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Development of multi-functional streetscape green infrastructure using a performance index approach

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ABSTRACT

This paper presents a performance evaluation framework for streetscape vegetation. A performance index (PI) is conceived using the following seven traits, specific to the street environments – Pollution Flux Potential (PFP), Carbon Sequestration Potential (CSP), Thermal Comfort Potential (TCP), Noise Attenuation Potential (NAP), Biomass Energy Potential (BEP), Environmental Stress Tolerance (EST) and Crown Projection Factor (CPF). Its application is demonstrated through a case study using fifteen street vegetation species from the UK, utilising a combination of direct field measurements and inventoried literature data. Our results indicate greater preference to small-to-medium size trees and evergreen shrubs over larger trees for streetscaping. The proposed PI approach can be potentially applied two-fold: one, for evaluation of the performance of the existing street vegetation, facilitating the prospects for further improving them through management strategies and better species selection; two, for planning new streetscapes and multi-functional biomass as part of extending the green urban infrastructure.

1. Introduction

Streets offer opportunities for increasing tree density in the existing urban fabric, particularly in the densely built-up inner cities. Urban proliferation, typically through scattered patterns of low-density developments, or infill of urban space with medium and high density dwellings, provide further potentials for boosting managed vegetation along streetscapes[1] comprising of roads, streets, sidewalks, squares, bridleways, etc. (LAEC, 2007; Jim and Chen, 2008; Ignatieva et al., 2010; Dawe, 2011). Planting trees along streetscapes has been considered useful for improving urban health and wellbeing, especially in densely populated inner-city built environments characterised by space constraints and high pollution levels (Pauleit, 2003; Roy et al., 2012; Vlachokostas et al., 2014). Through adequate policy measures and design strategies, street trees hold multifarious potentials for improving human comfort at modest costs, primarily through passive cooling, pollution alleviation (air, water, noise) and flood risk aversion (Shashua-Bar et al., 2010a; Armson et al., 2013a; Nowak et al., 2014; Gromke and Blocken, 2015). Recent findings suggest public and private benefits of street trees in terms of their positive contributions to neighbourhood development and sustainability (Pandit et al., 2013; Salmond et al., 2013). Street vegetation already constitutes a substantial portion of green space cover in such regions globally, with reported tree densities of up to 158 and 300 stands per km of street respectively in Melbourne, Australia and Guangzhou, China (Kendal et al., 2012). In cities with heavy industrial or traffic activities, 'green belts' have been integral part of streetscapes (along ring roads and arterial/trunk routes), primarily introduced to mitigate odour, noise and air pollution (Chaulya, 2004; Rao et al., 2004; Pathak et al., 2011).

Several local authorities have developed roadside vegetation management plans, inviting developers and residents to participate in increasing street tree population alongside their long term preservation (LAEC, 2007; Hawkesbury City Council, 2010; Hall et al., 2012; Heidrich et al., 2013). However, streets and other paved sites offer complex stress environments and therefore the

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[1] Streetscapes are defined as planted specimens growing along the verge of streets (Barber et al., 2013).

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suitability of trees for such sites requires higher priority to stress tolerance over their aesthetic and other functionalities. A review of Scandinavian tree species reported the existing information to be either piecemeal (and very general, lacking local perspective) or too specific (and contradictory) to meet the requirements of urban tree planners (Sjöman and Nielsen, 2010). Traditionally, the resilience of an urban tree population has been largely dependent on species selection to withstand pest infestations, i.e. natural selection (Raupp et al., 2006; Bassuk et al., 2009). Common considerations guiding the selection of species encompass, but are not limited to, their representativeness of native vegetation, decorativeness, salt tolerance, ability to uptake soil contaminants, and growth performance (Churkina et al., 2015). However, cities globally have witnessed habitat fragmentation and increased non-native diversity of streetscape vegetation as a result of newly introduced species. This has been further aggravated during recent drive to increase urban green cover through fast-track programs to plant millions of trees via national and/or international campaigns (Young, 2011; Zhao et al., 2013; Plant for the Planet, 2014). Such initiatives for creating 'naturopolises' are likely to succumb to environmental stresses from the drastic differences between urban and natural systems unless due consideration is given to developing resilient tree infrastructure using the scientific evidence on interactions between plants and urban ambient conditions (Churkina et al., 2015). Street trees in particular are exposed to a relatively high stress level, including high pollutant concentrations (Harris and Manning, 2010; Demuzere et al., 2014); damage from wind gusts, de-icing salt, high/low ambient temperatures; harsh growing conditions, including restricted rooting space owing to low quality growing substrate and soil compaction (Gill et al., 2008; Armson et al., 2013a), restricted space for crown development (Sæbø et al., 2005); and, insufficient access to water and oxygen, which are only likely to get worse with the projected adverse future climate (Roloff et al., 2009). Increased urbanisation would further influence the pollution dynamics and the alteration of the structure and function of the natural ecosystems (Williams et al., 2009). This will evidently influence future tree assemblages along streets, which in most cases is already dominated by just a few species. The European tree survey has shown that only three to five genera, including *Platanus, Assculus, Acer, Tilia*, account for 50%–70% of all street trees planted (Pauleit, 2003). Spain has only five genera representing 56% of all the trees planted in paved areas (Sæbø et al., 2005); England, UK, has only six species accounting for 37% of all trees and shrubs planted within cities, including Leyland cypress (×*Cupressocyparis Leylandii*), hawthorn (*Crataegus* spp.), sycamore (*Acer pseudoplatanus*), silver birch (*Betula pendula*), common ash (*Fraxinus excelsior*), and privet (*Ligustrum* spp.) (Britt and Johnston, 2008); the London Plane tree (*Platanus acerifolia*) is among the most numerous large street and park trees planted in Greater London (UK) (Davies et al., 2011).

