Forest Research

Research Note

Understanding the role of urban tree management on ecosystem services

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Urban forests provide ecosystem services that contribute to human health, liveability and sustainability. The management of trees influences the delivery of these ecosystem services and thus helps determine the total benefit provided by an urban forest. This Research Note summarises two Research Reports that assessed the delivery of regulating ecosystem services by 30 tree species common to the urban environment in the UK. The importance of characteristics such as tree size, stature and condition on ecosystem services delivery are examined, and how these vary across different species. Using academic, industry, central and local government sources, the implications of management practices for ecosystem services delivery by individual trees are discussed, as well as the cumulative impact of the whole urban forest. This is achieved by considering key drivers and vital practices in the four key stages of urban tree management, namely, species selection, planting and establishment, maintenance, and removal. The findings illustrate that management practices influence ecosystem services delivery by urban forests through selection of the trees planted, how trees are maintained, and when and for what reasons trees are removed. Healthy large trees are shown to provide the greatest quantities of ecosystem services per tree, emphasising the importance of urban forest management that values and protects these trees. However, constraints and challenges can inhibit the proactive management of urban trees.

Introduction

Urban forest is defined as 'all the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas' (Urban Forestry and Woodlands Advisory Committees Network, 2016). Urban forests contribute to green infrastructure and the wider urban ecosystem, and they provide a range of ecosystem services that help alleviate problems associated with urbanisation (Davies *et al*., 2017a). For example, they make urban spaces healthier by removing air pollutants and by creating greener spaces that encourage recreation, socialising and relaxation (Davies *et al*., 2017a). They also contribute to liveability by maintaining links to local culture, history and nature, and to urban sustainability by reducing stormwater run-off and sequestering carbon. Many of the benefits provided by urban trees contribute to national and local policy objectives, such as improving public health and well-being, and contributing to climate adaptation and mitigation. Consequently, planting is increasingly encouraged, for example by the creation of a Northern Forest (HM Government, 2018a).

The quantity of regulating ecosystem services delivered by an individual tree, such as carbon storage, rainfall interception and air pollution removal, is determined by characteristics including size, stature and condition (Davies *et al*., 2017a; Hand, Doick and Moss, 2019a,b), meaning that some trees provide greater quantities of ecosystem services than others. The content that follows discusses how management of urban trees can impact these characteristics, thus enhancing or constraining ecosystem services delivery by the urban forest. In doing so, this Research Note aims to inform urban forestry decision-making to achieve greater benefits from urban trees.

Ecosystem services delivery by urban trees

The ecosystem services delivery of urban trees can be assessed using tools such as i-Tree Eco (www.itreetools.org), which estimates carbon storage and sequestration, avoided stormwater run-off and air pollution removal. Drawing upon data collated from 10 i-Tree Eco studies in the UK, two Forestry Commission Research Reports detailed the delivery of these ecosystem services for (1) large stature tree species, defined as a species in which a healthy, isolated 20-year-old specimen growing in good soil conditions typically attains a height of greater than 12 m (Stokes *et al*., 2005; RHS, 2016; Hand, Doick and Moss, 2019a,b); and (2) small and medium stature tree species, defined as species in which a healthy, isolated 20-year-old specimen growing in good soil conditions typically attains a height of (small) less than 6 m or (medium) between 6 and 12 m (Hand, Doick and Moss, 2019a,b). Note that it is the species that is defined for stature and not the tree, and that this definition is also independent of age. The two reports featured 30 species common to UK towns and cities and investigated how ecosystem services delivery changed with increasing size, and how this varied among trees of different species and conditions. The main findings from both reports follow below.

