Manuscript Title: Urban Tree Diversity – Taking Stock and Looking Ahead

Authors: Morgenroth, J*[a]. Östberg, J.[b], Konijnendijk van den Bosch, C.[b], Nielsen, A.B.[c], Hauer, R.[d], Sjöman, H.[b], Chen, W.[e], Jansson, M.[b]

* Corresponding Author

a – School of Forestry, University of Canterbury, Christchurch, New Zealand, +64 (03) 364-2128, justin.morgenroth@canterbury.ac.nz

b - Department of Landscape Architecture, Planning and Management, Faculty of Landscape Planning, Horticulture and Agricultural Science, Swedish University of Agricultural Sciences

c - Department of Geosciences and Natural Resource Management, University of Copenhagen

d – College of Natural Resources, University of Wisconsin

e - Department of Geography, The University of Hong Kong

Urban Tree Diversity – Taking Stock and Looking Ahead

Abstract

The first International Conference on Urban Tree Diversity hosted in June 2014 by the Swedish University of Agricultural Science in Alnarp, Sweden highlighted the need for a better understanding of the current state of urban tree diversity. Here we present and discuss a selection of urban tree diversity themes with the intention of developing and sharing knowledge in a research area that is gaining momentum. We begin by discussing the specific role of species diversity in ecosystem service provision and ecosystem stability. This is followed by exploring the urban conditions that affect species richness. Having determined that many ecosystem services depend on urban tree species diversity and that urban environments are capable of supporting high species diversity, we conclude by addressing how to govern for urban tree diversity.

A Background to Urban Tree Species Diversity

As global population grows and migration demography shifts towards urbanization, the need for functional urban ecosystems to meet societal needs increases. Biodiversity has been shown to affect all levels of the ecosystem service hierarchy (Mace et al., 2012). While the concept of biodiversity embraces both the ecosystem, the species, and the gene levels, most research on urban biodiversity has focused on the species level, likely because it is well defined, quantifiable, and easily monitored and communicated beyond the scientific community (Farinha-Marques et al. 2011). It is therefore not surprising that urban tree diversity has developed as a theme of academic and practical importance. This topic was central to the first International Conference on Urban Tree Diversity at the Alnarp campus of the Swedish University of Agricultural Sciences in 2014 (Textbox 1). Here we use the conference content to facilitate a more through exploration of urban tree diversity and review the scientific literature in three sections: i) What ecosystem services result from urban tree species diversity? ii) Can urban environments support tree species diversity? and iii) Can cities govern for urban tree diversity? We conclude with recommendations for future research crucial to developing the body of knowledge surrounding urban tree species diversity.

Ecosystem Services and Tree Species Diversity

The ecosystem services provided by urban forests include tangible provisioning services (e.g. food and fuel production), regulating services (e.g. air pollution reduction, stormwater management), cultural services (recreation, physical and mental health benefits) and supporting services (e.g. wildlife habitat) (Costanza et al., 1997).Trees reduce air temperature (Bowler et al., 2010), sequester carbon (Nowak et al., 2013a), reduce atmospheric and particulate air pollution (Escobedo et al., 2011), attenuate stormwater runoff (Kirnbauer et al., 2013), improve human well-being (Dallimer et al., 2012), provide resilience during times of war (Lacan and McBride, 2009) or natural disasters (Morgenroth and Armstrong, 2012), provide food for humans (McLain et al., 2012), increase property values (Dimke et al., 2013), and provide energy savings (McPherson and Simpson, 2003).

Ecosystem services provided by urban forests are known to be moderated by canopy cover (Dobbs et al., 2011) and tree structure (Nowak et al., 2013b). But what is the impact of tree species diversity on ecosystem service provision and are all species equal? Anecdotally, because ecosystem services are a result of ecosystem processes, their provision depends on the intrinsic (i.e. morphological and physiological) and temporal (diurnal or seasonal effects) characteristics of different species (Clapp et al., 2014). Evidence has shown that species affects ecosystem services including rainfall interception (Xiao et al., 2000), air temperature moderation (Bowler et al., 2010), atmospheric pollution removal (Jim and Chen, 2008), human psychological well-being (Fuller et al., 2007), bird diversity (Nielsen et al., 2014b) and insect diversity (Scherber et al., 2014).

