority of infected trees will die, although a few may survive because of genetic factors that give them a tolerance of, or resistance to, the disease. The percentage of the UK's ash trees that are likely to be resistant to the fungus is still unknown. In woodlands, evidence in December 2018 suggests mortality rates may be between 70 per cent and 85 per cent, and mortality rates of up to 85% after 20 years have recently been reported on some sites across Europe.

Infection mostly occurs through wind-borne spores landing on leaves or twigs, but can also occur at the base of trunks (the root collar) when the fungus probably enters the tree through raised pores called lenticels. Each spore has the potential to colonise parts of the ash tree. The spores are produced from fruiting bodies (small white mushrooms) on the central stem (the rachis) of the previous year's fallen ash leaves (see **Figure 1**).

As it grows, the fungus destroys the infected tree's phloem and xylem – these are the complex tissues that transport nutrients and water around the tree. The resulting lack of water and nutrient movement causes the leaves to wilt and the tree's branches to fail, and eventually the tree 'dies back' (hence the name). Repeated loss of nutrition and water, the depletion of energy reserves from the lack of leaves, and the invasion of secondary root-killing pathogens (such as honey fungus, *Armillaria*), cause the tree to become brittle, lose branches and finally succumb to the disease (see **Figure 2**).

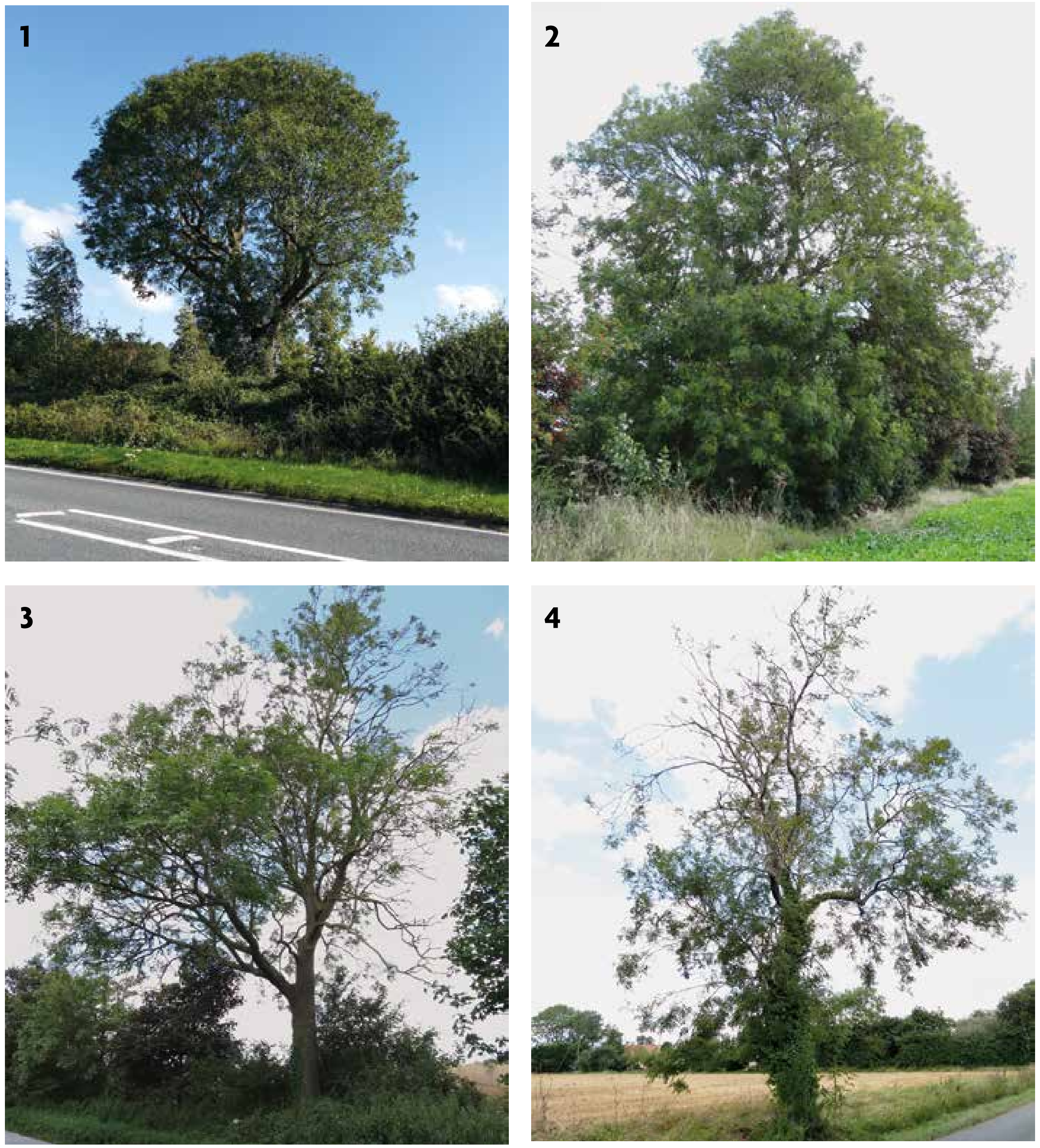
Trees with basal lesions can become unstable and dangerous within a year. The rot is usually associated with other secondary pathogens and can occur without any obvious symptoms in the canopy. This makes identifying 'dangerous' ash trees considerably harder.

ASSESSING THE HEALTH AND DECLINE OF ASH TREES

During 2014, Suffolk County Council developed a system to describe the health of an ash tree using a four-part categorisation which uses the state of the ash tree's canopy as a proxy for overall health (see **Figure 3**):

- Ash Health Class 1: 100–75 per cent of canopy remaining
- Ash Health Class 2: 75–50 per cent of canopy remaining
- Ash Health Class 3: 50–25 per cent of canopy remaining
- Ash Health Class 4: 25–0 per cent of canopy remaining

The speed of decline of any individual tree between health classes is currently impossible to predict and will be influenced by factors including soil type, soil moisture levels and topography.



▲ **Figure 3. Examples of the ash health classes. 1: 0% dieback – healthy crown; 2: 25% dieback; 3: 50% dieback; 4: 75% dieback. (All images © Gary Battell).**

As one example, **Figure 4** shows the change in a tree in Devon over a year (photographs taken on 6 July 2016 and 7 July 2017). The pictures show a 10–15 per cent decline in the canopy over that time, moving the tree from Ash Health Class 3 to Ash Health Class 4. Anecdotal reports from around the UK support this as a typical rate of decline.

However, some individual trees (depending on their health and condition) can decline much more rapidly, especially if other pathogens, such as honey fungus, are also present. Assessing and monitoring changes in an ash population's health is therefore vital in assessing the current and future scale of management issues organisations face.

▲ **Figure 4. The change in a tree from one year to the next. (Left: © Rob Wolton; right: © Jon Stokes).**

ESTIMATING HOW MANY ASH TREES ARE AT RISK

It has been estimated that there are over 2 billion ash trees in the UK, including saplings and seedlings. Of these, 125.9 million are trees located in woods. Between 27.2 and 60 million more trees are situated in non woodland areas. These calculations use the Forestry Commission definition of a tree as having a stem greater than 4 cm diameter at 1.3 m from the ground.

