***Title page**

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A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones

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Abstract

Urban trees can potentially mitigate environmental degradation accompanying rapid urbanisation via a range of tree-benefits and services. But uncertainty exists about the extent of tree benefits and services because urban trees also impose costs (e.g. asthma) and may create hazards (e.g. windthrow). Few researchers have systematically assessed how urban tree benefits and costs vary across different cities, geographic scales and climates. This paper provides a quantitative review of 115 original urban tree studies, examining: (i) research locations, (ii) research methods, and (iii) assessment techniques for tree services and disservices. Researchers published findings in 33 journals from diverse disciplines including: forestry, land use planning, ecology, and economics. Research has been geographically concentrated (64% of studies were conducted in North America). Nearly all studies (91.3%) used quantitative research, and most studies (60%) employed natural science methods. Demonstrated tree benefits include: economic, social, health, visual and aesthetic benefits; identified ecosystem services include: carbon sequestration, air quality improvement, storm water attenuation, and energy conservation. Disservices include: maintenance costs, light attenuation, infrastructure damage and health problems, among others. Additional research is required to better inform public policy, including comparative assessment of tree services and disservices, and assessment of urban residents and land managers' understanding of tree benefits and costs.

Keywords: trees, cities, ecosystem services, ecosystem disservices, assessment methods, land use policy

Introduction

Rapid urbanisation is destroying natural ecosystems and degrading the environmental quality of towns and cities (Folke *et al.*, 1997; Gregg *et al.*, 2003; Alberti and Marzluff, 2004). In recent decades, rates of urbanisation have intensified globally; over half of the world's population now inhabits cities, and ten percent lives in megacities of 10 million or more (United Nations, 2010). By 2050 this will be closer to seventy-five percent (Roberts, 2011). Many cities have been experiencing unprecedented growth, accompanied by severe environmental degradation (e.g. noise, carbon pollution, soil erosion, habitat loss, and species extirpation) (Zipperer *et al.*, 1997; Vesely, 2007; Young, 2010). Scholars and policy-makers have begun to direct their attention to evaluating the potential of urban trees to ameliorate some of this harm (Girardet, 1996; Hough, 2004; Register, 2006; Newman and Jennings, 2008).

Urban tree research has examined various aspects of trees (including ecosystem services and disservices), but a comprehensive assessment of this research is lacking. What is needed is a systematic assessment of: methods that have been used, where has research occurred, what studies have found, and where the most important gaps in the literature occur. This paper systematically analyses the literature on urban tree benefits and disbenefits (including ecosystem services and disservices) and assessment methods. The paper seeks to answer four research questions: (1) how have different studies assessed urban tree costs and benefits (e.g. field methods vs. remote sensing)?; (2) how do the results of different cost-benefit studies on urban trees compare?; (3) is there a common measure showing the same benefit or cost for the same trees in different cities in different climate zones?'; and (4) are there similar benefits and costs of urban trees in different parts of the world, and if so, what are they, and what factors are driving these similarities?

The paper begins by concisely defining the key terminology ('urban tree', 'urban forest', 'green-space', 'benefits', 'costs', 'ecosystem services' and 'ecosystem disservices') and then discusses the methods used in this study. Results of the systematic exploratory review of urban tree literature are then reported and discussed. Some suggestions are then made for future research and the paper concludes by identifying implications for urban policy. It should be noted from the outset that this paper is not about ecosystem services and disservices per se; rather it considers the benefits and costs of urban trees, some of which include ecosystem (dis)services. For this reason the paper addresses issues beyond the purview of the ecosystem services literature.

Seeing the trees from the forest – definition of key terms

Few studies of urban trees have actually defined what is meant by the term 'urban tree' and 'green-space' (Vesely 2007, is a notable exception). Indeed Randrup *et al.*, (2005) have observed that questions about: "which types of green space and which areas…to include [in research] have not been answered unambiguously". For the purpose of this paper, an urban tree is a woody perennial plant growing in towns and cities, typically having a single stem or trunk - and usually a distinct crown - growing to a considerable height, and bearing lateral branches at some height from the ground. Urban trees include individual trees as well as those occurring in stands, patches and groups within publicly-accessible green-spaces. Here the term urban tree relates to a *growth form* rather than to a vegetation type, thus defining the scope of the study.