We feel that it is self-evident that some species are better than others for optimizing individual ecosystem services - which begs the question, is diversity necessary? Both Zavaleta et al. (2010) and

Lundholm et al. (2010) demonstrate that optimization of multiple ecosystem services requires a mixture of species. Can the knowledge gained from these studies of grasslands and green roofs be generalized to the urban forest? If so, it seems likely that the plethora of ecosystem services we expect our urban forests to provide can be maximized with high species richness.

Species diversity may also be necessary for urban ecosystem stability. Can urban forests withstand disturbance (resistance) and how quickly will they return to normal function after disturbance (resilience)? Such stability allows for the long-term provision of ecosystem services (Colding, 2007) in the face of biotic and abiotic change (Hooper et al., 2005). Recent pest outbreaks (Poland and McCullough, 2006) and the environmental changes resulting from climate change (Easterling et al., 2000) highlight the need for species diversity to achieve a resilient urban tree stock as an important contributor to urban ecosystem stability.

Though high species diversity can optimize multiple ecosystem services (Zavaleta et al., 2010) and ensure urban forest stability in the face of disturbance (Colding, 2007), we join Richards (1993) in cautioning against managing only for diversity; increasing tree species diversity does not guarantee improved ecosystem function (Cook-Patton and Bauerle, 2012). Some species may be undesirable such as invasive exotic species, and some species have undesirable characteristics like those that emit volatile organic compounds, those whose pollen is an allergen, or those that cause infrastructure damage (Roy et al., 2012). These species may still play a role in providing species diversity. In fact, all tree species have good and bad characteristics. Species selection must be undertaken strategically to optimize desired ecosystem services and limit ecosystem disservices.

Though considerable empirical research into the relationship between urban tree species diversity and ecosystem services has been conducted, some questions remain under-explored. Chief amongst them is separating the effects of tree species and tree structure on ecosystem benefits. It is possible that the distribution and biomass of the urban forest is more important than species richness in terms of ecosystem service provision (Kowarik, 2011). Is species diversity simply a way of achieving structural diversity, so that ecosystem services are optimized? These are important questions to consider.

Cities and Tree Species Diversity

The ecosystem benefits and services provided by trees contribute to urban function – and tree species diversity provides the resistance and resilience necessary to ensure long-term provision of benefits and ecosystem services. But are cities capable of supporting high species diversity?

Previous studies have shown that despite urbanization posing a risk to global biodiversity via biotic homogenization (McKinney, 2006), cities usually have greater species richness compared with their rural surroundings (Knapp et al., 2009; Kühn et al., 2004; McKinney, 2002; Wania et al., 2006). High species richness for urban flora has typically been explained by a combination of four factors: (i) the high incidence of introduced species, (ii) socio-economic factors, (iii) land use and land cover heterogeneity, and (iv) diversity of environmental factors like soil and climate diversity. In combination, these four factors contribute to the observed relatively high levels of species richness in urban and suburban areas (Alvey, 2006).

(i) Urban Tree Diversity and Species Introductions

Many studies have found that the number (and proportion) of non-native species tends to increase along the urban–rural gradient, moving toward the urban centre (McKinney, 2002; Nielsen et al., 2014b). There are concerns that non-native species will out-compete native species (Chytrý et al., 2008; McKinney, 2006; Pysek et al., 2009) and therefore urban landscapes with too many non-native species will not function well in terms of providing ecosystem services even though they are diverse (Nielsen et al., 2014b). For example, Khera et al. (2009) found that while bird species richness in urban green spaces of Delhi, India was positively correlated with woody species richness, the correlation was negative when density of exotic woody species increased. On the other hand, the argument for the use of non-native species often refers to fluctuating environmental conditions, which are expected to increase under climate change (Easterling et al., 2000).Under such conditions it is suggested that non-native species have a better chance to cope with these fluctuations than native species. There are also suggestions that compromises should be made and that natural sites should be established that mainly contain natives, whereas semi-natural and artificial sites could accommodate both (Jim, 2013).

