Urban Forestry & Urban Greening 19 (2016) 223–236

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Allometric relationships for urban trees in Great Britain

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ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form 12 July 2016
Accepted 19 July 2016
Available online 22 July 2016

Keywords:
Allometry
Crown width
Diameter at breast height
Ecosystem services assessment
Tree height
Urban trees

ABSTRACT

Tree allometry describes the relationship between tree biometric variables, such as tree diameter (at breast height, DBH), height and crown width and helps urban foresters to assess many of the economic and ecological benefits provided by trees of different size. However, there is little knowledge on how the relationships established between those variables change between trees from different urban areas or species, especially within Great Britain (GB). This study aims to evaluate the variation in the allometric relationships of seven tree species growing in eight GB urban areas, and to understand if the use of generic curves representing relationships of trees growing across all locations is adequate. The variation between locations was highly significant; nevertheless, mean relationships of young trees growing in different locations were still accurately represented by a common species curve. Species with a similar stature also showed significant differences in their mean allometric relationships, reducing the level of accuracy when estimating mean relationships with multiple-species curves. Findings also suggest that crown width could be correctly predicted from DBH measurements. This knowledge can be used in citizen science based surveys, where the measurement of crown width is required but often challenging.

1. Introduction

The relationships between biometric variables of trees, such as diameter at breast height (DBH), height and crown width are key to predict tree growth and yield, and thus to inform on the best management practices (Temesgen and v. Gadow, 2004; Hemery et al., 2005). Consequently, the use of allometric models in rural forestry is long-established and numerous models have been defined for a range of trees and locations (e.g. Huang et al., 1992; Osman et al., 2013). The use of allometric models to assess changes in size of trees from urban forests is also important in defining urban forestry management practices but particularly in quantifying the ecosystem services provided by the urban forest. Tree and crown dimensions relate to tree biomass (Zianis et al., 2005) and canopy cover (Maco and McPherson, 2002), which influence a tree's ability to sequester carbon (Nowak, 1993; Timilsina et al., 2014), regulate surrounding temperatures (Gillner et al., 2015), intercept rainfall (Xiao and McPherson, 2002) and capture air pollutants (Nowak et al., 2006). Subsequently, the value of many of the ecosystem services provided by a tree depends on its size.

However, as the allometric relationships of trees are known to vary significantly with species (Osunkoya et al., 2007) and region (Kalliovirta and Tokola, 2005), best models representing changes in size of trees growing in rural forests cannot be adequately used to represent changes in size of trees growing in urban areas. On the one hand, trees in cities usually experience a lower level of competition, which can promote growth (Rhoades and Stipes, 1999). On the other hand, the urban environment poses additional stresses not experienced by trees in rural environments. For example, urban areas are warmer than rural ones (Oke, 1982), which increases the risk of pests and drought (Cregg and Dix, 2001). Urban areas also have compacted, low quality soils (Jim, 1998) and are more polluted than rural ones (Monn et al., 1995), which can compromise tree physiology and root growth (Jim, 1998; Klumpp et al., 2000). Consequently, the urban environment may also restrict overall tree growth.

While the understanding of the allometric relationships from urban trees is essential to make an accurate prediction of ecosystem service delivery, there is a lack of knowledge on how these relationships may vary between species and regions, particularly in temperate maritime climates such as that of GB. For example, Peper et al. (2001) modelled the relationships between tree height, crown diameter, leaf area and DBH or age for twelve common street trees in Modesto-USA, with a Mediterranean climate. Similar relationships were also found by Semenzato et al. (2011) for five species

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http://dx.doi.org/10.1016/j.ufug.2016.07.009
1618-8667/

typical of the temperate to sub-tropical north-eastern region of Italy, by Stoffberg et al. (2008) for three species present in the sub-tropical city of Tshwane-South Africa and by Troxel et al. (2013) for the ten most common genera in the humid continental area of New Haven-USA. Not only are these studies from areas of different climate they also do not investigate regional variations and so conclusions and broader application of the results are limited. Two exceptions lay with the studies by Moser et al. (2015) and Rust (2014), which investigated changes in tree growth relationships among several cities in Germany; though the first study focussed on a small dataset (two species and two locations) and the second one was constrained to tree height growth and slenderness only.

This study starts to address the gap in the knowledge of allometric relationships of species found in GB urban areas. In this study, the emphasis was on establishing relationships between measurable biometric variables that are critical for an ecosystem service assessment: DBH, tree height and crown width. To reduce the level of error in our comparisons, we have not included at this stage variables that are sometimes predicted from DBH, height or crown width measurements (e.g. age, Lukaszkiewicz and Kosmala, 2008). Specifically, we aimed to:

- Model the allometric relationships for different tree species across GB to investigate whether the relationships differ between locations or species,
- Test the use of a common species curve, or a multiple-species curve including species with a similar stature, for adequately representing mean allometric relationships across GB urban areas,
- Evaluate which of the selected biometric variables would be more suitable for predicting the others.