In the urban environment:

- It is estimated that there are 4 million urban ash trees in the UK (4.1 per cent of the 89 million urban trees).
- Highways England estimates that there are at least 4 million ash trees next to their road network.
- Network Rail estimates there are 400,000 large ash trees adjacent to the rail network.

These ash tree numbers provide national context, but a map produced by the Centre for Ecology and Hydrology (CEH), using the Countryside Survey Dataset to show the density of ash around the UK, gives a much greater understanding of the impact at a local level (see **Figure 5**).

ASSESSING THE COST OF ASH DIEBACK

Once a local estimate of the number of ash trees has been established, agencies can use this to gauge the costs of ash dieback. Modelling scenarios have been used that ask questions such as, "What would be the impact on expenditure and risk if 60/75/90 per cent of ash trees in this area are in decline/dead because of ash dieback in the next 5–10 years?" One county council's estimates can be seen in **Figure 6**. These numbers show that the costs of dealing with the health and safety impacts of ash dieback will be significant – without considering any issues that arise because of the loss of ecosystem services such as flood mitigation.

REBUILDING PRECIOUS TREESCAPES AFTER ASH DIEBACK

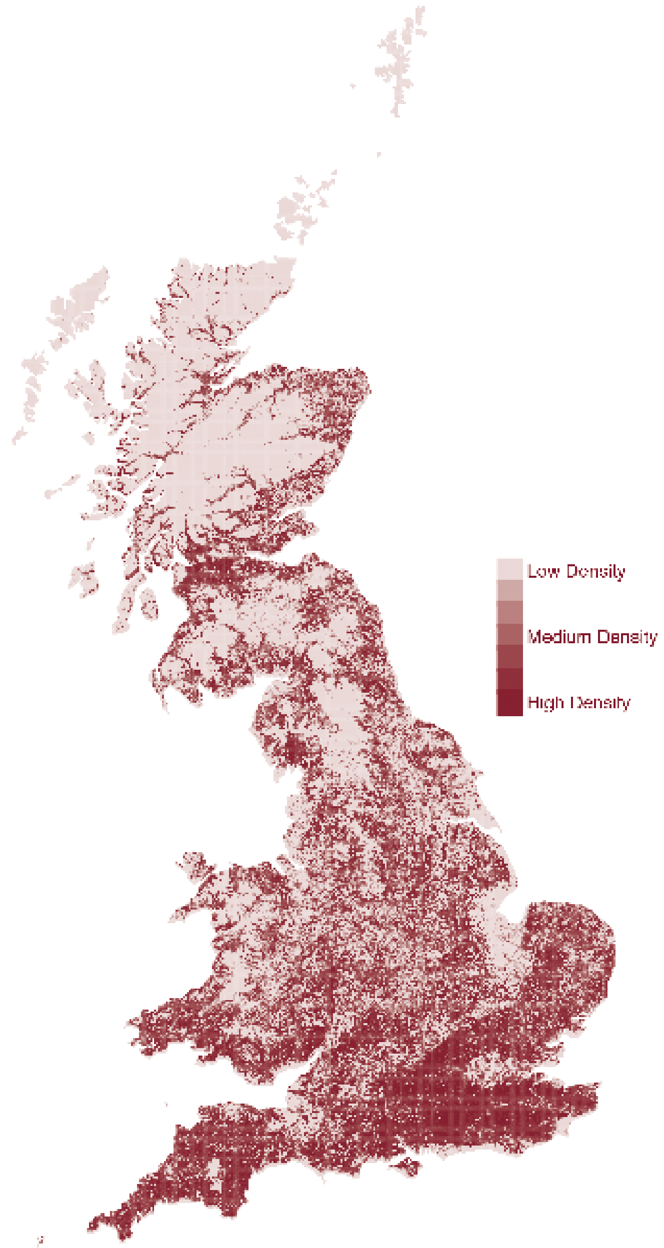
Ash trees provide a wide variety of benefits, including cooling, flood calming, improving air quality, wildlife habitats and adding to land values, as well as wellbeing and cultural gains.

As the impact of ash dieback starts to take its toll, alongside short-term tactics to deal with safety, a long-term vision is needed to recover the vital ecosystem services of removed ash trees and safeguard Britain's precious treescapes for generations to come.

We will need resilient planting and visionary thinking, delivered through local action plans that address the immediate and long-term threats to each community.

"The loss of ash is likely, due to its sheer abundance, to impact heavily on landscape quality, wildlife dependent on trees, the volume of storm run-off and the summer temperatures of cities and towns. Its loss will also have an impact on soil composition, specialist lichen communities and broadleaved timber products in woodlands."

Landscape and Ecological Resilience subgroup in the Devon Ash Dieback Resilience Forum.



▲ **Figure 5. Ash density in broadleaved woodland. (Used with permission; © Centre for Ecology and Hydrology).**

The Devon Ash Dieback Resilience Forum proposes eight steps for replacing lost trees:

1. Act now to minimise the landscape impact of ash tree loss – start planting new trees and taking better care of existing trees.
2. Use the 3/2/1 formula: at least three new trees for the loss of a large tree, two for a medium tree and one tree for a small tree.
3. Promote natural regeneration wherever possible, particularly in woodlands.
4. Grow the right trees in the right places in the right ways, and give them the right aftercare.
5. Encourage a diverse range of trees to develop a resilient landscape. No single species can substitute ash. However, alder, aspen, birch, disease-resistant elm, field maple, rowan and sycamore, along with native oaks, have some similar traits.
6. When choosing species, consider local factors such as what trees are characteristic of the area, soil type, management requirements, local stresses, etc.
7. For wildlife, landscape and wood fuel, choose native species, or those well established in the British Isles, such as crab apple, sycamore, white willow or wild pear. In urban areas it is more acceptable to use species from other parts of the world.
8. Reduce the risks of introducing new diseases by only planting trees sourced and grown in Britain.

Currently these concepts have been developed specifically for Devon, but as other agencies develop their ash dieback action plans these topics will be debated throughout the UK and national best practice will emerge.

ANALYSIS

Basic statistics:

6,020
ash trees recorded on adopted highway verges

Estimated
120,000
ash trees in private ownership and within falling distance of the highway

1,546
ash trees recorded in school grounds

Estimated
5,968
recorded woodland ash adjacent to public areas

83%
of the recorded ash trees are 6 m or more in size
(the size that requires work to be undertaken to remove safety risks)

Assumption
75%
mortality rate with £400 as the average cost of removal.

Cost implications of removal:

Adopted highways:
6,020 x 83% x 75% at £400 each =
£1,499,000

Private trees adjacent to highway:
120,000 x 83% x 75% at £400 each =
£29,880,000

Schools:
1,546 x 83% x 75% at £400 each =
£385,000

Woodlands:
5,968 x 83% x 75% at £400 =
£1,468,000

Tree planting to address loss:

Based on a free tree scheme for 83,000 trees lost at £15 per tree =
£1,245,000

Total potential costs at 75% mortality:
£34,477,000

Note: data anonymised; information supplied with permission.

▲ **Figure 6. The impacts of ash losses.**

A TOOLKIT FOR AGENCIES TACKLING ASH DIEBACK

Since the arrival of the disease, The Tree Council, in partnership with Fera Science Ltd, have led widespread research into ash dieback, looking at initial assessments and first responses to the disease from local authorities and agencies across the country. The research has shown that a strategic and coordinated response is required to deal with the multiple issues that ash dieback presents. In February 2019, we published a toolkit to help public agencies develop action plans to deal with the removal of dying and dangerous ash trees.

