ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 49-50, 2016, 33-39

FIRST RESULTS OF ALLOMETRIC AND GROWTH INVESTIGATIONS IN HUNGARIAN URBAN TREE STANDS IN AN ECOSYSTEM SERVICE CONTEXT

Z GYŐRI, J PIKÓ, Á GULYÁS, Z PÁDÁR and M KISS

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: gyorizsa@gmail.com

Summary: The methodology of evaluating urban ecosystem services gains much importance in the context of global climate change and international policy processes. Urban trees provide important climate-related regulating services, which can be evaluated using specifically developed models. Some of these approaches need location-specific data about the growth characteristics of frequently planted tree species in urban circumstances, for exact ecosystem service quantification and indicator development. One main task is to accurately calculate biomass growth, in order to quantify service provision more precisely in life-cycle assessments. Besides, mathematical relations between different size parameters of trees might be needed for the background calculations of some model applications. In this paper, we present some methodological investigations and preliminary results for these purposes. Growth curves of carbon storage potential and potential leaf area were developed for two important urban tree species (Common hackberry**,** Japanese pagoda tree). The results highlight the need to take worse tree condition at high ages into account in further improvements and real applications. In the second part of the study, we present the first results of allometric models to predict crown diameter from diameter at breast height of the trees, based on the tree cadastre dataset of the city of Szeged.

Key words: urban trees, ecosystem services, leaf area, carbon storage, allometric relations

1. INTRODUCTION

The evaluation of ecosystem services is gaining a major role in environmental sciences and practical environment management (MEA 2005, TEEB 2010). Their purpose is to enable the quantification of resources used by humans directly or indirectly from the perspective of securing human welfare (Termorshuizen and Opdam 2009, Kovács et al. 2011, Gómez-Baggethun et al. 2013). Ecosystem services are divided into four different groups. They are: maintenance (supportive), provisional, regulatory and cultural services. The most important task of the new methodology, which evaluates the natural resources from the perspective of contributing to human welfare, is the technical support of the environmental protection goals and biodiversity protection. In recent years more and more research is being conducted on the green space ecosystem services of urban areas (Haase et al. 2012, Hubacek and Kronenberg 2013). Their benefits, originating from their regulating services are of paramount importance, like climate regulation by the shading and evapotranspiration of trees, decreasing stormwater runoff, air pollution removal and carbon sequestration (Kirnbauer et al. 2013, Nowak et al. 2013, Jim and Chen 2014). In the case of urban green areas we are talking about ecosystems suffering from strong anthropogenic impact which affect the life quality for many people in densely populated areas, so that they can also be an important subject of monetary or non-monetary evaluations.

The appearance of the methodology is more and more frequent at a policy level too, proved by the fact that the first thematic TEEB report dealt with urban environment management (TEEB 2011). Besides, the Green Infrastructure Development Goal which is part of the EU Biodiversity Strategy 2020, specifically mentions the urban green areas, highlighting their contribution to the health and a number of other factors of the well-being of the population. The evaluation of ecosystem services is performed by developing and mapping indicators or integrating them into more complex models.

The quantitative assessment of the regulating ecosystem services of urban trees can be realized on a model basis. Several specific models have been created in different parts of the world primarily for the evaluation of climate-related services (i-Tree 2014, Peng et al. 2008). Most of these assessment tools, like the Eco package of the most elaborated i-Tree software, are only suitable for static evaluation. Nevertheless in many cases, the analyses of the services provided by the tree would be required to consider the life-cycle i.e. monitoring these services in parallel with the growth of trees. For example for the installation of urban trees or green areas it would be needed to know in how much time will they be able to provide the same service volume as their predecessor tree stands. Certain model applications have been made specifically for that purpose, for example the i-Tree Design application that is easy to use (on a web interface) by non-professional users. This application is suitable for the calculations of the provided services by a tree of a selected species (also in economic terms) installed at a predetermined location in an arbitrary period of time. However this application is designed for the USA. The growth of trees and deposition of pollutants are significantly affected by climatic conditions, therefore applications developed for local conditions would be needed to use more descriptive functions of ecosystem services under the local conditions.

Furthermore, in certain applications the specification of additional tree parameters may be required. It has to be noted that some of those measurements are more difficult to carry out (e.g. the measurement of the crown diameter which is necessary to calculate the shading capability of trees, thereby to estimate the energy savings of heating and cooling). Another possible use is the estimation of trunk parameters from crown parameters derived from photogrammetric investigations. The relations between these tree size parameters are given by so-called allometric equations. Nowak (1996) has developed regression equations to calculate the leaf area and leaf biomass of urban trees. These equations form the base e.g. for the widely used i-Tree model suite (i-Tree 2014 – formerly UFORE – Urban Forest Effects Model). The aim of the works of Peper et al. (2001a, 2001b) was to develop prediction models for diameter at breast height (DBH) based on age, and that the tree height, crown diameter, crown height, and leaf area are based on DBH. Logarithmic regression models were used for all variables except for leaf area predictions, for which a nonlinear exponential model was used.