2. Methodology

2.1. Data collection

Biometric data was collected from i-Tree Eco assessments carried out from 2010 to 2014 across GB, within the urban areas of Edinburgh, Glasgow, Wrexham, Bridgend, Swansea and the Tawe catchment (hereafter: 'Swansea'), Luton, London (including Victoria Business Improvement District and Greater London areas) and Torbay (including Torbay and Paignton) (Fig. 1). i-Tree Eco is a tool developed by the USDA Forest Service to quantify a range of ecosystem services provided by urban trees and uses a standardised field collection method as described in the i-Tree Eco Manual (i-Tree, 2016). All measurements were carried out as defined in the manual. For full details see available reports (Rogers et al., 2011, 2012; Hutchings et al., 2012; Rumble et al., 2014, 2015; Rogers et al., 2015; Doick et al., 2016a, 2016b).

2.2. Data description

Seven tree species, representing the most commonly surveyed species, were selected for this study, including three small stature tree species: *Acer campestre* L. (field maple), *Betula pendula* Roth (silver birch) and *Ilex aquifolium* L. (holly) and four large stature tree species: *Acer pseudoplatanus* L. (sycamore), *Fagus sylvatica* L. (common beech), *Fraxinus excelsior* L. (common ash) and *Quercus robur* L. (English oak). Small stature tree species are those with maximum height ≤20 m and/or maximum crown width ≤12 m (Fig. 2).

Data extracted from the i-Tree Eco surveys included: tree species identification (only trees identified by their full species name were included); biometric variables (tree height, height to live top, crown width (a mean of two measurements made in north-south and east-west orientations), all in metres and DBH in centimetres); crown light exposure; percentage of crown dieback, and land use information. DBH information also included the height of measurement (with the standard height of measurement being at 1.37 m) and DBH values of up to 6 stems in the case of multi-stemmed trees.

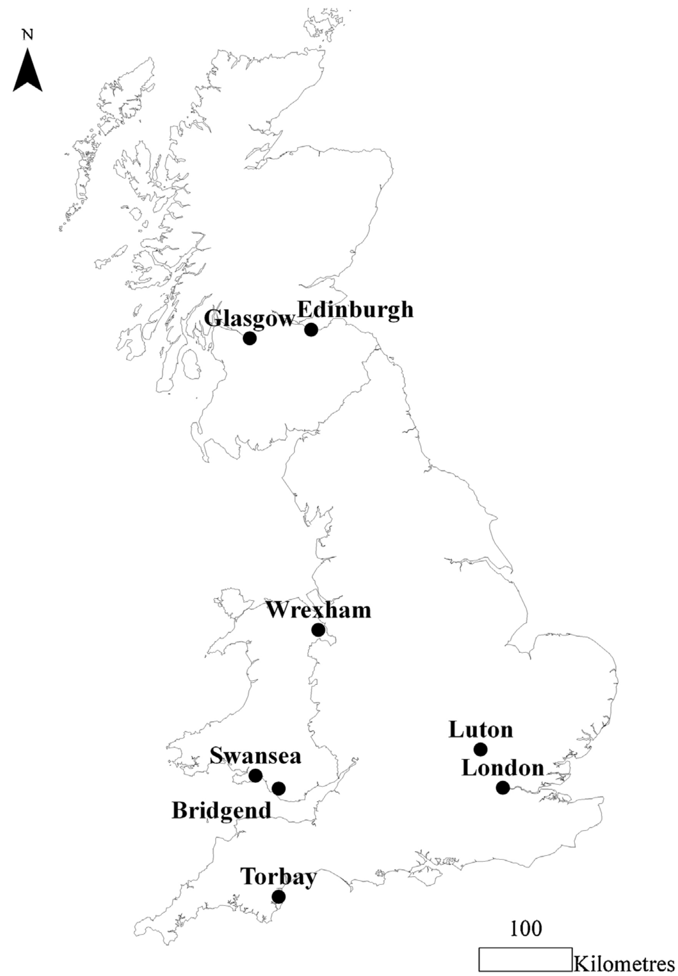

Fig. 1. Location of all urban areas included in the study (© Crown copyright and database right [2016] Ordnance Survey [100021242]).

Some trees were immediately excluded from the datasets. These included trees with DBH <7 cm, dead trees, trees where the total tree height and the height to live top were different or where crown dieback was >50%, as these were assumed to have an extensive crown defect. They also included trees with extremely low or high height to DBH or crown width to DBH ratios, compared to the other trees, as it was assumed that an error may have occurred when measuring or recording data or that a tree had been subjected to intensive pruning or pollarding. Trees where the diameter was measured much below the standard height (<1 m) were also excluded, as were groups of trees from a certain subplot that had a similar height and crown width, where we considered it to be a hedge.

Furthermore, many of the trees pre-selected were multi-stemmed trees. A general procedure used by urban foresters when surveying DBH of multi-stemmed trees is to model a single DBH by using the formula recommended by Swiecki and Bernhardt (2001):

$$DBH_{MS} = \sqrt{\sum_{i=1}^{6} DBH_i^2} \quad (1)$$

where DBH_{MS} is the estimated DBH of multi-stemmed trees and the DBH_i is the DBH for the ith stem, i = 1, 2. . .6. This methodology was used by Ab Shukor et al. (1994) and was also adopted in this study.