(ii) Urban Tree Diversity and Socio-Economic Factors

Urban areas are not only divided by an urban–rural gradient, but also consist of areas separated by socioeconomic and cultural differences (Kinzig et al., 2005). Socioeconomic status and culture are shaping forces for urban biodiversity. For example, higher socioeconomic status is correlated with greater species diversity; Luz de la Maza et al. (2002) found that high income areas in Santiago had 28 species per hectare compared to only 16 species per hectare in low income areas. This can be explained by the greater possibility for landowners within the higher socioeconomic areas to shape their surroundings and plant a more diverse range of species.

(iii) Urban Tree Diversity and Land Use/Land Cover Heterogeneity

“Urban ecosystems represent the most complex mosaic of vegetative land cover and multiple land uses of any landscape” (Foresman et al., 1997), which may be because they are formed by human design (Lister, 2014). Cities are characterized by a diverse range of site conditions, not often found in the surrounding countryside, and due to these varied site conditions, urban areas can accommodate a surprisingly varied flora (Jim, 2013). Research has documented that cities are disproportionately located in pre-existing biodiversity hot spots (Kühn et al., 2004; Nielsen et al., 2014b) with high ecosystem productivity or junctions of ecosystems where different land and water types meet. There are, however, differences within cities where the lowest species diversities along the urban–rural gradient occur in the intensively “built” environments of the urban core, and a peak in richness occurs in the suburban areas between the core and rural areas (Kowarik, 1995).

(iv) Urban Tree Diversity and Environmental Factors

The stressful urban environment (e.g. exposure to heat, low air humidity, periods of drought, high soil pH, limited soil volume, de-icing salt and other pollutants (Bassuk and Grabosky, 2014; Bassuk and Whitlow, 1988; Pauleit, 2003; Sieghardt et al., 2005)), together with the predicted climate-change-related increases in average temperature and more frequent heat waves and droughts in some areas during summer (Solomon et al., 2007) creates challenges, but also opportunities for diversification of the urban tree population. The increase in the already heterogeneous site conditions offered in the urban environment creates an even wider range of growth conditions, which often differs greatly from the countryside.

Governing for Tree Species Diversity

Despite appearing capable of supporting high diversity, many cities experience low and even declining tree diversity (Sjöman et al., 2012), and despite high overall species richness, normally a group of a few species dominates the urban tree population (Raupp et al., 2006). Kendal et al. (2014) measured species diversity for 108 cities worldwide and found that on average 20% of trees in an urban forest were of the same species, 26% were of the same genus, and 32% were of the same family. Therefore there is a need for increased emphasis on tree diversity in urban forestry strategic decision-making, design and management.

Guidelines for tree diversity

Tree diversity has been addressed in policy and planning mostly via general guidelines or 'rules-of-thumb'. Numerous species diversity guidelines exist, including Frank Santamour's 10-20-30 rule, which recommends planting not more than 10% of a single species, not more than 20% of a single genus, and not more than 30% of a family (Santamour, 1990). Other scholars have suggested working with mathematically computed indices, such as the Simpson and Shannon-Weiner indexes, and recommend diversifying urban forests at higher taxonomic levels than that of species, as pests generally operate at the genus and family levels (Subburayalu and Sydnor, 2012).