The toolkit is a step-by-step guide, including examples from local authorities and others who are currently active in managing ash dieback. The examples are works in progress, supplied with the generous agreement of the agencies and bodies that created them. As our knowledge and understanding of ash dieback expands, the toolkit will be modified and updated.

CONCLUSIONS

Nationally, we are in the early stages of understanding how to deal with ash dieback – the most significant tree disease to affect the UK since Dutch elm disease.

Ash dieback will lead to changes to our landscape and tree populations, and changes to biodiversity and landscape character. It could increase problems such as flooding caused by changes in the way water interacts with the environment. Given that ash is so widespread across our landscape, especially alongside roads and streets, simply dealing with the scale of health and safety risks caused by ash dieback will mean an end to business as usual for any organisation managing ash trees.

The Tree Council believes that we should work together and share our collective experience and best practice to tackle this significant threat to our landscape and environment. It will require effort and determination, but we must join forces to restore and enhance our historic British treescape. If we can achieve this, it will be an extraordinary legacy for generations to come. The toolkit is free and can be downloaded from www.treecouncil.org.uk/Ash-Dieback. ES

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✉ **info@treecouncil.org.uk**

The Northern Forest – a partnership for the long term

© McCoy Wynne | Mersey Forest

CASE STUDY

Iain Taylor outlines the essential elements to ensure the delivery of an ambitious and important project.

"Make no little plans; they have no magic to stir men's blood."
Daniel H. Burnham (1846–1912)

The north of England has a woodland cover of only 7.6 per cent, much lower than England's average of 10 per cent. The Northern Forest aims to increase woodland cover and work alongside major economic infrastructure programmes to improve the natural capital of the north for the benefit of all. It will consist of the community forests that are located in and around England's largest towns and cities: the Mersey Forest, City of Trees (Greater Manchester), the White Rose Forest (Yorkshire), HEYwoods (Hull and East Riding). Set up in 2018, the partnership of the Community Forest Trust, the Woodland Trust and those community forests will be responsible for planting 50 million trees over the next 25 years. Effective partnership working, supported by local councils and stakeholders with clear planning policy support (in the National Planning Policy Framework) has enabled the development of respected forest plans to be adopted and developed, and already millions of trees planted and countless communities and individuals engaged.

The Northern Forest is taking shape because of the vision and determination of the core partners. Partnerships in 2016 were well established with regard to economic development priorities such as the Atlantic Gateway and Northern Powerhouse, yet there was no such partnership of comparable scale articulating the case for a better, more resilient and valuable natural environment. This is important because the economy is, of course, the wholly owned subsidiary of the environment.

GOVERNANCE AND ENGAGEMENT

The Northern Forest is therefore a partnership of partnerships with a long-term shared goal. Sustaining this partnership over the long term is recognised as a key challenge, and with support from Heritage Lottery Fund, the partners are working with Northern Lights, a team of consultants based in Sheffield that is proving supporting with experience in partnership development, facilitation and appraisal. Together they will explore new governance models and approaches that will help sustain delivery over the project's lifetime. These will include informal arrangements supported with bespoke terms of reference and, if necessary, memorandums of understanding, as well as more formal structures usually associated with charities and companies with governing councils, directors and trustees. This article explores some of the lessons from another such long-term partnership, the Mersey Basin Campaign, which were:

- Periodic re-evaluation and adaptation in response to changing contexts;
- Independence; and
- A structure that allows for the engagement of individuals, stakeholders and organisations at a range of levels.

With the recognition of the Northern Forest by the Prime Minister on *The Andrew Marr Show* in January 2018 and significant reference in the Department for the Environment, Food and Rural Affairs' 25 Year Environment Plan (including initial funding of £5.7 million for a four-year planting and project development programme), the partnership needed to come together in a more structured way to facilitate the management of resources and to allow for the effective engagement of key third parties such as the water companies, Network Rail and Highways England.

The Northern Forest is steered and governed by a partnership board with representatives from the community forests, the Community Forest Trust and the Woodland Trust. It is also supported by the government (Defra and the Forestry Commission) with a specific interest in the governance of government investment. The community forests by their nature are small, dynamic, delivery-focused organisations, hugely sensitive and responsive to the demands of their partners and communities. The Woodland Trust has grown significantly and relies on policies and processes to control its activities, not unusual for a large national charity. In these early days of the partnership, the group functions through a mix of styles, both organisational and individual. We acknowledge the group is limited in the scope of its membership, so wider engagement beyond this core group is important. Whilst the founding partners will maintain their own approaches to partnership working, one thing is clear: the Northern Forest should create its own identity and approach, such that it can build on the foundations established and flourish into a successful long-term partnership.

A key strength of the partnership is the relationship between the core team members, all of whom have connections and trust built up over many years. The relatively rapid progress (50,000 trees have already been planted and more than 1 million have been pledged by partners) is in part down to the strength of the existing relationships. It is therefore important to establish the Northern Forest on a firm partnership footing before individuals move on. As outlined earlier, it will be important to bring others on board and extend the reach and engagement to new partners. Other key strengths include the growing recognition of the Community Forest Trust as the national community forestry charity, which works to promote and secure additional resources to benefit the sector across England, as well as the substantial resources and expertise within the Woodland Trust.

Picking up on one of the themes identified in the evaluation of the Mersey Basin Campaign, the Northern Forest partners recognise that re-evaluation and adaptation is key. We have therefore secured funding from the Heritage Lottery Fund to begin a year-long process, facilitated by an external consultant team, to work across the partnership on a new governance model that reflects the strengths and opportunities of the existing structure, and at the same time facilitates change and adaption to an ever-changing context. Only

▼ **The components of the Northern Forest from west to east: the Mersey Forest, City of Trees, the White Rose Forest and HEYwoods.**

THE COMMUNITY FORESTS ARE CELEBRATING THEIR 25TH ANNIVERSARY THIS YEAR. EACH OF THE COMMUNITY FORESTS IS STRUCTURED DIFFERENTLY AND THEIR INDIVIDUAL APPROACHES ARE WORTH REFLECTING ON.

The Mersey Forest has broad local authority and partner support, in particular from its host councils – Cheshire West and Chester Council – and a dynamic and engaged steering group, which recently celebrating its 100th meeting. Mersey Forest has an agreed forest plan and has effective partnership programmes in communities across the Liverpool City Region. Its key strength has been the innovation of community forestry into new areas, including health, water management, climate-change mitigation and schools. Mersey Forest has particular expertise in complex partnerships and EU and UK funding programmes.

City of Trees works across Greater Manchester. It has a range of effective governance and stakeholder engagement partnerships that maintain engagement with the business community, major funders, local authorities, as well as its governance through the Community Forest Trust. In this way, City of Trees is redefining community forestry as a growing and dynamic movement to support the involvement of individuals as well as organisations and business to plant trees, manage woods and engage people. City of Trees has undertaken one of the largest detailed surveys of trees for a city region and using the results to produce Greater Manchester's tree and woodland strategy. This crucial work will strongly embed the trees and woods agenda in policy along with delivery at the local and Greater Manchester levels.