While the related term 'urban forest' has been excluded from this study (because much urban forest research is beyond the scope of the paper), it is nonetheless useful to differentiate urban trees from urban forests. Escobedo *et al.,* (2011) have defined 'urban forest' as: "the sum of all urban trees, shrubs, lawns, and pervious soils located in highly altered and extremely complex ecosystems where humans are the main drivers of their types, amounts, and distribution”. Their definition conceptualises urban forest as a *vegetation type*. Following Randrup *et al.*, (2005) this paper conceptualises urban trees as a subset of urban forests, because urban forests are not just the sum of urban trees, but include shrubs and grass too (see figure 1).

While James *et al.*, (2009) have defined green-space as: “unsealed, permeable and soft surfaces such as soil, grass, shrubs, trees and water”, this definition is simultaneously too broad and too restrictive for this paper. Green-space in this study is a term referring to: “parks, sporting fields, bushland, [riparian areas of] creeks, rivers and bays, plazas, community gardens, bikeways and paths, …as well as attractive and safe streets and ‘green’ links between these various elements … [and may include] communal space around apartment buildings, [as well as] cemeteries, rock walls, street verges and medians, school grounds, rooftop parks, and storm-water channels, and [unpaved] parking lots and open-air, publicly accessible shopping malls” (Byrne *et al.*, 2010) and also includes street trees. Green spaces also encompass golf courses, botanic gardens, greenways, and utility easements (Vesely, 2007; Young, 2010). Following Tratalos *et al.*, (2007), this review is specifically limited to publicly accessible green-spaces and does not include private gardens, yards, or private campuses.

INSERT FIGURE 1 AROUND HERE

The well-established ecosystem services literature (Costanza and Farber, 2002; Chee, 2004; Zhao *et al.*, 2009; Liu *et al.*, 2010; Pittman and McCormick, 2010; Sagoff, 2011; Seppelt *et al.*, 2011) includes many studies on the *benefits* of urban trees. Much of this literature stems from ecological economics (De Groot *et al.*, 2002; Farber *et al.*, 2002;

Howarth and Farber, 2002; Kumar and Kumar, 2008; Sagoff, 2011) and conservation biology (Brown *et al.*, 2007; Wallace, 2007). But environmental economics, and environmental science have also examined this topic in some detail (Sundar, 2005; Daily *et al.*, 2009; Zhao *et al.*, 2009; Dick *et al.*, 2011; Oikonomou *et al.*, 2011).

Urban trees confer a wide range of benefits on city-dwellers. However, scholars from various disciplines have defined the concepts of 'tree benefits' and 'tree services' differently (Tyrväinen *et al.*, 2005). The urban forest and pollution literature for example, has focused on the functional effects of urban forest ecosystem structure (McPherson *et al.*, 1998; Nowak and Dwyer, 2000; Nowak *et al.*, 2006; Cavanagh *et al.*, 2009), whereas the economic, ecological, environmental, and natural resource literatures have tended to directly link ecosystem functions to human benefits (De Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2005; De Groot, 2006; Daily *et al.*, 2009).

Ecological economists distinguish explicitly between *ecosystem functions* and ecosystem *goods and services*. Ecosystem function refers to "the capacity of natural processes and components to provide goods and services that satisfy human needs" and include: *regulation functions* (e.g. life-support), *habitat functions* (space for refuge and reproduction), *productive functions* (energy conversion to biomass); *information functions* (e.g. opportunities for aesthetic experience) and *carrier functions* (e.g. transportation) whereas specific ecosystem products/outputs related to identifiable and measurable human benefits (e.g. goods and services) are defined as *ecosystem services* (De Groot *et al.*, 2002; see also De Groot, 2006; Boyd and Banzhaf, 2007; Kroeger and Casey, 2007 and De Groot *et al.*, 2010). To paraphrase Escobedo *et al.*, (2011), ecosystem services are the "specific results of ecosystem functions or aspects of ecosystems utilized actively or passively, directly or indirectly, to sustain or enhance human and non-human life" (see also Chee, 2004; Brown *et al.*, 2007; Wallace, 2007, and Fisher *et al.*, 2009).