Tree inventories and tree selection

Strategic governance and planning for tree diversity needs to be based on the current state and composition of the urban forest (Alvey, 2006). City authorities worldwide have increasingly developed tree inventories, although the focus has mostly been on publicly owned trees (reviewed in Nielsen et al., 2014a). Also, inventories have become valuable data sources for researchers studying the ecosystem services provided by urban trees. Modern technology (e.g., hyperspectral satellite imagery, LiDAR) offers opportunities for comprehensive inventories of all urban trees (Alonzo et al., 2014; Zhang and Qiu, 2012). Tree inventories can provide a basis for diversity-related decision making.

In planning for species diversity, the range of available / desired species and genotypes needs to be explored. Sjöman et al. (2012) warn against rushing to the use of new species without proper testing. The authors also argue for including better information on, for example, species stress tolerance under different growing conditions. There is a need for ecological and physiological knowledge of tree genotypes and how these are linked to different urban sites and the provision of different ecosystem services. Nurseries play an important role, both in testing new plant material and also through matching the supply of planting material with new demands.

Towards governance for urban tree diversity

Urban forest governance not only involves municipal ‘tree’ officers and urban foresters, but also planners and other public officials, as well as a wide range of other actors, and not in the least local citizens (Lawrence et al., 2013). Local residents can have strong opinions about which trees, urban forest structure and urban forest services they prefer (Gundersen and Frivold, 2008), but are not always involved in decision making. With diversifying human populations, the range of 'tree preferences' can also be expected to increase (Fraser and Kenney, 2000). Concepts such as biocultural diversity, which provides an integrative perspective on biodiversity and local cultural diversity (Maffi and Woodley, 2010), offer promising new perspectives.

Good planning and governance practices for greater urban tree diversity do exist across the globe. Enhanced tree diversity has become integrated in Singapore's green infrastructure planning (Textbox 1), while cities such as Copenhagen, Denmark try to get away from a tradition of using only a few, dominating tree species, such as elm and lime (Sjöman et al., 2012). Santa Monica, USA, developed its urban tree diversity by planting single-species along individual streets, thus achieving diversity at city-level, while also strengthening local distinctiveness. Yet, it is also facing the challenge of *Washingtonia robusta* comprising over 40% of the entire urban forest (Textbox 1). Finally, cities and research organisations focus on urban tree diversity by establishing tree arboretums (Bühler and Kristoffersen, 2009), which provide excellent tools for communication and public involvement (Frediani, 2014).

Concluding Remarks

Examples of governance and management practices to promote urban tree diversity exist globally. Cities and towns are experimenting with ways to increase tree species richness as a means to deliver ecosystem stability and services. Rather than limiting richness, cities appear capable of supporting species diversity due to environmental and land cover heterogeneity, socioeconomic factors, and species introductions. While ecosystem service provision of urban forests is well documented, the role of tree species diversity is poorly understood. Improving our understanding of this and other diversity-related questions expressed in this paper will ensure that urban forests continue to provide the ecosystem services necessary to support an urbanizing global population.

Textbox 1 – First International Conference on Urban Tree Diversity at SLU Alnarp, Sweden

During 16-18 June 2014, the first International Conference on Urban Tree Diversity was held at the Alnarp campus of the Swedish University of Agricultural Sciences. About 300 international delegates discussed themes related to urban tree diversity, including tree selection, ecosystem service provision, strategies and planning, managing threats, and links between tree diversity and people diversity. Keynote speakers included:

- Dr *Leong Chee Chiew*, Commissioner for Parks and Recreation of Singapore, and deputy CEO of the country's National Parks Board. He provided a unique insight into the city-state's impressive greening programme and the importance of trees and other vegetation in sustainable urban development.
- Professor Ingo Kowarik, Technical University of Berlin. He focused on the role of trees in urban ecology, as well as the issue of exotic species. He provided a nuanced view on the use of non-natives, highlighting the long history of exotic tree species as important components of urban forests.
- Matthew Wells, urban forester, City of Santa Monica. He showed how urban tree diversity policies can be implemented in practical management.