In line with these general goals, the aim of our study is to pave the way for the development of model applications that take into account the above mentioned aspects and local conditions, therefore especially suit the data needs regarding common tree species in Hungary. On the one hand the change of the ecosystem services provided by the trees are examined during their lifecycle. On the other hand, some allometric models predicting a crown size parameter from the DBH are tested.

2. METHODS

In the first part of the study, we present the life cycle curves of two important ecosystem service indicators, the amount of stored carbon in tree biomass (indicating carbon sequestration), and the leaf area (which is a widely used indicator of air pollutant removal and stormwater runoff reduction). In the calculation process of the i-Tree Eco model, the so-called standardized growth is used. It is quantified based on an average constant growth rate (in DBH), and is corrected based on climatic parameters. Crown light exposure and tree condition are used as correction factors. In our calculation, we used the growth observations used in Hungarian horticultural and green space management practice (Radó 1999). These growth curves are based on measurements of trunk diameter in relation with the tree's age, using a dataset of thousands of tree individuals in Hungary.

For calculations of carbon storage and leaf area, our methodology is mainly based on the workflow of commonly used methods (e.g. in i-Tree Eco). From multiplying the DBH and the shading factor by the regression coefficients we obtained the natural logarithm of the leaf area from which the leaf area was calculated by a simple exponent function (Nowak 1996). Equations based on the DBH are of the following form:

$$\ln Y = b_0 + b_1 X + b_2 S \tag{1}$$

where Y is the leaf area (m^2), X is the DBH (cm), b_0-b_2 are the regression coefficients and S (percentage of light intensity intercepted by foliated tree crowns) is the average shading factor for the individual species (McPherson 1984). We made the calculations for two commonly planted street and park tree species, Common hackberry (*Celtis occidentalis*) and Japanese pagoda tree (*Sophora japonica*). The shading factors are 0.88 for hackberry and 0.78 for pagoda tree. The calculation of the stored amount of carbon was based on species-specific equations, using the DBH as a single parameter (CUFR 2008, Liu and Li 2012).

Table 1 The species investigated with allometric investigations

Common name	Scientific name	Number of trees
Goldenrain tree	*Koelreuteria paniculata*	23
Silver lime	*Tilia tomentosa*	148
Japanese pagoda tree	*Sophora japonica*	41
Small-leaved lime	*Tilia cordata*	42
Early maple	*Acer platanoides*	32
Ash	*Fraxinus excelsior*	27
Big-leaf linden	*Tilia platyphyllos*	24
Common hackberry	*Celtis occidentalis*	63
Maple Leaf plane	*Platanus hybrida*	32
Total		432

In the second part of our research, allometric models were tested to predict one of the most important size parameter of tree crowns, the crown diameter, from the more easily measurable parameter of DBH. The statistical calculations were based on a field-based tree database for the downtown area of Szeged (Hungary). The selection of specimens was carried from the tree cadastral database created and maintained by the Department of Climatology and Landscape Ecology of the University of Szeged, in cooperation with the local environmental management company (Takács et al. 2015). For allometric investigations, trees in a good condition should be chosen. The selection criteria were the following: the place of the tree is a typical urban location (mainly street trees); missing crown ratio does not exceed 10%. The whole tree cadastre database contains several parameters (tree size parameters, health-related attributes, location information). For the purposes of this study, the DBH and average crown diameter data were used. Crown diameter was measured with Vertex III equipment. From the total tree cadastre database, 432 specimens fulfilled the criteria, the surveyed species are summarized in Table 1.

Curve fitting algorithms were executed to test the fit of different regression models for the trees of different species. The calculations were carried out in SPSS 19.0 software, the used functions are summarized in Table 2.

Table 2 The tested allometric models to predict crown diameter (CD, m) from diameter at breast height (DBH, cm), b_0-b_3 are regression coefficients

The type of function	Equation
Linear	$CD = b_0 + b_1 \cdot DBH$
Logarithmic	$CD = b_0 + b_1 \cdot \ln DBH$
Inverse	$CD = b_0 + b_1 / DBH$
Parabolic	$CD = b_0 + b_1 \cdot DBH + b_2 \cdot DBH^2$
Cubic	$CD = b_0 + b_1 \cdot DBH + b_2 \cdot DBH^2 + b_3 \cdot DBH^3$
Power	$CD = b_0 \cdot DBH^{b1}$
Exponential	$CD = b_0 \cdot b_1^{DBH}$
Sigmoidal	$CD = \mathrm{e}^{b0 + b1 / DBH}$
Growth	$CD = \mathrm{e}^{b0 + b1 \cdot DBH}$

The values of the adjusted coefficients of determination (R^2_{adj}) were calculated, together with standard error of estimate (SEE) values.