The White Rose Forest works through a local-authority-based joint venture agreement between a range of delivery partners across the Leeds city region, including charities, community groups, the Forestry Commission and the Community Forest Trust. The partnership is referenced in key local enterprise partnership strategies and is facilitated by Kirklees Council as the accountable body. The partnership is working towards a forest plan for 2020 in collaboration with key stakeholders, including the Woodland Trust, the Environment Agency and Yorkshire Water, with aim of increasing tree cover by one-third by 2036. A priority focus for landowner engagement is the Aire catchment, driven by the need to reduce flood risk in Leeds city centre with forestry-based natural flood management. Its Green Streets® principles approach aims to ensure that urban forestry is incorporated into the design of transport-related infrastructure projects from the outset, with trials being undertaken in the East Leeds Orbital Route and the A62 corridor.

HEYwoods is supported and facilitated by East Riding of Yorkshire Council and Hull City Council, and works with local groups on the identification and delivery of tree and woodland projects across Hull and East Yorkshire. Activity is guided by the HEYwoods strategy, which identifies local priorities and acts as a framework for stakeholder participation. The partnership chair alternates between the two partner councils and provides an open forum for ideas that creates a vibrant and positive context for partnership development and networking. The group has remained stable throughout recent years, a testament to the engagement of stakeholders and the value the group brings to the area and agenda.

Overall woodland cover

13%	31%	33%	32%	68%
UK	France	Germany	Italy	Sweden

Our area is changing – we need to respond

With below-average woodland cover, but above-average ambition, the north of England is perfectly placed to leverage huge value from renewed investment in community forests.

13m Population ↑ **9%** In the next 20 years

650K New homes planned for the Northern forest area

7.6% Woodland cover

UK average = 13%
EU average = 44%

>£75bn Infrastructure investment planned over the next 25 years

The area has an abundance of transport infrastructure, with key gateways served by

2 Ports **& 7** Airports

Plus a new unified transport body, Transport for the North.

1 million companies help the area generate over

£304bn (that's 18% of England's GDP)

© HEYwoods

an open-minded positive engagement in this process by all will support a sustainable outcome. We must also be mindful that the partnership will require continued evolution over time to succeed.

COLLABORATION AND INDEPENDENCE

Working through partnerships and collaboratively with core partners such as the Community Forest Trust, the Woodland Trust and the government is core to the proposition and as such the Northern Forest is not owned by a single entity. This is hugely important as its independence is a strength and should be protected. Local engagement is the key to delivery locally, and strategic relationships and resources should be aligned to an independent core. The imminent facilitated work on governance should consider this as being a key aspect.

The role of government in cross-sector partnerships is hugely significant. The government has committed to funding some staff resources in this initial phase. The community forests, to varying degrees, rely on core funding from partners to make up the shortfall in revenues generated by project delivery. Core support to the Northern Forest and the community forests would enable them the capacity to develop leadership and new programmes, and in turn better support a more independent Northern Forest partnership.

The Northern Forest has already achieved a great deal and has the inherent strengths of a clear objective – 50 million trees planted in 25 years – and a dynamic, flexible and independent approach backed by a structure that allows for engagement and delivery at all levels. Yet, to achieve its full potential, the partnership needs sufficient resources of its own at its core. It also needs to continue to innovate and find new ways to engage partners, communities, landowners and government. **ES**

Iain Taylor is Chair of the Northern Forest Steering Group and Chair of Community Forest Trust. He is Executive Director of the Atlantic Gateway partnership, which works to promote collaboration and investment across Liverpool City Region, Greater Manchester and Cheshire and Warrington. He has a passion for partnership working, having been Partnerships Director with the Peel Group and Development Director with the Mersey Basin Campaign.

ANALYSIS

Veteran trees: Value, vulnerability and revitalisation

Helen Read, Vikki Bengtsson and **Phil Wheater** outline what needs to be done to conserve these significant habitats.

Ancient and veteran trees (see **Box 1**)[1] are of significant conservation importance because they often have extensive decaying wood supporting many rare species of fungi and saproxylic invertebrates (those that are dependent on dead or decaying wood). Despite Britain having a paucity of wildlife compared to similar latitudes of continental Europe, its saproxylic fauna is comparatively rich.[2] Wood pasture habitats, which frequently support such trees, were historically widespread across several areas of Europe, probably mimicking landscapes present before major human interference.[3] Management by grazing (with livestock, deer or rabbits) is fundamental to the existence of wood pasture.[4]

BOX 1: WHAT ARE ANCIENT AND VETERAN TREES?

The *Ancient Tree Guide No. 4* describes an ancient tree as 'one that has passed beyond maturity and is old, or aged, in comparison with other trees of the same species'. In the same document, they define a veteran tree as 'a tree with habitat features such as wounds or decay' and trunk hollowing is a key indicator of this.

Although all ancient trees are veteran, not all veteran trees are ancient. The important distinction is that veteran trees display some features associated with ancient trees that could be a result of their age, environment or management. These features include trunk hollowing and decaying wood supporting fungi and a range of invertebrates. Management techniques such as pollarding, as well as environmental factors such as lightning strikes and stress due to drought, can stimulate the natural decay processes.

The historical management of wood pastures has declined over the last century or so, leading to a loss of habitat and in particular a decline in the sustainability of veteran trees themselves. Despite this decline, southern England is still one of the best places in Northern Europe for ancient and veteran trees. The only other place in Europe with substantial numbers of English (pedunculate) oaks (*Quercus robur*) and sessile oaks (*Q. petraea*) with diameters of 6 m or more is southern Sweden.[5]

◀ **Grazing is fundamental to wood pasture as here at Burnham Beeches, U.K. (© City of London).**

▲ The creation of new pollards is a form of veteranisation that helps to ensure saproxylic habitats for the future (Burnham Beeches, U.K.) (© City of London).

Our research on veteran trees in southern England has established a number of recommendations to maintain these important trees and provide new generations for the future.

TRADITIONAL MANAGEMENT

In the UK, wood pasture featuring veteran trees occurs in wooded commons and historic parks and Forests (the capital 'F' indicates landscapes originally set aside for hunting that were not necessarily dominated by woodland – some Forests were moorland or heathland). Commons, as areas of high-intensity management that were abundant in the 12th and 13th centuries, provided fuel, small-scale wood and grazing for domestic animals.[6] English Forests and chases, used for hunting, at one time covered approximately one-fifth of England;[7] their management constraints limited the felling of trees. From the 13th century parks flourished in lowland England, with up to one park per 38 km^2, and until the 18th century, they were fenced areas for deer or feral cattle kept for hunting. Later, many parks were formally landscaped, often retaining older trees and continuing to be grazed by livestock or deer. Many trees on grazed commons, wood pasture, and historic Forests and parks were pollarded (involving the repeated removal of branches above the height that animals browse), a process that may extend the life of the tree. Pollarding was carried out either on a long rotation to provide wood for fencing and building materials, or on a shorter rotation to provide leaves for fodder.[8,9,10] At one time, in parts of East Anglia possibly 60 per cent of the oak trees (including those in hedgerows) were pollarded.[9]

CURRENT VETERAN TREE DISTRIBUTION

The current distribution of veteran trees in the UK is influenced by several factors, including:

- Commons with trees established on poor-quality land were less attractive for agricultural intensification and subsequent development. Management of commons was relatively stable for generations.
- Land inheritance in the UK tended to maintain large estates, reducing the likelihood of deer parks and chases being broken up. The management was also relatively stable over time.
- Rapid urban growth in the mid-19th century led to attempts to improve conditions for city workers, including protecting accessible green spaces outside London. Consequently, some important sites for wood pasture (and veteran trees) around London, such as Epping Forest (a large ancient Forest on the border between London and Essex) and Burnham Beeches (an ancient wood pasture in Buckinghamshire), were preserved by the City of London Corporation.
- Conservation organisations, including the National Trust, acquired land and protected the trees on it; one example is Hatfield Forest.

