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Short communication

Urban tree diversity—Taking stock and looking ahead

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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

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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).

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 towards 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).

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 socio-economic 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.

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