3. RESULTS AND DISCUSSION

The potential leaf area and carbon storage of the two tree species in relation with age can be seen on Fig. 1, the results will be discussed focusing on the state achieved at high ages (around 55 years). The higher growth was observed in the case of pagoda tree, which may potentially exceed 1200 m^2 in leaf area and 1400 kg of stored carbon at high ages. The leaf area values for common hackberry are around 1000 m^2 and below 1000 kg. In our field-based dataset, containing individual-based estimates calculated with the growth equations of the i-Tree Eco model (Kiss et al. 2015), we can see that there are only some trees in the complete inventory for the city centre with the above-mentioned values. The main reason for this might be that street trees at high ages have high values of missing crown parts and crown dieback (beacuse of bad health status in urban circumstances, and because of pruning and other management activities – the mentioned reference database is the total tree cadastre inventory, which contains trees in bad condition as well). This decreases mainly the leaf area, and the amount of biomass (and consequently the stored carbon) to a high extent. Therefore, there are very few tree specimens with these quite high values in our city. It is the case in particular for the pagoda tree, its population is in a considerably bad condition in the investigated stands according to the i-Tree categorization (Kiss et al. 2015). The management of old-growth urban trees is a very important topic in urban green space management. These trees are in a worse condition which results in higher management costs. But meanwhile they provide a very high amount of ecosystem services, as it might be indicated by the growth curves presented in our study for climate-related regulating services.

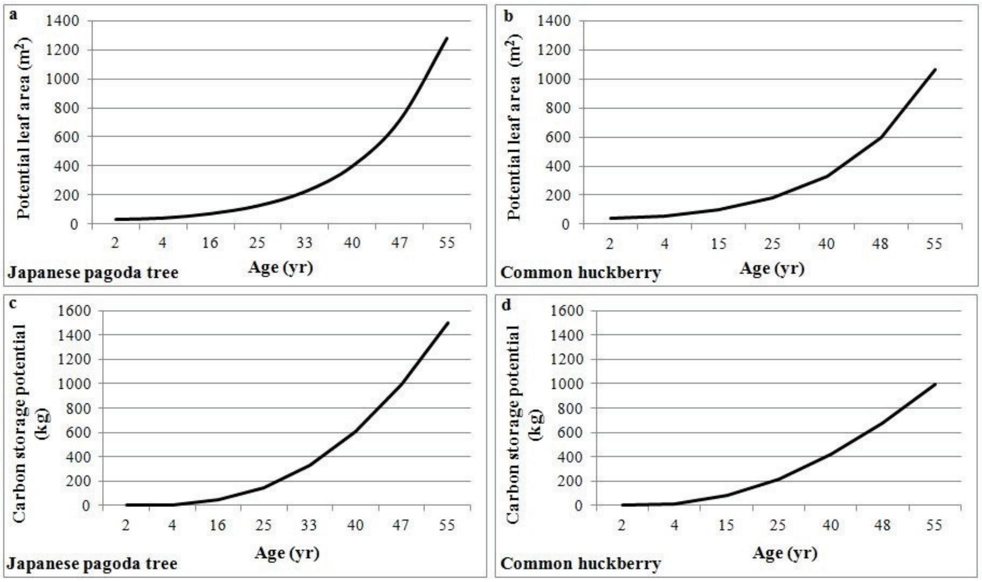

Fig. 1 Potential leaf area (a, b) and carbon storage potential (c, d) depending on the age at the two investigated species

Table 3 Best fitting models and their parameter estimates relating crown diameter and DBH for the investigated species

Species	**Model**	**Fitting**		**The function parameters**	
		R^2_{adj}	SEE	b0	b1
Big-leaf linden	power	0.862	0.208	44.838	0.841
Silver linden	power	0.866	0.203	28.566	0.940
Golden rain tree	power	0.529	0.327	42.488	0.819
London plane	power	0.620	0.200	57.031	0.733
Common hackberry	power	0.628	0.253	130.707	0.543
Ash	power	0.661	0.309	75.472	0.642
Japanese pagoda tree	exponential	0.666	0.271	431.611	0.018
Early maple	sigmoidal	0.801	0.275	7.106	-11.693
Small-leaved linden	power	0.788	0.315	50.199	0.788