Size

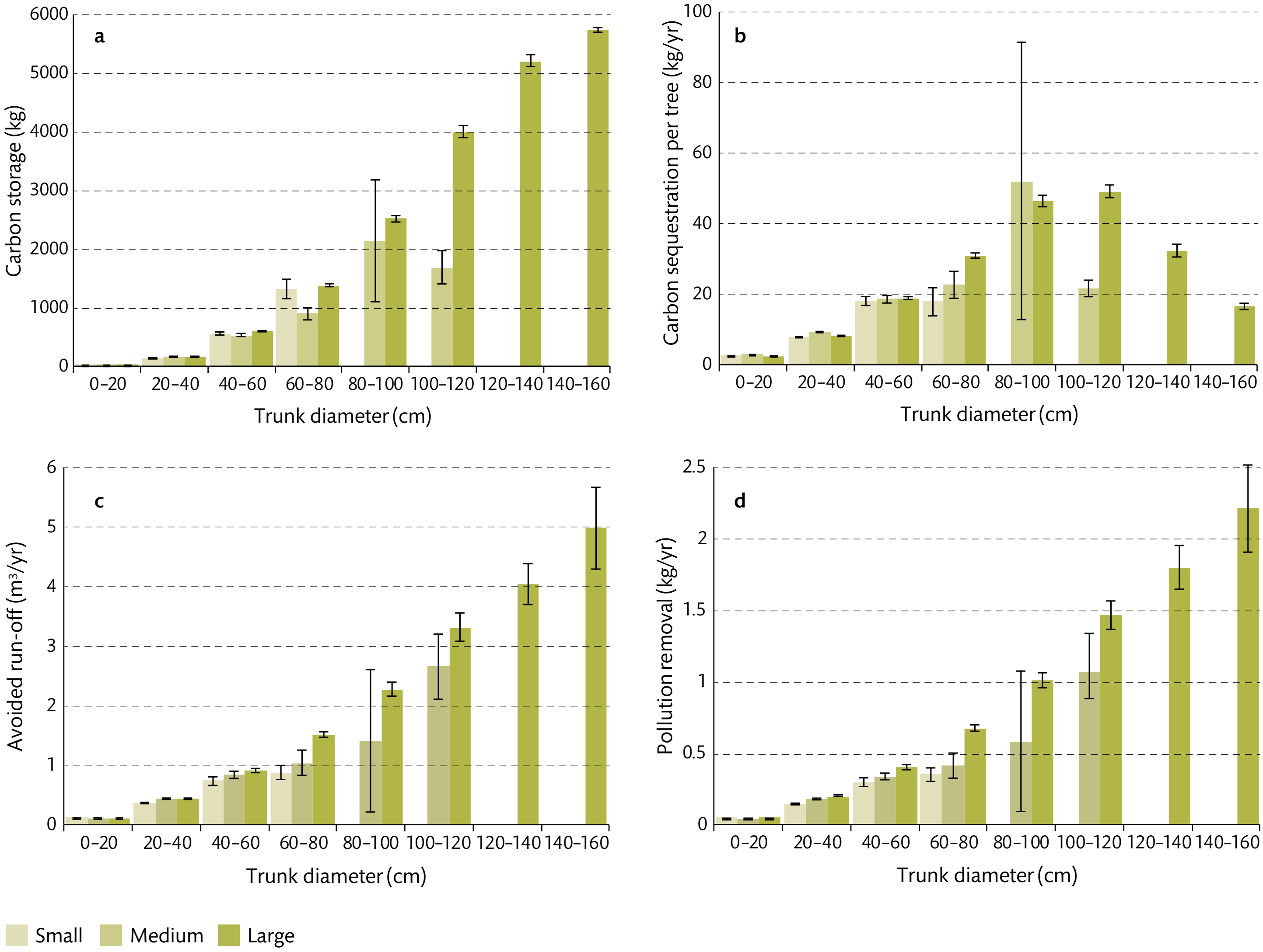
Figure 1 presents the changes in ecosystem services delivery with increase in trunk diameter for large, medium and small stature trees. The graphs show that ecosystem services delivery estimated for these urban trees was strongly linked to tree size. Specifically, for carbon storage (total carbon stored), avoided stormwater run-off and air pollution removal, ecosystem services delivery grew steadily with increased trunk diameter. For carbon sequestration, the rate of uptake increased to a peak and then started to decline, in agreement with research showing that growth rates slow down as trees pass maturity (White, 1998; Nowak and Crane, 2002). Ecosystem services delivery was also found to increase with increasing tree stature (Figure 1). This trend is insignificant when trees are small; however, above a trunk diameter of 60 cm the trend is significant across the modelled range of ecosystem services (Hand, Doick and Moss, 2019a,b) (Figure 1). Trees that were capable of growing to a greater trunk diameter had a larger woody biomass and stored a greater mass of carbon than smaller trees. Similarly, rainfall and air pollution interception increased with the greater tree canopy size and total leaf area associated with greater size (Hand, Doick and Moss, 2019a,b).