Urban trees provide a range of ‘services’ for urban residents including: mitigating carbon pollution, improving urban air quality, attenuating storm-water flooding, conserving energy, and reducing noise, among others (Arthur and Martin, 1981; Miller, 1997; Low *et al.*, 2005; Burden, 2006). Urban trees also provide habitat for urban wildlife - a benefit because many urban dwellers enjoy encounters with urban animals (Tzilkowski *et al.*, 1986; Gorman, 2004; Lohr *et al.*, 2004; McPherson *et al.*, 2011). Many of these ecosystem services are ostensibly quantifiable, and have been measured using various assessment tools (Longcore *et al.*, 2004; Jim and Chen, 2008; Nowak *et al.*, 2008a; Escobedo *et al.*, 2010). Urban trees also provide diverse social, economic, psychological, medical, and aesthetic benefits (Dwyer *et al.*, 1992; Burden, 2006; Good, 2008), some of which stem from the ecosystem services – but many of which may not be quantifiable (Dwyer *et al.*, 1991).

However, the presence of urban trees is not entirely positive. Environmental, social, economic, health, visual and aesthetic problems have been reported, and can be considered to be tree costs, or collectively as ‘ecosystem disservices’ (Dwyer *et al.*, 1992; Gorman, 2004; Lohr *et al.*, 2004; Lyytimäki and Sipilä, 2009). Ecosystem disservices have been defined as impacts or costs that negatively affect human well-being, such as nuisance, fear, threat of physical harm, health risks, aesthetic problems and different types of pollution (McPherson *et al.*, 1998; Nowak and Dwyer, 2000; Zhang *et al.*, 2007; Lyytimäki and Sipilä, 2009; Dobbs *et al.*, 2011). For the purpose of this study, urban tree ecosystem disservices include the negative impacts of trees that degrade the quality of life of city dwellers and impose financial, health and maintenance burdens upon urban residents and municipal land managers.

Despite the high level of scholarly interest, a comprehensive understanding of the extent of the benefits and costs that urban trees provide across various continents, climatic zones, countries and in differing built environments, is noticeably absent from the literature.

To date, a systematic comparative analysis of the urban tree literature has not been undertaken. This paper begins to address that knowledge gap.

Methods

A systematic quantitative literature review was performed using a methodology which has been extensively used in the health sciences and social sciences (Pettigrew, 2001) By systematically searching and categorising the relevant literature, such reviews provide reproducible, reliable assessments of the current status of a field of research. The ways that papers are found, selected and categorised is clearly articulated apriori, thus minimising potential biases that can occur in some narrative style reviews (Pettigrew, 2001). The resulting 'quantitative assessment' assesses the geographical spread of the literature, the types of methods used, and the types of results obtained.

Scholarly electronic databases were searched to identify original research papers published in English language journals related to 'urban trees'. These databases included: Scopus, Science Direct, ProQuest, Web of Knowledge, Sage, Google Scholar as well as Google. Databases were searched between June 2010 and November 2011. Keywords used for the search included: 'urban trees', 'urban tree benefits', 'urban tree ecosystem services' and 'urban tree disservices'[1]. Additional papers were identified from the reference list of those research papers found through the database search.

From each original research paper examining urban trees, the following eleven items of information were recorded in a Microsoft Excel database: (i) author(s), (ii) journal, (iii) year of publication, (iv) study location (city, state, country, continent and climatic zone), (v) research methodology, (vi) tree assessment methods, (vii) tree valuation methods, (viii) tree

[1] Other terms searched for were: 'street trees', 'ecosystem services', 'trees in subtropical cities', 'trees mitigating climate change', 'value of trees / street trees' and urban tree ecology.

benefits, (ix) tree services, (x) tree disservices (problems and hazards, costs and expenditure) and (xi) any other relevant tree aspect.

Based on location, research papers were grouped by continents and major climatic zones to determine if geographic patterns exist in the research. The conventional division of seven continents was used, that is: North America (the Caribbean Islands, Central America and the Canada), South America, Africa, Europe, Asia (including the middle east), Australia (including all Australian territories, New Zealand, Papua New Guinea, Fiji, Solomons, Micronesia, Melanesia and Polynesia, and South Pacific islands). Antarctica - with limited settlements and no trees - was excluded from the study (see figure 2). Studies spanning continents were categorised under the heading - 'general'.

Climatic zone was recorded using a modified Koeppen classification system (recognising six principal groups of world climates - tropical, dry, temperate, continental, polar and alpine) (Lohmann *et al.*, 1993; Stern *et al.*, 2000; Kottek *et al.*, 2006; Peel *et al.*, 2007). The temperate zone was however split into separate subtropical and temperate climatic zones, due to likely differences in tree types and the concomitant benefits derived. There were no papers from polar or alpine climatic zones. Studies examining urban trees across multiple climatic zones were categorised under a 'general' heading.