DECLINE IN MANAGEMENT

Once products from pollarding were no longer valued, management ceased. In the UK, many old pollards have not been cut for at least 100 years, resulting in large, heavy branches on hollow stems, leading to trees being more likely to fall over or fall apart. In addition, as a result of the natural ageing process, trees retrench as they get older and their crowns reduce in height. Where lack of grazing allows the growth of younger, more vigorous trees, veteran trees may become shaded out. In Burnham Beeches pollarding began to decline in the 18th century but continued until about 1820, with the last trees pollarded being those that were smaller and more accessible. By the 1930s there were 1,795 pollards on 81 hectares[11] but this has declined to fewer than 400 ancient pollards surviving today. In Epping Forest, the abundant hornbeam pollards were considered unsightly and were heavily thinned, with the loss of tens of thousands of these trees across the Forest in the late 1800s.[12]

There has also been lack of management of the trees themselves, primarily of regular pollarding. Many wood pastures were lost following agricultural intensification, including removal of their associated trees. Even where trees remain, when surrounding land is ploughed, fertilised and reseeded, trees are directly impacted. Rackham identified that the 18th and 19th centuries saw the greatest destruction of wood pasture systems.[13]

ANALYSIS

▲ New pollards also create a very characteristic landscape appearance. (© City of London).

Fewer were lost in the 20th century, although increased coniferisation destroyed essential elements of some wood pastures. Increased urban development also had an impact, with housing developments built on old wood pastures. Following development, wood pastures are often smaller and more isolated, with the associated species having populations that are less viable and less able to move between remaining patches.

DEVELOPMENT OF MANAGEMENT TO MAINTAIN ANCIENT POLLARDS

There has been increasing interest in developing appropriate management techniques for veteran trees over the last 30 years[14,15,16,17] with the Ancient Tree Forum being the lead organisation in the UK. Some of this work has involved research at Burnham Beeches, where there are currently 377 ancient pollards (299 beeches [*Fagus sylvatica*] and 78 oaks). In the 1930s, tree-ring examination determined that the trees were 270–360 years old.[11] They were first cut at 25–35 years and subsequently on an irregular cycle of 11–12 years (and up to 15 years in some older trees).

There is no first-hand knowledge of exactly how trees such as oaks and beeches in wood pastures were traditionally pollarded in the UK, since most were last cut over 100 years ago. Traditional methods were not written down in detail, so it is now important to adopt methods from elsewhere, interpret techniques from the structure of the trees and find new techniques from experimentation. Because trees are now out of a regular pollarding cycle, an issue that previous workers did not have to deal with, we need additional management techniques to deal with this.

Change of practice also applies to grazing: previously domestic livestock were herded and their grazing was directed, but now animals are unattended most of the day. Some traditional breeds that foraged these systems are no longer available or are difficult to obtain and require specialist knowledge for management. The general public may also be unfamiliar with grazing animals and can perceive fencing as a restriction on their rights to roam, especially where visitor pressure is high and concentrated. Conflicts between livestock and visitors (and their dogs) are common.

▲ **In many abandoned wood pastures the veteran trees have become shaded by younger trees and require haloing (Ashtead Common, U.K.) (© City of London).**

Pests such as grey squirrels *(Sciurus carolinensis)* impact on beech trees, and diseases such as mildew cause problems with oaks. In addition, the numbers of pests and diseases on trees has shown a significant increase since 2000[18] and many old trees suffer from new pests and diseases. Examples from wood pastures in southern England include oak processionary moth (*Thaumetopoea processionea*; Richmond Park, Ashtead Common), acute oak decline (Ashtead Common, Aspal Close), and ash dieback *(Hymenoscyphus fraxineus*; Hatfield Forest).

MANAGEMENT OF ABANDONED VETERAN TREES

Within the UK, the Ancient Tree Forum, the People's Trust for Endangered Species, Natural England, Woodland Trust and other partners (through the Wood Pasture and Parkland Network) are raising the conservation profile of wood pasture and disseminating knowledge on veteran tree management.[15,16]

Several stages are required for successful management of wood pasture and the associated old trees. Restoration needs to be phased, to avoid shocking old trees with major changes. The use of grazing animals is the best option for managing the land around veteran trees and essential for a fully functioning wood pasture. Probably the best long-term solution is grazing with cattle but the use of hardy sheep breeds can be useful to control the regrowth of woody material following clearance, as long as they do not damage the veteran trees. The Rare Breeds Survival Trust and the Grazing Animals Project encourage using traditional livestock breeds that are better at browsing areas and thriving where there is poor-quality fodder.

Competing young trees growing under and through the canopy of the old trees need to be removed early on, opening up a few metres around the canopy. After a few years, larger rings of open areas can be created around old trees, ensuring that they are not over-exposed to sun and wind. Focusing on trees in groups (rather than individual trees) is more effective.[19] The technique of carrying out a slow, phased clearance around single trees or groups has been termed haloing.

▲ **Pruning of ancient trees is a last resort. At Burnham Beeches (U.K.) an access platform is used to reduce the height and weight of trees vulnerable to falling apart. (© City of London).**

▲ **Left: Ancient trees provide exceptional saproxylic habitats due largely to the action of fungi decaying non functional wood (Burnham Beeches, U.K.). Right: People value ancient trees for their sense of antiquity and interesting forms (Ashtead Common, U.K.). (© City of London).**

The management of lapsed pollards that are out of a regular cycle of cutting is a new problem. Historically, problematic trees were probably left uncut and those that died would probably have been replaced. However, current lapsed pollards are precious remnants of a landscape and culture that is no longer active and of trees that are declining in number. They therefore need to be kept alive for as long as possible. This requires new skills and, although early experiences in the 1980s and 1990s were not always positive, from our research into managing lapsed pollards in wood pastures in southern England[20,21] we suggest the following principles:

- Prior to cutting the target tree, ensure sufficient light by cutting back young trees that overshadow the older trees, making sure this is done in small stages.
- Reduce damage to roots and surrounding soil by removing the source of the problem. Mulching can be used to restore compacted or eroded soils, whilst fencing or boardwalks may be appropriate if trampling is particularly heavy and cannot otherwise be avoided.
- Re-establish grazing if possible, using a low stocking density and appropriate stock that will not damage the trees.
- Cutting the target tree should be a last resort, although for very top-heavy and fragile lapsed pollards it may be necessary.