Species

Ecosystem services delivery varies among species. Table 1 ranks 30 common urban tree species by ecosystem services provision, as modelled by Hand, Doick and Moss (2019a,b). In general, the larger stature species ranked higher than the smaller stature species, although exceptions do occur. For example, Scots pine (a large stature species) ranks below many medium stature species for the four ecosystem services under consideration. Furthermore, some species (for example, downy birch) perform well for one ecosystem service but not for another (Table 1). Characteristics linked to differences in ecosystem services delivery include:

- broadleaf or conifer trees, evergreen and/or deciduous, for example, interception of airborne pollutants and rainfall by deciduous trees decrease when leafless (Xiao and McPherson, 2002; Clapp *et al*, 2014);

Figure 1 Comparison of ecosystem services provision by small, medium and large stature trees within 20 cm bands of trunk diameter (after Hand, Doick and Moss, 2019a,b). Ecosystem services shown are: (a) carbon storage, (b) carbon sequestration, (c) avoided run-off and (d) air pollution removal.



Note: Estimates shown are ± 1 standard error of the mean. Here, large error bars are a consequence of a small sample size. Hand, Doick and Moss (2019a,b) did not feature any small stature trees with a diameter >80 cm, or any medium stature trees with a diameter of >120 cm, as expected for the definitions used to define the stature groups.

- bark and leaf physiology, for example, trees with rough or flaky bark, or rough or hairy leaf surfaces trap and retain more air pollutants than tree species with smooth bark and leaves (Chen *et al*., 2017);
- branch structure and crown density, for example, trees with multi-layered branching and denser canopies intercept more rainfall than tree species with an open canopy (Xiao and McPherson, 2002; Nisbet, 2005).

The difference in ecosystem services delivery between the first and last ranked species was considerable. For example, as trees matured, oak species provided >70 times more carbon storage compared with plum species, and annually sequestered 10-fold more carbon compared with elder. London plane delivered >20 times more avoided run-off and air pollution removal than elder.

Condition

Trees in poor condition provide lower ecosystem services delivery. Poor condition impedes growth, slowing carbon sequestration (Nowak *et al*., 2008), and may also lead to canopy dieback, reducing the capacity to intercept precipitation and airborne pollutants (Alonso *et al*., 2011; Xiao and McPherson, 2002).

Table 1 Tree species ranked by their ecosystem services delivery as mature trees, in descending order.

Rank	Carbon storage per tree	Gross carbon sequestration per tree	Avoided run-off per tree	Pollution removal per tree
1	Oak spp.	Oak spp.	London plane	London plane
2	London plane	English elm	English elm	English elm
3	English yew	English yew	Oak spp.	Oak spp.
4	Beech	London plane	English yew	Wych elm
5	Sycamore	Beech	Wych elm	Beech
6	Ash	Sycamore	Beech	English yew
7	English elm	Holm oak	Lime spp.	Lime spp.
8	Holm oak	Ash	Sycamore	Sycamore
9	Wych elm	Wych elm	Norway maple	Norway maple
10	Norway maple	Silver birch	Ash	Ash
11	Lime spp.	Sweet cherry	Holm oak	Holm oak
12	Hornbeam	Lime spp.	Sweet cherry	Sweet cherry
13	Silver birch	Norway maple	Hornbeam	Hornbeam
14	Scots pine	Hornbeam	Silver birch	Scots pine
15	Sweet cherry	Scots pine	Scots pine	Silver birch
16	Lawson's cypress	Alder	Lawson's cypress	Lawson's cypress
17	Alder	Rowan	Field maple	Field maple
18	Downy birch	Field maple	Holly	Leyland cypress
19	Field maple	Lawson's cypress	Leyland cypress	Holly
20	Leyland cypress	Hawthorn	Bird cherry	Goat willow
21	Hawthorn	Downy birch	Goat willow	Bird cherry
22	Goat willow	Apple spp.	Rowan	Rowan
23	Apple spp.	Leyland cypress	Alder	Alder
24	Holly	Goat willow	Hawthorn	Hawthorn
25	Rowan	Holly	Hazel	Hazel
26	Hazel	Callery pear	Apple spp.	Apple spp.
27	Callery pear	Hazel	Downy birch	Downy birch
28	Bird cherry	Bird cherry	Callery pear	Callery pear
29	Elder	Plum spp.	Plum spp.	Plum spp.
30	Plum spp.	Elder	Elder	Elder

Small   Medium   Large

Note: In the absence of field records for mature English elm, rankings were based on simulated tree data. A comparison of simulated trees and field surveyed trees revealed an overestimation of ecosystem services provision by the simulated trees, therefore, the ranking of English elm should be treated with caution (Hand, Doick and Moss, 2019a).