Each paper was also classified based on research methods used. This included natural science methods (e.g. field experiments, field surveys and modelling) social science methods (e.g. interviews, questionnaires, surveys, focus groups and participant observation) and mixed methods (e.g. combination of experiments, interviews, questionnaires and surveys). Methods were also classified into qualitative approaches (interviews, content and text analysis, case studies, observations, and focus groups), quantitative approaches (questionnaire surveys, field-surveys and samples, field experiments, Geographic Information Systems (GIS) analysis, remote sensing and satellite imagery) or a mixed approach (including existing data base and records searches, or other literature analysis).

Information related to benefits/services and costs/disservices were extracted from each paper and assigned to relevant categories and sub-categories. For ecosystem services, the sub-categories were related to carbon sequestration, air quality, storm water attenuation, energy reduction, habitat provision, noise reduction and provision of microclimate. The services and disservices were sub-categorised according to social, economic, health, environmental, and aesthetic aspects (using a modified version of De Groot *et al's*., (2010) classification schema). For each tree service and disservice, information was also recorded about whether the aspect was studied and discussed, or actually demonstrated (e.g. found).

Finally, the methods used to assess or measure ecosystem services and tree benefits were also recorded. Urban trees have been previously assessed using various assessment tools and methods including GIS-based computer programs such as CITYGreen and i-Tree, as well as mathematical derivations (e.g. mathematical models and equations, linear and quadratic regression equations, logarithmic equations, correlation, extrapolation), remote sensing and economic modelling among others. If a paper assessed the economic or other value of urban trees, the method used was also recorded (market prices, surrogate market approach, production function approach, stated preference approach, cost based valuation method, and cost-benefit analysis method among others).

Results

A total of 115 original, peer reviewed research papers on urban trees were identified (table 1). Reflecting the trans-disciplinary interest in this topic, papers were published in 33 different journals spanning a wide range of disciplines (table 2). Three fields were dominant – arboriculture/urban forestry, environment/ecology and landscape. Just over 40% of the papers were published in arboriculture and forestry journals, with 28 (24.4%) of the papers published in *Arboriculture and Urban Forestry* (previously *Journal of Arboriculture)* and 14 (12.2%) published in *Urban Forestry and Urban Greening*. The next most common discipline was environment and ecology, with 28 (24%) papers of which 7 (6%) were in *Environmental Pollution,* and 5 (4.4%) each in *Urban Ecology* and *Atmospheric Environment*. This was followed by landscape, with 20 (17.4%) papers in total; all but one published in the journal *Landscape and Urban Planning*. Other disciplines were represented but their contributions to date have not been as substantial. For example, *Ecological Economics* published 4 (3.4%) papers while the *Journal of Forestry*, *Energy and Buildings*, *Building and Environment* and the *Journal of Environmental Management* published 3 (2.6%) papers each. Twenty one journals contained just a single paper.

INSERT TABLE 1 AROUND HERE

The earliest research paper (examining the status of municipal tree programs across 72 cities in the United States) was published in *Urban Ecology* (Beatty and Heckman, 1981) (see table 1). The same issue of that journal also published a research paper on Syracuse (New York) street tree diversity (Sanders, 1981). Since then, research on urban trees has escalated substantially, with 7% of papers published in the 1980's, 20% in the 1990's and 50% published from 2000 to the end of 2009 (table 1). From 2010 to March 2011 alone a further 25 (22%) papers were published, of which 7 (6%) were published in *Landscape and Urban Planning* and *Urban Forestry & Urban Greening*.

Geographic distribution of studies

Urban trees have attracted diverse scholarly interest, across the globe. Although research is predominantly from within North America (63.5% of papers), other continents are represented, including: Asia (14.8%), Europe (6.9%), Africa (5.2%), South America (2.6%) and Australia (3.5%) (see figure 2). Most papers examined urban trees growing in the subtropical climatic zones (41.7%), with continental zones (16.5%) also well represented. Studies across two or more climatic zones accounted for 24.3% of published papers (figure 3). Out of the 73 papers looking at urban trees in North America, 21 provided comparative analysis of urban trees across different cities and climatic zones. Some cities were the focus of several papers including Syracuse (5), Los Angeles (4), Sacramento (4), Chicago (3), and Philadelphia (3) in the USA, Santiago (3) in Chile, Tel Aviv (3) in Israel, and Tshwane (3) in South Africa (table 1). A total of twelve papers (10.5%) studied urban trees within a megacity including four in Los Angeles (Corchnoy *et al.*, 1992; Akbari *et al.*, 2001; Longcore *et al.*, 2004; McPherson *et al.*, 2011), two each in Beijing (Profous, 1992; Yang *et al.*, 2005) and London (Tiwary *et al.*, 2009; Tallis *et al.*, 2011), one each in Cairo (Fahmy *et al.*, 2010), Guangzhou (Jim and Chen, 2008), New York (Morani *et al.*, 2011) and Tokyo (Gao and Asami, 2007).