Cutting lapsed pollards tends to be most successful on trees that have many branches arising from the bolling (the swollen part of the tree where branches were cut back to when pollarded), because those trees have probably responded well to previous pruning. It is also best to choose trees where there is little other stress (e.g. soil compaction, low light levels or trees with low vitality). When cutting is employed, then as little leaf area and

▲ **Left: This tree shows an example of veteranisation where a woodpecker hole was created using a chainsaw. The photo was taken two years after the work was done. Right: This old lime pollard is still cut regularly within a wooded meadow in south-eastern Sweden. (© Vikki Bengtsson).**

branch material should be removed as possible, making the smallest wounds possible. Old branches tend to produce little wound wood and therefore callous growth over cuts is unusual. New growth from the stubs of these bigger branches may be vulnerable in the long term as the central decay weakens their attachment.[15,22] With beech it is better to leave long stubs (50 cm or more), and ideally branches over 30 years old should not be cut[21] because the live sapwood cells in beech start to die naturally at this age. Only a small number of trees in any group should be cut at any one time.

VETERAN TREES FOR THE FUTURE

If there are no trees of intermediate age to provide decaying wood habitats for the important species of fungi and saproxylic insects, veteranisation can be carried out. These are techniques whereby younger trees are managed in a way that may speed up the process of development of valuable dead and decaying wood habitats. Pollarding is just one technique that, done regularly, encourages hollowing in trees earlier than would be the case in the absence of pollarding.[23] Other methods of veteranisation can be used to damage younger trees (that might otherwise be removed in the process of haloing or wood pasture restoration) to create suitable habitats to encourage the development of decay and, for example, attract saproxylic insects.[24]

Veteran trees in wood pastures often contain some of the highest biodiversity remaining in otherwise heavily exploited landscapes. Conserving such trees and managing their replacements can be problematic, not least since the resource is declining. Careful management of the immediate environment and individual trees, and pollarding a new generation of trees, provides the best opportunities to ensure the continuation of this important conservation resource. **ES**

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Trees for cities: Planting the seeds for the next generation

Devika Jina and **Kathy Silenga** describe the ways in which trees make urban environments worldwide more liveable.

Trees for Cities is the only UK charity working at an international scale to improve lives by planting trees in cities. Since our inception in 1993, our volunteers have planted over 1,000,000 trees. Over 25 years we have engaged more than 100,000 community members, volunteers and school children in activities from planting trees to getting excited about fruit and vegetables. They have all been part of making cities greener.

Our world is becoming increasingly urbanised: about 70 per cent of the population will live in cities by 2050. With declining air quality and increasing temperatures, planting trees is a simple but effective

▼ Mango and papayas at Magwa Primary in Jinja, Uganda. (© Trees for Cities and SALVE International).

part of the solution to create liveable cities: trees provide countless benefits by cleaning and cooling the air, sequestering carbon, dulling noise pollution, supporting wildlife and so much more.

Besides the environmental benefits, trees support our quality of life by providing a source of healthy food and improving our mental health. Time amongst trees decreases levels of the stress hormone cortisol and increases people's sense of wellbeing. Even the physical signs of stress, such as muscle tension and pulse rate, are measurably reduced within as little as three to four minutes spent in leafy green surroundings. This is why urban communities stand to benefit a great deal from more trees in cities.

HOW WE WORK

Over the last 25 years we have continuously refined the way in which we go about planting trees to maximise the value for urban communities. Two elements of urban tree planting are essential for a successful project: the planting design and engaging local people.

- **Design:** activities include site and soil surveys, informed species selection, management planning, community consultation and fit with local policy, all of which ensure that we plant the right tree in the right place so that it will establish, flourish and be a real asset to the environment and people living in it.
- **Engaging people:** Trees for Cities plants trees for people, so it makes sense to consult and engage local people throughout each project. We engage residents of all ages through activities such as project consultation, school workshops, community planting days and training to plant and care for trees. Robust community engagement sustains the environmental and social impact of each tree for years after project completion.

Our approach has been tested and refined – in London since our inception, then more widely in the UK and globally from 2006. We have engaged with local partners in cities in east Africa, South America, Asia and mainland Europe. Whilst there are obvious environmental, social and economic differences in

▲ **Planting in Benue, Nigeria. (© Trees for Cities and WEP).**

▲ **Where trees grow, people grow! (© Trees for Cities and ANA Rwanda).**

each city, the principle of urban tree planting remains the same. By working with local partners to engage communities, projects are designed to meet specific needs, whether those are providing a sustainable source of healthy food or combating desertification. In developing countries, using tree planting as our tool, we have helped create alternative livelihood strategies for urban communities. Projects have taught people how to grow fruit from trees and promoted selling of produce to generate income. We have established tree nurseries and worked with beneficiaries to develop seed propagation techniques and local demand for tree seedlings.

Many projects plant fruit and nut species to increase food security, reduce food miles and improve nutrition. A range of edible species have been planted, including apple, avocado, guava, mango, orange, papaya, passion fruit and plum, which (depending on species) can produce up to 200 kg in fruit a year for up to 200 years. In cities such as Addis Ababa, where fruit is expensive and only accessible to the wealthiest households, our activities improve both access and equality. Establishing fruit trees in school grounds means that schools can provide pupils with nutritious food, which in turn impacts on both attendance and attainment levels in class.

In Africa there is a proverb: 'We straighten the tree when it is still young', meaning that the future health of our planet depends not only on our actions today, but also on the behaviour of children tomorrow. Our projects engage children in environmental learning and tree planting activities by establishing environmental clubs and integrating environment education into the curriculum. In doing this we are inspiring a generation to care for trees and appreciate the many benefits they provide.

UGANDA – JINJA

SALVE International is a charity dedicated to reintegrating street children into society, providing them shelter, familial connections and access to healthy food. In 2013, Trees for Cities worked with

CASE STUDY

▲ **Students planting trees in Jinja, Uganda. Bottom right image shows Edwin with an avocado tree. (©Trees for Cities and SALVE International).**

SALVE International on a project called Trees for Integration, which brought together street and school children to learn about trees and plant some in school grounds. Species planted included fruit trees such as guava, jackfruit, mango and orange.

Together, we planted a total of 2,830 trees across 13 schools and at SALVE's rehabilitation centre, providing a sustainable source of healthy, free food to boost physical and mental health. Each school signed an agreement to ensure that they would provide food to more vulnerable pupils and street children. The project also led to a noticeable change in the perception of street children as 'bad kids'. The opportunity for children of different backgrounds to relate with each other and invest care and attention in their community has in turn helped open hearts and minds.

Edwin, a child supported by SALVE International, said:

"I love fruit trees so much, I took part in the tree planting so that I can learn how to plant trees and be in a school again. Fruit trees are sources of income, and they provide people with vitamins."

NIGERIA – FOUR STATE CAPITALS

Desertification or land degradation resulting from drying conditions is a growing problem in Nigeria, spreading south from the Sahara with increasing tree felling and climatic change. Trees are cut down for fuel, to clear land for new housing for a growing population, and for farmland. Yet, by cutting trees for farmland, the soil becomes more arid and less fit for purpose. This has forced herders and farmers to migrate further south, increasing demand and strain on resources in these areas. Trees in the ground help combat dry conditions and improve soils, making them part of the solution to the problem.

Trees for Cities partnered with Women Environmental Programme (WEP) to plant trees as part of the Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI), which will span the entire 8,000 km width of Africa, to curb desertification and improve living conditions for communities in affected areas. Together we planted 2,000 trees across four state capitals in central and northern Nigeria: Abuja, Benue, Kano and Katsina. The trees will help to restore land and regenerate resources, supporting local people, particularly farmers, to rebuild their livelihoods. In all locations, the species planted were selected for their suitability for the environment and wherever possible included those with economic benefit (such as mango and cashew), which directly support local livelihoods.