Table 3 shows the best predictive models for the crown diameter of trees of the investigated species (with the highest R^2 values, together with low SEE). Four species have a model with a relatively good fit ($R^2_{adj}>0.70$, $p<0.01$) to the measured dataset. For most species, the power function seems to be the best model to predict the investigated parameter, and it might be considered as a possible general model type. Linden species have better fitting models, which can be explained by their relatively healthy crowns. In contrast, pagoda trees have a sparse canopy structure with high variation in crown diameter, which makes curve fitting harder. Worse fits might be caused in general by heterogeneity in the tree locations (which affects the forms of the crowns and other growth characteristics of the trees). Besides that, although trees had been chosen with crowns in a good condition, the shapes of the crowns are affected by light exposure and may be affected by pruning and other management activities, which might cause greater variation in the investigated size parameter. Further investigations from other cities in this climate zone would increase the reliability of the models for practical applications.

4. CONCLUSION

We carried out some background studies on some aspects of the growth and allometric relationships of urban trees in the context of ecosystem services. The main aims were to correct the models for calculating two important climate-related ecosystem service indicators (leaf area and stored carbon) based on Hungarian growth functions. Based on our results and their comparison with the field-based estimates of the referring values, we consider that our approach is usable for planning targeted simulation modeling tools. Further research is needed for suitable methods to take the loss of biomass at high ages into account, if the ecosystem service providing capacity of old trees is in the focus of investigations. Another goal was to test curve fitting algorithms to form a base for allometric equations describing relations between two size parameters of trees. The models should be refined based on more extended datasets. We consider that management-oriented tree cadastres are suitable for determining allometric models for predicting certain size parameters or biomass indicators from more easily measurable parameters.

REFERENCES

CUFR (2008) CUFR Tree Carbon Calculator – Documentation. US Forest Service, Washington DC

Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. Ecol Econ 86:235-245

Haase D, Schwarz N, Strohbach M, Kroll F, Seppelt R (2012) Synergies, trade-offs, and losses of ecosystem services in urban regions: an integrated multiscale framework applied to the Leipzig-Halle region, Germany. Ecol Soc 17:22

Hubacek K, Kronenberg J (2013) Synthesizing different perspectives on the value of urban ecosystem services. Landscape Urban Plan 109:1-6

I-Tree (2014) i-Tree Eco User Manual v5.0

Jim CY, Chen WY (2014) Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J Environ Manage 88:665-676

Kirnbauer MC, Baetzb BW, Kenneyc WA (2013) Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels. Urban For Urban Gree 12:401-407

Kiss M, Takács Á, Pogácsás R, Gulyás Á (2015) The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). Morav Geogr Rep 3:36-46

Kovács E, Pataki Gy, Kelemen E, Kalóczkai Á (2011) Az ökoszisztéma-szolgáltatások fogalma a társadalomkutató szemszögéből. [Concept of ecosystem services from the perspective of the sociologist. (in Hungarian)] Magyar Tudomány 7:780-787

Liu C, Li X (2012) Carbon storage and sequestration by urban forests in Shenyang, China. Urb For Urb Green 11:121-128

McPherson, EG (1984) Planting design for solar control. Energy-conserving site designe. American Society of Landscape Architects, Washington, DC, 141-164

MEA (2005) Millennium Ecosystem Assessment: Ecosystems and Human Well-being –Synthesis. Island Press, Washington, DC

Nowak D (1996) Estimating leaf area and leaf biomass of open-grown deciduous urban trees. Forest Sci 42:504-507

Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. Environ Pollut 178:229-236

Peng L, Chen S, Liu Y, Wang J (2008) Application of CITYgreen model in benefit assessment of Nanjing urban green space in carbon fixation and runoff reduction. Fron Forest China, 3:177-182

Peper P, McPherson E, Mori S (2001a) Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. J Arboric 27:306-317

Peper P, McPherson E, Mori S (2001b) Predictive equations for dimensions and leaf area of coastal southern california street trees. J Arboric 27:169

Radó D (1999) Bel- és külterületi fasorok EU-módszer szerinti értékelése. [Urban and suburban alleys evaluated by the EU-method. (in Hungarian)] Lélegzet 7-8:1-12

Takács Á, Kiss M, Tanács E, Varga L, Gulyás Á (2015) Investigation of tree stands of public spaces in Szeged. J Env Geogr 8:33-39

TEEB (2010a) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature. A synthesis of the approach, conclusions and recommendations of TEEB. Earthscan, London-Washington

TEEB (2010b) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature. Ecological and Economic Foundations. Earthscan, London-Washington

TEEB (2011) TEEB Manual for Cities: Ecosystem Services in Urban Management. Earthscan, London-Washington

Termorshuizen JW, Opdam P (2009) Landscape services as a bridge between landscape ecology and sustainable development. Landscape Ecol 24:1037-1052