INSERT FIGURE 2 AROUND HERE

Methods used in urban tree research

A wide range of methods have been used to assess urban trees. Many studies have used multiple methods to collect data (figure 3). Most studies (60%) have employed natural science methods; social science methods and mixed methods were each used by just 13.9% of studies, while 12.1% of studies used other methods including data from previous studies. Under half of the papers (39.1%) used field surveys and samples, followed by literature analysis and simulation (32.2%), existing data base and record searches (24.3%), and field experiments (21.7%). Only 14.8% of studies used surveys, followed by questionnaires (7.8%), interviews (4.3%), and case studies (2.6%). No studies used observations, content/text analysis or focus groups – pointing to possible lacunae in the research (table 3).

INSERT TABLE 2 AROUND HERE

In keeping with a general trend to quantify and assign monetary value to ecosystem services and management, nearly all studies (91.3%) adopted quantitative research strategies, with few using mixed approaches (5.2%) (see figure 3). Most of the identified research papers (79.1%) used mathematical derivations, while 12 (13.9%) used the program i-Tree, and only 3 used the program CITYGreen (figure 3). Of the 115 papers identified, only 42 (36.5%) studied tree values, with some studies using more than one method (see table 4). The cost-benefit analysis method was used by 18 (15.6%) studies, followed by the hedonic pricing method used by 11 (9.5%) of studies, as part of the surrogate market approach. As part of the cost based valuation method, replacement cost and preventative expenditure methods were used by 6 and 3 studies respectively, while the contingent valuation method was used by just 3 studies. Though 32 (28%) studies used a production function approach to quantify the tree services/disservices, only six (5.2%) of them actually assigned a dollar value to the tree services/disservices (e.g. Nowak *et al.*, 2006; Escobedo *et al.*, 2010; McPherson *et al.*, 2011).

INSERT FIGURE 3 AROUND HERE

Benefits provided by urban trees

In this section we refer to the term 'demonstrated'. Demonstrated means that a study not only discussed a cost or benefit, but the study also provides evidence that such a cost of benefit actually exists. Urban trees have been found to provide social, economic, health, visual and aesthetic benefits to humans, with 34 (29.6%) papers discussing these benefits (see table 5). Of the 28 (24.3%) papers examining economic benefits, all but one demonstrated an economic benefit from urban trees. Increasing property value was the most common benefit (demonstrated by 12 papers). Other demonstrated economic benefits included: reduced expenditure on air pollution removal (6 papers); reduced expenditure on storm water infrastructure (3 papers); saved investment in new power supplies (2 papers); reduced heating and cooling costs (2 papers); and reduced time on housing market for selling property (1 paper) among others. Only seven papers (6%) examined social benefits, with five demonstrating an actual benefit which was often associated with increased quality of life. Health benefits were the focus of just five studies (4.3%), with only one study demonstrating the actual benefit of stress relief (Lohr *et al.*, 2004), and one demonstrating the benefits of 'averting respiratory hospital admissions and premature death' (Tiwary *et al.*, 2009). Other papers merely mentioned reduced stress, improved physical health, and faster recovery from illness. Visual and aesthetic benefits were examined by six papers (5.2%), with five demonstrating a benefit - improved scenic quality. Other demonstrated aesthetic benefits included: providing a sense of place and identity, creating seasonal interest, and providing privacy.

INSERT TABLE 3 AROUND HERE

Ecosystem services provided by urban trees

Ecosystem services provided by urban trees have been either demonstrated or simply examined in just over than half the papers assessed (62 papers; 53.9%) (see table 6). This included papers examining ecosystem services related to carbon storage and sequestration, air quality improvement, storm water attenuation, energy conservation, habitat preservation, noise reduction and microclimate amelioration. Most papers examined more than one aspect of ecosystem services associated with urban trees. Of the 62 papers examining ecosystem services, 38 (33%) examined air quality, of which 34 (29.5%) demonstrated changes in air quality from urban trees. Demonstrated air quality improvement included: removing pollutants such as airborne particle matters/suspended particles, ozone, sulphur dioxide, nitrogen dioxide and carbon monoxide followed by filtering air reducing carbon dioxide emissions, producing oxygen, and removing dust and smog (table 6).