A comprehensive conference programme and abstract book documents all presentations, highlighting the complexity of urban tree diversity discussions and the need for more comprehensive research and policy (Konijnendijk van den Bosch and Östberg, 2014). The second International Conference on Urban Tree Diversity is scheduled for February 2016 in Melbourne, Australia (www.urbantreediversity.org).

References

Acar, C., Acar, H., Eroğlu, E., 2007. Evaluation of ornamental plant resources to urban biodiversity and cultural changing: A case study of residential landscapes in Trabzon city (Turkey). Building and Environment 42, 218-229.

Alonzo, M., Bookhagen, B., Roberts, D.A., 2014. Urban tree species mapping using hyperspectral and lidar data fusion. Remote Sensing of Environment 148, 70-83.

Alvey, A.A., 2006. Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening 5, 195-201.

Bassuk, N., Grabosky, J., 2014. Urban sites are made for plant diversity, International conference on Urban Tree Diversity, Alnarp, Sweden.

Bassuk, N., Whitlow, T., 1988. Environmental stress in street trees. Arboricultural Journal 12, 195-201.

Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning 97, 147-155.

Bühler, O., Kristoffersen, P., 2009. The Urban Tree Arboretum in Hørsholm, Denmark: A new tool towards an improved education of arborists and tree managers. Urban Forestry & Urban Greening 8, 55-61.

Chytrý, M., Maskell, L.C., Pino, J., Pyšek, P., Vilà, M., Font, X., Smart, S.M., 2008. Habitat invasions by alien plants: A quantitative comparison among Mediterranean, subcontinental and oceanic regions of Europe. Journal of Applied Ecology 45, 448-458.

Clapp, J.C., Ryan, H.P., Harper, R.W., Bloniarz, D.V., 2014. Rationale for the increased use of conifers as functional green infrastructure: A literature review and synthesis. Arboricultural Journal.

Colding, J., 2007. 'Ecological land-use complementation' for building resilience in urban ecosystems. Landscape and Urban Planning 81, 46-55.

Cook-Patton, S.C., Bauerle, T.L., 2012. Potential benefits of plant diversity on vegetated roofs: A literature review. Journal of Environmental Management 106, 85-92.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van Den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253-260.

Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies, Z.G., Rouquette, J.R., Maltby, L.L., Warren, P.H., Armsworth, P.R., Gaston, K.J., 2012. Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. BioScience 62, 47-55.

Dimke, K.C., Sydnor, T.D., Gardner, D.S., 2013. The effect of landscape trees on residential property values of six communities in Cincinnati, Ohio. Arboriculture and Urban Forestry 39, 49-55.

Dobbs, C., Escobedo, F.J., Zipperer, W.C., 2011. A framework for developing urban forest ecosystem services and goods indicators. Landscape and Urban Planning 99, 196-206.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R., Mearns, L.O., 2000. Climate extremes: Observations, modeling, and impacts. Science 289, 2068-2074.

Escobedo, F.J., Kroeger, T., Wagner, J.E., 2011. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. Environ. Pollut. 159, 2078-2087.

Foresman, T.W., Pickett, S.T., Zipperer, W.C., 1997. Methods for spatial and temporal land use and land cover assessment for urban ecosystems and application in the greater Baltimore-Chesapeake region. Urban Ecosystems 1, 201-216.

Fraser, E.D.G., Kenney, W.A., 2000. Cultural background and landscape history as factors affecting perceptions of the urban forest. Journal of Arboriculture 26, 106-113.

Frediani, K., 2014. The Urban Arboretum, Arboricultural Association's 48th Amenity Trees Conference, Royal Holloway, University of London, UK.

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H., Gaston, K.J., 2007. Psychological benefits of greenspace increase with biodiversity. Biology Letters 3, 390-394.