Planting sites were carefully selected to ensure commitment from the schools or community members to look after the trees. In Abuja, where the trees were planted on an estate, trees were planted in front of households, which then had the responsibility of looking after them and eventually taking the harvest. In schools, the school administration will be responsible for harvesting and distribution. To ensure that communities and schools take ownership of the project, an intensive consultation and sensitisation of the communities was carried out prior to the choice of planting sites. Only communities that demonstrated that they needed the trees and had a commitment to care for them were selected.

PERU – ICA

In Ica we worked with the Royal Botanical Gardens, Kew and the Association for the Children and Environment (ANIA) to establish a permanent tree nursery at a school in the centre of the city, the Colegio Antonia Moreno de Caceres. Ica is situated in the dry valleys of the country's southern coastal desert, where the riparian huarango *(Prosopis limensis)* dry forests are found. This area has seen mass deforestation due to intensive agriculture and demand for industrial fuel. The relics of the forest are still being rapidly depleted, leaving local communities with limited access to the huarango, a tree that provides multiple benefits, including a valuable and highly nutritious fruit that can support the livelihoods of local people. Other native species that have a similarly positive impact yet are in decline include espino *(Acacia macracantha)*, Peruvian pepper, *(Schinus molle)* and lúcuma *(Pouteria lucuma)*.

The tree nursery, built in 2014, is still used to teach local people and school pupils how to sow, grow and propagate tree seeds; five teachers from the science, technology and environment department take responsibility for lessons. Under their guidance and with support from ANIA, all 524 school pupils take part in weekly sessions at the nursery and, along with local residents, they are actively involved in planting new trees in Ica to restore lost woodland. In its first year of operation alone, residents and school pupils raised a total of 1,354 seedlings, most of which were planted out at sites across Ica. With the nursery now established as a permanent facility, it is expected that a minimum of 4,000 seedlings will be successfully raised and planted each year to help to restore depleted areas of the dry forest.

Pupils equipped with this knowledge are able to pass it on to their families, so they too can contribute to the restoration of Peru's dry forest and understand how to use natural resources sustainably. With the impact of climate change increasing, particularly in developing countries, this understanding is crucial for forests to be managed responsibly for future generations.

MORE TREES IN MORE CITIES

As we move through the Urban Century, there is much that can be done to make cities more liveable and resilient to future change. With recent advances in city planning demonstrating how trees can be an integral part of increasingly urban environments, tree planting is a cost-effective, vital part of the solution. Besides engaging local communities to ensure that the principle of 'right tree, right place' is lived out so that they are of real and lasting value, it is essential to drive forward innovation and thinking about how trees can address issues from the short-term impact of sea-level rise to improving air quality around city schools. **ES**

Devika Jina studied Philosophy at Heythrop College, University of London. After graduating she embarked on a career in the environmental charity sector, working in marketing. Today, she is Marketing and Communications Manager at Trees for Cities where she is responsible for press and media, content, and the charity's marketing strategy.

Kathy Silenga has a degree in Zoology from the University of Edinburgh and 18 years experience working in conservation. This includes five years in Zambia where she conducted surveys in national parks and was manager of a wildlife sanctuary. She spent four years in Ghana with West African Primate Conservation Action as Country Coordinator. She is currently UK & International Projects Manager for Trees for Cities, where her responsibilities include fundraising, partnership working, project development and delivery.

CASE STUDY

The National Forest

John Everitt highlights the approaches and techniques that have been successful the creation of the National Forest.

On the face of it, tree planting is easy: you dig a hole, insert a tree, backfill with soil and watch the tree grow. Yet, despite this seemingly simple process, increasing tree cover significantly across England has proved frustratingly difficult in recent years. Now, with government targets focused on planting 11 million trees, a national tree champion appointed and a range of new initiatives proposed, the opportunities for afforestation are looking up. But with all this enthusiasm we still need to ensure that we are planting the right tree in the right place. The experience of the National Forest demonstrates how it is possible to achieve woodland creation at scale, even in lowland England, whilst not compromising the benefits of multi-purpose forestry.

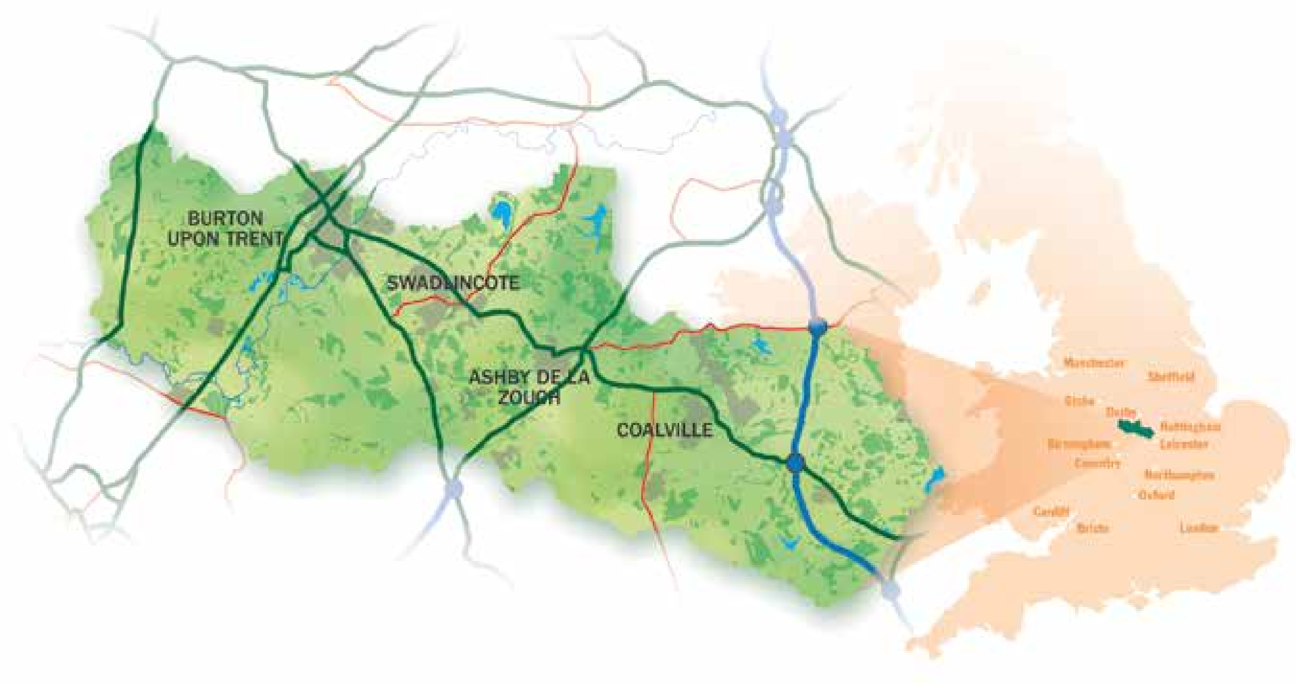
The National Forest was initiated in the late 1980s by the Countryside Commission as a response to the growing need for rural regeneration. An area of 500 km² across parts of Derbyshire, Leicestershire and Staffordshire was selected for the creation of this new Forest (see **Figure 1**), based on its central location – within 90 minutes' drive for some 10 million people, the serious dereliction of the landscape from years of heavy industry, and strong public support. It would be an exemplar of environmentally led regeneration using trees as a catalyst for change.