Urban tree management

In this section, literature from academic, industry, central and local government sources on four key stages of urban tree management is reviewed to reveal the drivers and the role of management practices on stature, attainable size and the condition of urban trees. The review of local authority (LA) policies from England, Scotland and Wales only considered those introduced after 2000. The implications of these management practices for ecosystem services delivery by individual trees are considered and the cumulative impact on ecosystem services delivery by the whole urban forest is discussed. The four stages of management are species selection, planting and establishment, maintenance, and removal.

Species selection

Several factors must be considered if a tree is to establish, be healthy, grow to its full potential, and provide optimal benefit for the location. The *Urban Tree Manual* (Forestry Commission England, 2018) outlines selection criteria that can be used to define the tolerances and qualities that a species or cultivar must meet to provide the optimal tree for a given location. These selection criteria are grouped under four headings: tree suitability, ecosystem services delivery, ecosystem disservices and climate change resilience (Box 1).

Tree species preferences, as stated in the reviewed LA policies, are similarly concentrated around four main themes: preference for native species, diversity for forest resilience, preference for large trees, and ensuring the right tree is planted in the right place (Box 1). Some LA tree policies focused on a single preference only, such as Newport City Council (2015) or Braintree District Council (2016). Others included a range of preferences guiding species selection, for example, Waltham Forest London Borough Council (2017) and Dundee City Council (2009). A few identified criteria were less frequently listed, such as threatened or rare species (Braintree District Council, 2016), broadleaf species and trees with high amenity value (Redcar and Cleveland Borough Council, 2013).

Despite these stated preferences of LAs, a trend of preferentially planting smaller stature tree species has been observed (Forestry Commission Working Group, n.d.). This has been attributed to attempts to minimise the risk and potential costs arising from damage to property or injury to the public (London Assembly, 2007; Britt and Johnston, 2008; Forestry Commission Working Group, n.d.). Indeed, risk aversion in urban tree management, which includes species selection, has been reported to constrain benefit delivery by an urban forest (van der Jagt and Lawrence, 2015; Davies *et al*., 2017b).

Box 1 – Species selection criteria for urban tree planting

Urban Tree Manual (Forestry Commission England, 2018) selection criteria:

- Tree suitability: site category, substrate availability and other site constraints, tree characteristics and growth requirements;
- Ecosystem services delivery: visual amenity, shading, air pollution removal and carbon sequestration;
- Ecosystem disservices: nuisance associated with some species, including high pollen production, fruit and leaf fall, or raised roots;
- Climate change resilience: tolerance to the changing climate and to future climate extremes, including unseasonal frosts and periods of extended drought, and susceptibility to exotic pests and diseases.

Most common LA preferences in tree species selection:

- Native species: to support biodiversity (e.g. Camden London Borough Council, 2015; Fareham Borough Council, 2012);
- Species diversity/forest resilience: to increase resilience (e.g. New Forest District Council, 2014; Durham County Council, 2014);
- Large stature trees: to increase the benefits that society receives from trees (e.g. Ealing London Borough Council, 2013; Nottingham City Council, 2012);
- Right tree, right place: to ensure appropriate species selection and hence tree survival, considering tree and local environment characteristics (e.g. Camden London Borough Council, 2015; Newport City Council, 2015).

Stating a range of criteria that should be considered in species selection promotes the multi-functional roles that trees can play in the urban environment.

Planting and establishment

Once the right tree species (or cultivar) is selected for a location, good practice in planting and establishment is required to ensure survival and healthy growth and thus ecosystem services delivery. The first few years after planting are the most crucial: young trees must adjust to the new conditions, and in urban environments this typically means coping with limited soil moisture, soil compaction and air pollution, each of which presents challenges to survival (Hirons and Percival, 2012).

In addition, transportation to the planting site, pit design, planting technique and maintenance during the establishment period can impact on the chances of tree survival and long-term healthy growth (Trees and Design Action Group, 2012; Johnston and Hirons, 2014).

Britt and Johnston (2008) reported mortality rates of around 20% for newly planted trees in English LAs, possibly resulting from only an average of 65% of newly planted trees receiving post-planting care. Despite this, there is little governance at national or local level on tree planting and establishment beyond powers allowing LAs to plant trees (Dandy, 2010). Many LA tree policies did not contain protocols for tree planting and establishment. While best practice guidance is available, for example, BS 3936 and BS 8545 (British Standards Institute, 1992, 2014; National Joint Utilities Group 2007), the reviewed policies rarely state whether there is a requirement for LAs, contractors and developers to follow them. Some LAs provided supplementary planning guidance with protocols on tree planting for developers and planning applicants (e.g. Lichfield District Council, 2016), while others required funding to cover the costs of maintaining newly planted trees in developments (e.g. Lancaster City Council, 2010).