INSERT TABLE 4 AROUND HERE

Of the 30 papers examining carbon, 27 (23.5%) demonstrated the effect of storing/sequestering carbon. Of the 25 papers examining the effect of urban trees on microclimate, all found an effect including: providing shade, reducing air temperature, reducing heat island effects, modifying microclimate, reducing wind speed followed by reducing solar radiation, relative humidity, glare and reflection. Of the 20 studies on energy related ecosystem services, 18 (15.6%) found an effect including: reducing household annual energy use, lowering summer energy use, lessening seasonal cooling, and diminishing carbon dioxide emissions from power plants. Only ten papers (8.6%) addressed storm water related ecosystem services, and nine of those demonstrated storm water services such as: reducing the rate and volume of storm water runoff, minimising flooding damage, improving water quality and recharging groundwater. Of the eight papers (7%) that examined noise related ecosystem services provided by trees, five found noise reduction and one found they 'reduced apparent loudness' (Bolund and Hunhammar, 1999). Only seven papers (6%) examined the wildlife habitat benefits of urban trees, and of those five demonstrated this ecosystem service (table 7).

INSERT TABLE 5 AROUND HERE

Ecosystem disservices associated with urban trees

Out of 115 papers reviewed, 18 (15.6%) either demonstrated or merely studied and discussed problems and hazards associated with urban trees (table 7). The most prevalent problems examined were environmental ones (19 papers), of which 17 studies demonstrated problems. Generating and releasing volatile organic compounds was the predominant 'demonstrated' environmental problem (12 papers) followed by: reduced solar access; carbon pollution through landscape and tree management practices; tree-root-induced cracked sidewalks; maintenance problems caused by dropped branches, leaves, flowers and seeds; and pollen. Four papers examined health problems, three of which demonstrated problems - increasing allergies from pollen, and promoting insect and other animal attacks (e.g. nesting birds). Four papers examined visual and aesthetic problems, three of which demonstrated the problem of obscured views. Just one paper examined social problems, including inducing fears of crime, disease, insects and other animals (Dwyer *et al.*, 1992).

Only seven papers (6%) looked at the costs and expenditures aspect of urban trees with six demonstrating the same. Of the various costs involved, those related to planting, establishment, maintenance, management and urban infrastructure repairs were the most commonly studied and demonstrated (table 7).

INSERT TABLE 6 AROUND HERE

Ecology of urban trees

As discussed at the beginning of this paper, the systematic review also addressed the ecology of urban trees, with a view to assessing whether studies have reported interactions between urban tree ecology and tree benefits and costs. Less than half the papers (36.5%) addressed the ecology of urban trees (table 8). Out of these 42 papers, 29 (69%) were related to aspects of tree populations, with 11 papers focusing on assessment of ‘urban forest structure’. Ten papers were related to tree growth, including predicting diameter, height, crown width, and leaf area of trees. Comparatively fewer papers studied and demonstrated issues related to tree selection (12%). Fewer still (9.5%) considered issues such as: the relationships between street-tree characteristics and tree use by urban birds; the influence of urban environments on tree vitality, and developing sustainability indicators for urban trees. The dearth of papers on these topics is taken up in the discussion.

INSERT TABLE 7 AROUND HERE

Discussion

This systematic analytical review of the literature has considered English-language research papers on urban trees. The systematic review has demonstrated that research on urban trees is geographically limited (predominantly North American focused) but is diverse in scope. As shown in figure 2, most research to date has been conducted in cities within the United States (USA). Limited research has been undertaken in cities within other English speaking countries such as Australia, Canada, United Kingdom, South Africa and New Zealand. Such limited geographic distribution could be attributed to several factors including: (1) the database search of this study was limited to English language journals; (2) there may be a greater interest in studying urban and street trees in the USA than elsewhere and; (3) there are comparatively more academics in the USA conducting research on urban and street trees than in other countries. It is likely that the first and third explanations account for most of the observed urban tree research disparities.