Gundersen, V.S., Frivold, L.H., 2008. Public preferences for forest structures: A review of quantitative surveys from Finland, Norway and Sweden. Urban Forestry and Urban Greening 7, 241-258.

Hooper, D.U., Chapin Iii, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs 75, 3-35.

Jim, C.Y., 2013. Sustainable urban greening strategies for compact cities in developing and developed economies. Urban Ecosystems 16, 741-761.

Jim, C.Y., Chen, W.Y., 2008. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). Journal of Environmental Management 88, 665-676.

Kendal, D., Dobbs, C., Lohr, V.I., 2014. Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? Urban Forestry and Urban Greening 13, 411-417.

Khera, N., Mehta, V., Sabata, B.C., 2009. Interrelationship of birds and habitat features in urban greenspaces in Delhi, India. Urban Forestry and Urban Greening 8, 187-196.

Kinzig, A.P., Warren, P., Martin, C., Hope, D., Katti, M., 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. Ecology and Society 10.

Kirnbauer, M.C., Baetz, B.W., Kenney, W.A., 2013. Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels. Urban Forestry and Urban Greening 12, 401-407.

Knapp, S., Kühn, I., Bakker, J.P., Kleyer, M., Klotz, S., Ozinga, W.A., Poschlod, P., Thompson, K., Thuiller, W., Römermann, C., 2009. How species traits and affinity to urban land use control large-scale species frequency. Diversity and Distributions 15, 533-546.

Konijnendijk van den Bosch, C., Östberg, J., 2014. Programme & abstract book, International Conference on Urban Tree Diversity. Swedish University of Agricultural Sciences, Alnarp, Sweden.

Kowarik, I., 2011. Novel urban ecosystems, biodiversity, and conservation. Environ. Pollut. 159, 1974-1983.

Kowarik, I., 2014. Aliens in the city!? Considering context dependence helps calming down the heated alien-native debate, International conference on Urban Tree Diversity, Alnarp, Sweden.

Kühn, I., Brandl, R., Klotz, S., 2004. The flora of German cities is naturally species rich. Evolutionary Ecology Research 6, 749-764.

Lacan, I., McBride, J.R., 2009. War and trees: The destruction and replanting of the urban and peri-urban forest of Sarajevo, Bosnia and Herzegovina. Urban Forestry and Urban Greening 8, 133-148.

Lawrence, A., De Vreese, R., Johnston, M., Konijnendijk van den Bosch, C.C., Sanesi, G., 2013. Urban forest governance: Towards a framework for comparing approaches. Urban Forestry and Urban Greening 12, 464-473.

Lister, N.-M., 2014. Landscape as infrastructure: Towards an Ecological Urbanism, International conference on Urban Tree Diversity, Alnarp, Sweden.

Lundholm, J., MacIvor, J.S., MacDougall, Z., Ranalli, M., 2010. Plant species and functional group combinations affect green roof ecosystem functions. PLoS One 5.

Luz de la Maza, C., Hernández, J., Bown, H., Rodríguez, M., Escobedo, F., 2002. Vegetation diversity in the Santiago de Chile urban ecosystem. Arboricultural Journal 26, 347-357.

Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: A multilayered relationship. Trends in Ecology and Evolution 27, 19-25.

Maffi, L., Woodley, E., 2010. Biocultural Diversity Conservation: A Global Sourcebook. Earthscan.

McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. BioScience 52, 883-890.

McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127, 247-260.

McLain, R., Poe, M., Hurley, P.T., Lecompte-Mastenbrook, J., Emery, M.R., 2012. Producing edible landscapes in Seattle's urban forest. Urban Forestry & Urban Greening 11, 187-194.

McPherson, E.G., Simpson, J.R., 2003. Potential energy savings in buildings by an urban tree planting programme in California. Urban Forestry and Urban Greening 2, 73-86.

Morgenroth, J., Armstrong, T., 2012. The impact of significant earthquakes on Christchurch, New Zealand's urban forest. Urban Forestry and Urban Greening 11, 383-389.