The costs associated with tree losses can be significant when the value of unrealised ecosystem services benefit delivery is added to the replacement costs (Widney *et al*., 2016). High levels of mortality in planting schemes can also make attaining urban canopy cover targets a difficulty (McPherson *et al*., 2011). However, reducing mortality rates by only a few percent can significantly improve long-term total ecosystem services delivery (McPherson *et al*., 2011; Morani *et al*., 2011) and need not be expensive. In the USA, Roman *et al*. (2015) showed that engaging with local residents to support tree establishment resulted in improved tree survival. Residents were involved in watering the trees and some were trained in formative pruning to encourage tree growth that suited the surrounding environment (Roman *et al*., 2015). Such public stewardship not only enhances tree health and survival, but helps deliver additional benefits such as connecting people with nature. Formative pruning also reduces the need for substantial remedial action when the tree is larger and more expensive to prune (Ryder and Moore, 2013).

Maintenance

Once a tree is established, the necessary maintenance activities decline in frequency and instead centre on inspection, pruning, and managing pests and diseases (Koeser *et al*., 2013; Vogt et al., 2015). The LA policies reviewed varied in the level of detail provided on tree maintenance. Most described the factors determining whether they will (or will not) prune trees. Some went further, describing inspection and pruning programmes (e.g. Ipswich Borough Council, 2010) and approaches to managing pests and diseases (e.g. Wrexham County Borough Council, 2016). Nearly all LA policies stated that they would prune trees to manage health and safety risks. However, most of them stated that they would not normally prune trees for reasons constituting a 'nuisance', such as access to light, disruption of television signals, or fruit fall onto footpaths, but would for reasons regarding access to pathways and highways, as well as sightlines for CCTV and street signs (e.g. Harrow London Borough Council, 2015; Canterbury City Council, 2017). Many stated that the British Standard Institutes guidance (2010) on tree work (BS 3998) must be adhered to, and for some, where subsidence was a concern, the London Tree Officers Association's guidance (2008a, 2008b) on assessing and mitigating risk from subsidence was referenced (e.g. Nottingham City Council. 2012; Bromley London Borough Council, 2016). Only a handful of policies included a role in providing advice to private tree owners to prevent poor quality or unnecessary tree pruning (e.g. Redcar and Cleveland Borough Council, 2013).

Tree maintenance work may be systematic, that is, planned as part of a programme of tree work, or reactive, that is, carried out as required (Johnston and Hirons, 2014). A number of LAs were working towards planned cycles of tree inspection and maintenance (e.g. Newcastle-under-Lyme Borough Council, 2013; Harrow London Borough Council, 2015). Some tree work will always be reactive, for example, in response to emergency issues such as storm damage. However, reviews of LA tree management indicated that a high proportion of all tree maintenance is reactive, which can leave the maintenance needs of other trees neglected (Britt and Johnston, 2008; van der Jagt and Lawrence, 2015).

Tree pruning, in particular, has been criticised in some areas as being overly aggressive, for example, removing large portions of tree canopy or pruning trees too frequently (London Assembly, 2007, 2011). The removal of canopy reduces the ecosystem services provision by trees, can reduce growth rates, and leads to pruning wounds vulnerable to infection. Such approaches are attributed to LAs attempting to minimise damage to buildings or injury to persons and subsequent liability claims (London Assembly, 2011). The risk of such claims has been identified as one of the main threats to LA urban tree programmes (Britt and Johnston, 2008). Furthermore, reduced budgets have caused some LAs to reduce the frequency of pruning cycles (London Tree Officers Association, 2016), resulting in more severe prunes when trees are visited (London Assembly, 2011) and less time to provide maintenance of the highest quality (London Tree Officers Association, 2016).