A considerable amount of research efforts have gone into assessing the effects of air pollution on roadside vegetation (Lau and Luk, 2001; Truscott et al., 2005; Wagh et al., 2006; Bignal et al., 2008) and conversely on their role in mitigating air pollution (Yang et al., 2005; Nowak et al., 2006; McDonald et al., 2007; Tiwary et al., 2009). Evaluation of the net effect of increased vegetation on the urban air quality in the local-to-neighbourhood scale street environment has been a central theme of recent research studies (Salmond et al., 2013; Gromke and Blocken, 2015). Increased traffic-generated N-emissions have been associated with accelerated growth of some 'lower plant' species (e.g. bryophytes) along streets, mainly owing to fertilisation effects of the scavenged NO_x, HNO_2 and/or NH_3 emissions on their surfaces (Bignal et al., 2008). Certain tree species have been earmarked for plantations along the roads as bio-monitors for vehicle emissions (Moreno et al., 2003; Hofman and Samson, 2014). However, despite some generalised modelling studies, there is still much to be learned about the characteristics and ecophysiology of different types of urban vegetation and their interaction with the street environment (Calfapietra et al., 2015). This indicates an urgent need to improve our understanding of the environmental responses of the vegetation species used before decisions are made about streetscape species selection. Street tree good practice guides have been developed – outlining the design criteria for street plantations, choice of suitable tree species and maintenance requirements – with increasing emphasis on planting smaller tree species as street trees because they fit better into narrow pavements and are easier to manage (Pauleit, 2003; Britt and Johnston, 2008; Armson et al., 2013b; Forest Research, 2014). A generalised prescription for suitable streetscape vegetation species and genotypes include – tree life span; required growth space and adaptability to the local environment; tree functionality (pollution/noise attenuation, cooling, flood risk aversion, storm water reduction, etc.); cost of propagation, establishment and management; aesthetics; stress and drought tolerance; potential allergenicity of species (Sæbø et al., 2005; Vlachokostas et al., 2014).

The scope of this study is to evaluate the inherent traits of high-performing streetscape vegetation, deemed important for sustainable and widespread climate change mitigation as well as adaptation. It is motivated by the emerging trends of adaptation strategies based on urban greening, maximising the potentials for multiple benefits while avoiding the conflicting influences on meeting the sustainability objectives (CLG, 2007). The development of a Performance Index (PI) framework is meant to facilitate the decision-support of planners/practitioners by providing a repeatable metric for comparative evaluations on the multitude of streetscaping prospects, such as planting a line of seasonal woody tree biomass vs. perennial shrubs, or developing a vegetation mix, combining sparse line of trees with an understory etc. The first part of this paper describes the methodological framework in developing the performance index. The application of this methodology is demonstrated through a case study in the second part of the paper. This is followed by a discussion on the relevance of such an approach, as well as its limitations to conducting an all-inclusive evaluation of streetscape vegetation.

2. Development of a performance index

Understanding and improving the environmental performance of street/roadside vegetation comprehensively (trees, shrubs, forbs etc.) has motivated the development of index-based frameworks. Several researchers have expended efforts towards developing performance indices for specific application of urban trees – for example, towards greenbelt development for pollution alleviation (Prajapati and Tripathi, 2008); for reducing of traffic-generated noise (Pathak et al., 2011); for more comprehensive evaluation of their ecosystem services and goods from urban forests (Dobbs et al., 2011; Kenney et al., 2011), etc. A recent study developed a decision-making scheme for benchmarking/prioritising tree species in urban environments using a framework which combines two multi-criteria methods to provide an optimal ranking. The set of multiple criteria include tree life span, required growth space, planting capability in built environment, aesthetics, tolerance, pollution attenuation, adaptation to local climate, crown density, cost, and potential allergenicity of the species (Vlachokostas et al., 2014). However, their study does not appear to address the issues pertaining to street environment and has not considered biogenic emissions (BVOCs) from vegetation *per se*.

The performance index (PI) is conceived in this study as a combination of the following seven performance traits for streetscaping

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