In contrast to the narrow geographic distribution of research, urban trees have attracted scholarly research interest from a wide range of natural and social science disciplines, including: arboriculture, forestry, environmental science, ecology, energy, geography, landscape planning / architecture, and economics. This diversity could reflect the complex nature of urban tree services, their wide-ranging implications for built environments, and increasing attention within the academy to what have been termed 'socio-natures' or 'coupled human-natural systems' (Swyngedouw and Heynen, 2003; Swyngedouw, 2010). The diverse cross-disciplinary interest in urban trees also partly accounts for why different studies used different field methods – reflecting disciplinary predilections and biases.

INSERT TABLE 8 AROUND HERE

Papers related to disciplines of arboriculture and forestry, environment and ecology and landscape planning/architecture have dominated the literature. They have focused on an array of urban tree benefits (Tyrväinen and Väänänen, 1998; Gorman, 2004) and services (Rowntree and Nowak, 1991; McPherson *et al.*, 1997; McPherson, 2003; Lohr *et al.*, 2004; Soares *et al.*, 2011) including social, economic, environmental, health, visual, aesthetic and other benefits (Dwyer *et al.*, 1992; Jim and Chen, 2009b; McPherson *et al.*, 2011). However, papers related to the disciplines of geography and economics were more concerned with studying aspects of urban trees related to socio-demographic and socio-cultural concerns, such as land - use and land management issues, socio-ecological issues such as equity of access to ecosystem benefits, and human-environment interactions (Bolund and Hunhammar, 1999; Longcore *et al.*, 2004; Mansfield *et al.*, 2005; Jim and Chen, 2009a; Pandit and Laband, 2010a; Sander *et al.*, 2010) with only two studies actually demonstrating ecosystem services (Kooten *et al.*, 2002; Vesely, 2007).

Researchers' choice of study methods has been influenced by several factors, including: scale of the study area, purpose of the study, and availability of information and data. Field surveys, samples and experiments have primarily been used for analysis where it has been feasible to assess all existing trees (Heisler, 1986a; Corchnoy *et al.*, 1992). Techniques including GIS, aerial photography and remote sensing have been used for relatively larger study areas encompassing regions, metropolitan areas and cross-city, inter-state and international comparative research (Nowak, 1996; Nowak *et al.*, 2001; Myeong *et al.*, 2006; Walton *et al.*, 2008; McPherson *et al.*, 2011). Depending on data availability, researchers have mostly studied either one or just a couple of significant benefits/ecosystem services, and in isolation, rather than comparing all benefits across range of species, cities and climate zones. Consequently, urban tree researchers have yet to establish a uniformly-accepted way to determine the absolute benefit or cost and value(s) of urban tree species across geographical boundaries.

While this systematic review has focused specifically on urban trees, many urban tree papers also discussed urban forest structure. Urban forest structure (including species composition, tree leaf-surface area) across different cities in different climate zones appears to be influenced by number of key factors including: urban morphology (e.g. patterns of horizontal and vertical urban development and distribution of open spaces); natural factors (e.g. temperature, rainfall, soil characteristics, hydrology etc.); and human management systems (e.g. land-use distributions, municipal tree planting programs, maintenance regimes etc.) (Sanders, 1984; Jim, 1992; Chen and Jim, 2008). However, a more systematic review of the 'urban forest literature' should be undertaken to determine the generalisability of these findings, because papers that focus specifically on urban trees are a subset of the urban forest literature.

Urban tree structure and physiology appears to play a strong role in shaping urban tree ecosystem (dis)services. Studies have found that the extent of urban tree benefits and costs, and ecosystem services/ disservices, depends on several factors including: tree structure and physiology (e.g. tree size, trunk diameter at breast height, leaf area, leaf biomass, evergreen vs. deciduous) (Nowak, 1996; McPherson *et al.*, 1997; Nowak, 2008; Escobedo and Nowak, 2009; Tallis *et al.*, 2011); the character of the built environment (e.g. high-density urban form with isolated tree pockets compared with lower-density development with contiguous tree-lined corridors) (NG *et al.*, 2012); and surrounding 'natural' environmental conditions (e.g. visibility, air temperature, precipitation, relative humidity, wind speed etc.) (Heisler, 1986a; Gómez-Muñoz *et al.*, 2010; Hamada and Ohta, 2010; Tsiros, 2010).