To enable a proactive approach to tree management, LAs have been encouraged to make greater portions of their tree work systematic (Greater London Authority, 2005; London Tree Officers Association, 2008a). Systematic approaches enable a LA to demonstrate that they are fulfilling their duty of care required under the Occupiers Liability Act (1957, 1984)(UK Parliament, 1957 and 1984), including the use of a risk-based inspection register. The systematic approach can be a cost-effective use of resources (Nottingham City Council, 2012) by helping to identify issues early when they are least expensive to address, reducing the likelihood of an issue progressing to a point where tree removal is required, and helping to avert the declines in tree health which can follow when tree maintenance is delayed (Vogt *et al*., 2015). For example, the London Tree Officers Association (LTOA) advocated cyclical (i.e. systematic) pruning regimes to mitigate subsidence liability. Subsidence liability became a major issue when it became an insured risk in the 1970s, and this frequently created pressure for nearby trees to be removed, even although other factors may have been responsible (Institute of Structural Engineers, 2000). The LTOA state that more trees in subsidence risk areas can be retained by pruning trees systematically. This approach has succeeded in halving the numbers of trees felled for subsidence claims within some LAs (London Tree Officers Association, 2008a). While the retained trees have less canopy area, removed trees may not be replaced, or are more likely to be replaced with a smaller tree with comparatively lower ecosystem services delivery. Furthermore, retaining large trees means that pruning can be reduced, allowing trees to enlarge their canopies; and ecosystem services provision would be enhanced should there be changes in technical solutions for subsidence, greater demand for the climate change benefits of trees and/or greater tolerance of minor nuisance from trees.

Removal

The main driver for removal tends to be health and safety concerns; other reasons include subsidence claims, development pressures, the installation of services and demand for improved access (London Assembly, 2007; Dandy, 2010). The UK policy affords more powers for tree removal than tree planting or management (Dandy, 2010). The main powers to protect trees in private ownership from removal are in the Town and Country Planning Act (1990) (UK Parliament, 1990), which allows LAs to designate a tree with a Tree Preservation Order (TPO), thus protecting it from pruning or removal without consent. For trees in public ownership, LAs' own policies on tree preservation and removal provide protection.

Most of the LA tree policies discussed TPOs to some extent. After conception, TPO designation was awarded to protect the amenity value of trees: its powers were limited to protecting trees with high public visibility, which were of large size and under some threat of removal (Dandy, 2010). However, this left trees vulnerable where their importance fell outside one of these categories. More recently, TPO designation has been supported for trees that contribute to amenity, plus other benefits including, for example, mitigating the impacts of climate change (e.g. Cambridge City Council, 2016). Trees in development areas can also be protected by placing conditions on planning permissions. However, these were less frequently mentioned than the use of TPOs; those that did reference their use included Solihull Metropolitan Borough Council (2010) and Cannock Chase District Council (2013).

Large and mature trees appear to be particularly at risk of removal. They can pose a significant risk to people or property (Randrup *et al*., 2001) and have greater management costs because of more labour-intensive maintenance (Vogt *et al*., 2015). However, precisely estimating the likelihood of a tree causing significant damage is extremely difficult, and concerns over the severity of the event invariably dominate the risk assessment (Britt and Johnston, 2008). This concern, plus the predominance of large trees in some towns and cities, has resulted in significant losses of large and mature trees in certain urban areas (London Assembly, 2007; Natural Resources Wales, 2016).

There has been increasing recognition in national policy (e.g. the National Planning Policy Framework. HM Government, 2018b) of the greater ecosystem services value of large and mature trees, particularly those identified as 'veteran' trees. Such recognition may lead to the introduction of policies that support tree retention, and has already led to national calls for the risks posed by trees to be robustly evidenced and objectively evaluated against the benefits they provide (National Tree Safety Group, 2011). At the local level, policies often referred to the importance of large and mature trees, for example, Braintree District Council (2016) and Harrow London Borough Council (2015). Occasionally this was translated into targets for the identification and protection of mature large stature trees (e.g. Nottingham City Council, 2012).

The impact of removal of large trees on ecosystem services delivery is two-fold: the immediate loss in delivery of ecosystem services by the tree to be removed, and the time-lag caused by the planting, establishment and maturing of the replacement tree. Retention of existing large and mature trees can therefore be just as important as new tree planting in maintaining ecosystem services benefits. Capturing and reporting the benefits that urban trees provide to society has been shown to be a powerful method to justify improved tree management (Hall *et al*., 2018). Cost-benefit analyses have also demonstrated significantly greater benefits over the lifetime of a tree from planting large rather than small stature trees (Armour *et al.*, 2012). Furthermore, use of the Capital Asset Value of Amenity Trees (CAVAT) valuation tool has helped to establish urban trees as assets requiring long-term systematic management (Doick et al., 2018). Consideration of tree benefits that are not easily quantified or valued, such as cultural ecosystem services (Chan *et al.*, 2012), as well as the regulating ecosystem services provided by urban trees summarised here, lend further justification for management that aims to maximise tree longevity, size and health, and therefore increases the ecosystem services provided by an urban forest.

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