Nielsen, A.B., Östberg, J., Delshammar, T., 2014a. Review of urban tree inventory methods used to collect data at single-tree level. Arboriculture and Urban Forestry 40, 96-111.

Nielsen, A.B., van den Bosch, M., Maruthaveeran, S., van den Bosch, C.K., 2014b. Species richness in urban parks and its drivers: A review of empirical evidence. Urban Ecosystems 17, 305-327.

Nowak, D.J., Greenfield, E.J., Hoehn, R.E., Lapoint, E., 2013a. Carbon storage and sequestration by trees in urban and community areas of the United States. Environ. Pollut. 178, 229-236.

Nowak, D.J., Hoehn, R.E., Bodine, A.R., Greenfield, E.J., O'Neil-Dunne, J., 2013b. Urban forest structure, ecosystem services and change in Syracuse, NY. Urban Ecosystems, 1-23.

Pauleit, S., 2003. Urban street tree plantings: Identifying the key requirements. Proceedings of the Institution of Civil Engineers: Municipal Engineer 156, 43-50.

Poland, T.M., McCullough, D.G., 2006. Emerald ash borer: Invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry 104, 118-124.

Pysek, P., Křivánek, M., Jarošik, V., 2009. Planting intensity, residence time, and species traits determine invasion success of alien woody species. Ecology 90, 2734-2744.

Raupp, M.J., Cumming, A.B., Raupp, E.C., 2006. Street tree diversity in eastern North America and its potential for tree loss to exotic borers. Arboriculture and Urban Forestry 32, 297-304.

Richards, N.A., 1993. Reasonable guidelines for street tree diversity. Journal of Arboriculture 19, 344-349.

Roy, S., Byrne, J., Pickering, C., 2012. A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban Forestry and Urban Greening 11, 351-363.

Santamour, F.S., 1990. Trees for urban planting: diversity, uniformity, and common sense, 7th Conference of the Metropolitan Tree Improvement Alliance, The Morton Arboretum, Lisle, Illinois, USA.

Scherber, C., Vockenhuber, E.A., Stark, A., Meyer, H., Tscharntke, T., 2014. Effects of tree and herb biodiversity on Diptera, a hyperdiverse insect order. Oecologia 174, 1387-1400.

Sieghardt, M., Mursch-Radlgruber, E., Paoletti, E., Couenberg, E., Dimitrakopoulus, A., Rego, F., Hatzistathis, A., Randrup, T.B., 2005. The abiotic urban environment: Impact of urban growing conditions on urban vegetation, Urban Forests and Trees: A Reference Book, pp. 281-323.

Sjöman, H., Östberg, J., Bühler, O., 2012. Diversity and distribution of the urban tree population in ten major Nordic cities. Urban Forestry and Urban Greening 11, 31-39.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., Miller, H., 2007. IPCC, 2007: Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.

Subburayalu, S., Sydnor, T.D., 2012. Assessing street tree diversity in four Ohio communities using the weighted Simpson index. Landscape and Urban Planning 106, 44-50.

Wania, A., Kühn, I., Klotz, S., 2006. Plant richness patterns in agricultural and urban landscapes in Central Germany - Spatial gradients of species richness. Landscape and Urban Planning 75, 97-110.

Xiao, Q., McPherson, E.G., Ustin, S.L., Grismer, M.E., Simpson, J.R., 2000. Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrological Processes 14, 763-784.

Zavaleta, E.S., Pasari, J.R., Hulvey, K.B., Tilman, G.D., 2010. Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. Proc. Natl. Acad. Sci. U. S. A. 107, 1443-1446.

Zhang, C., Qiu, F., 2012. Mapping individual tree species in an urban forest using airborne lidar data and hyperspectral imagery: AAG remote sensing specialty group 2011 award winner. Photogrammetric Engineering and Remote Sensing 78, 1079-1087.