By 1991, the first trees were being planted. At the time, forest cover across the National Forest was just 6 per cent of the land area, and consisted of the fragmented remnants of the former Needwood and Charnwood Forests. Scroll forward 28 years to today and forest cover now stands at 21 per cent (see **Figure 2**), more than double the national average for England and still increasing at a steady rate. What is particularly remarkable about this achievement is that the core vision established in the early days of the National Forest has been maintained throughout, helping to underpin the principle of the right tree in the right place.

The vision has been built on the two key pillars of form and function:

- **Form** – taking account of the value of mixed land use and the importance of landscape character in planting location, scale and design, as well as recognising that 'forest' is a mosaic of habitats and not simply an area of densely planted trees; and
- **Function** – focused on creating a predominantly broadleaved forest with strong ecological credentials and commercial opportunities while ensuring public access for new woodlands so that the benefits can be enjoyed by everyone.

Holding firm to this vision, by resisting the temptation to compromise on form in order to meet targets or rein back from function to secure quick wins, has not been easy. Interestingly, the rationale for both form and function has gained momentum and strengthened over time, giving greater coherence to the Forest itself.



▲ **Figure 1. Map of the National Forest and surrounding cities. (© National Forest Company).**

▲ **Figure 2. Maps of 1991 and 2018 to show change in forest cover. (© National Forest Company).**

CASE STUDY

FORM

The National Forest has six distinct landscape types (see **Table 1**), and landscape character has been an important feature in defining the species mix and the planting design. This has meant restricting planting to lower-grade agricultural land, derelict sites, urban sites and amenity grassland. It has also meant tailoring schemes to fit, including more scattered trees and parklands in open landscapes and the larger estates, wet woodland in the Trent Valley, pioneer species such as birch across the former coalfields, and oak on the granite of Charnwood.

In the same way, non-woodland priority habitats have been recognised and enhanced to provide more connected blocks of heathland, grassland and wetland that mirror the underlying geology. Guidelines for planting design and species use for each landscape type have been produced to steer individual schemes, evolving as the landscapes themselves change. Promoting and enhancing a new landscape character in this way is defining a sense of place that is not only influencing the choice of tree species, but is increasingly shaping the built landscape and surrounding infrastructure.

FUNCTION

A strong commitment to ecology has favoured broadleaved planting over conifers (at a ratio of about 80:20) and the use of native species. Mixed planting has also been a priority, with few stands of any single tree species in the Forest, helping to reduce the impact of diseases (such as ash dieback) and building long-term resilience. One eye on the commercial use of the Forest has meant that higher-value hardwood species have been promoted as dominant species, and some commercial conifer blocks exist with broadleaved buffer strips. This approach has also initiated a strong focus on woodland management at the first thinnings stage: some trees are taken out to encourage strong growth in the remaining trees, and this also helps to combat disease, diversify habitats and maintain access. Such commitment has increased woods in active management to an impressive 75 per cent against a national figure of less than 60 per cent.

There is an argument for favouring natural regeneration over tree planting to promote afforestation. Indeed, in areas with an existing seed bank, where woodlands are being extended or in areas with less disturbance, natural regeneration has worked well. But for the National Forest, the majority of planting needed more of a helping hand: impoverished soils meant that the seed bank was depleted and the establishment of pioneer species was slow. This, coupled with the speed at which an impact was needed meant that tree planting has been the preferred approach.

Almost uniquely across the country, the National Forest planting has required public access to be created, and today around 80 per cent of new planting is accessible. This has been no mean feat across multiple ownerships and, crucially, it has enabled local communities, businesses and visitors to engage with woodlands and build a new woodland culture.

▼ **Table 1: The landscape character planting types in the National Forest.**

Landscape zone	Landscape characteristics
Needwood	Historic, well-wooded plateau.
Trent Valley	Extensive flat floodplain, with strong industrial and urban influences with sand and gravel workings; major transport routes; wetland.
Mease Lowlands	Rolling agricultural landscape, relatively un-wooded.
Melbourne Parklands	Undulating, upland feel; wooded estates; sparsely wooded plateau top.
Coalfield	Urban influences, woodland planted on former derelict land and spoil heaps.
Charnwood	Rugged upland character with heathland and exposed crags; productive stone quarries.

▲ **Sence Valley opencast mining before tranformation to Sence Valley Forest Park. (© The National Forest).**

▼ **Table 2: Planning and the National Forest.**

Planning policies for the National Forest, including guidelines for creating attractive, wooded settings for new development, have been adopted into core strategies, local plans and neighbourhood plans. In exceptional circumstances, where planting cannot be accommodated to this scale within the development, the shortfall should be addressed by a contribution to off-site planting of £35,000 per hectare secured through a Section 106 agreement.

Development type	Thresholds	Proportion of site to be Forest green infrastructure
Residential	Between 0.5 ha and 10 ha	20 per cent
Employment	Between 1 ha and 10 ha	20 per cent
All development types	More than 10 ha	30 per cent

MECHANISMS USED

The National Forest's success in increasing forest cover has come from using a range of different mechanisms to promote new forest creation. The largest contributions have been through incentive schemes and the innovative Tender Scheme, in which landowners put in bids to deliver new planting alongside other benefits. But the planning process has also played a significant part, contributing almost a quarter of all new habitat, with policies across all county and district authorities ensuring that new woodland is created on the back of landfill, mineral extraction, housing or other developments (see **Table 2**). A proportion has also come through new land acquisition from the public and the voluntary sector, as well as a range of community schemes and individual planting. This could have been very fragmented, with landowners, planners and developers all working in different directions on their own individual schemes. However, the guidance, advice and incentives have been consistent, ensuring that planting is complementary and coherent.

THE FUTURE

The intention is still to push beyond the current 21 per cent forest cover figure, modelling future aspirations on the level of forest cover in the New Forest of about a third. Mapping work has demonstrated that this should be possible given the levels of suitable land available. In addition, the upcoming changes in agri-environment payments may open up new opportunities. With the planned increases in housing and infrastructure across the Midlands, the Forest is likely to become even more important in enabling so-called clean growth.

The core principles of the National Forest have stood the test of time well, and whilst climate change is challenging the choice of species and the economics are shifting the broadleaved/conifer mix, those principles still hold true. Trees are a long-term venture and 28 years is still a short spell in the life of a forest, but the National Forest confirms that trees can still be a vital part of our future landscape. ES

John Everitt is a British environmentalist who has worked in conservation for more than 25 years and has a particular interest in the interplay between people and the environment. As the Chief Executive of the National Forest Company, he plays a key role on boards and networks across the region, including the East Midlands Committee for the Heritage Lottery Fund, the Lowland Derbyshire and Nottinghamshire Local Nature Partnership, and the Charnwood Forest Regional Park. He has held senior positions in the sector, including Director of Conservation for The Wildlife Trusts, a Director of Wildlife & Countryside Link, a member of the UK Biodiversity Group and Chair of the Sherwood Forest Regional Park.

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