Although similarities exist between studies for the generic categories of urban tree benefits (e.g. social, economic, aesthetic), as well as generic ecosystem services (i.e. carbon sequestration, air quality, storm water) and disservices (i.e. social, environmental, and economic costs), the actual extent of specific benefits and services varies considerably across geographical boundaries (Nowak *et al.*, 2002a; McPherson, 2003; McPherson *et al.*, 2005; Stoffberg *et al.*, 2010). For example, in comparison to most U.S. cities, Lisbon's street trees have a higher benefit–cost ratio of 4.48:1, but less than that reported for NewYork City (5.80:1) and Indianapolis (6.09:1) (Soares *et al.*, 2011). In Modesto California, of the ten species evaluated, *Platanus acerifolia* (the London Plane Tree) was the outstanding performer (with benefit-cost ratio 24.3:1) (McPherson, 2003). While *Platanus acerifolia* is widely distributed in cities in both temperate and subtropical climates in Europe, Asia, North America, South America and Australia, we are unaware of any study that has compared the costs and benefits of this urban tree across different cities located within different climatic zones. This tree also has a range of negative health effects (e.g. asthma), resulting in some cities recommending its replacment with other species, thus negating some of the benefits the tree provides.

Also, across geographical boundaries some benefits and ecosystem services provided are more significant than others (McPherson *et al.*, 2005; Stoffberg *et al.*, 2010; Soares *et al.*, 2011). For example, while the value of energy savings ($6.20/tree), carbon dioxide reduction ($0.33/tree) and air pollutant deposition ($5.40/tree) in Lisbon were comparable to several other USA cities, the large values associated with stormwater runoff reduction ($47.80/tree) and increased real estate value ($144.70/tree) were substantially greater than values obtained in U.S. cities (Soares *et al.*, 2011). However, for the purpose of the above analysis in i-Tree software[2] (which is based on US urban tree data), for each of the predominant species in the Lisbon inventory, a corresponding tree species from US reference cities had to be assigned to achieve a "best fit" scenario. So direct comparability was very limited.

Though previous urban tree research has been diverse (as discussed above), there are six significant problems that remain poorly represented in the literature, thus warranting further investigation. These include: (1) assessing whether there are differences in how planted trees and natural vegetation remnants perform within urban environments; (2) assessing the ecosystem services of urban trees within and between megacities across different climatic zones; (3) analysing and comparing tree benefits, ecosystem services, costs and problems within urban environments of different cities in different climatic zones; (4) assessing appropriate economic valuation methods and assessment tools for trees to

[2] i-TREE, UFORE and STREETS are part of the same software programs but not the same models.

accommodate and reflect local environmental and economic conditions; (5) exploring attitudes of municipal managers and residents towards trees within urban environments and; (6) assessing the economic and non-market values attached to urban tree services by urban land managers, decision-makers and local authorities.

In particular, future research might seek to quantify if the same tree species provides different benefits in different parts of the world. It would also be useful to know what information would be required to modify the algorithms of urban tree assessment tools so that the same tool could be used to accurately quantify tree benefits in different cities in different countries with both similar and different climates. For example, there are only a few studies that have employed CITYgreen or i-Tree outside the United States (e.g. Zhang *et al.*, 2006; Peng *et al.*, 2008), and it is not clear whether they successfully modified storm-water algorithms to account for local conditions; nor is it clear if species not endemic to the USA were successfully evaluated by these USA-based applications.

It is also important to understand how stressful urban environments affect the ability of urban trees to provide various ecosystem services, and in turn how this affects the veracity of assessment tools such as CITYgreen, which employ algorithms based on data from non-urban plantations. Such research is essential and will help scholars and land managers to better understand the role and significance of trees within built environments, and to improve education programs designed to influence residents' perceptions of urban trees, thus providing a more-compelling argument for urban greening.

Finally, it is likely that urban tree literature from Japan, China and the emerging industrialised economies of South America and India will contain insights that have not been addressed by this review. This is a limitation, and future research should endeavour to undertake a multi-language review on this topic to address the problematic assumption that most scientific research is published in English-language journals.

Conclusions

Increased urbanisation is destroying natural ecosystems and degrading the environment of urban areas. The services provided by urban trees can mitigate some of these problems. Current urban tree literature addresses a wide range of issues, but is quite limited in terms of geographical distribution. Moreover, the social aspects of urban tree management appear to be poorly represented in the literature. While isolated attempts have previously been made to address some of these issues, it is now essential to initiate a holistic research agenda with the aim of better understanding the cumulative effect of urban tree benefits, tree services and disservices, resident and land manager perceptions, and the impact of these perceptions on decision-makers and local authorities. Additional research to understand and adequately quantify the ecosystem services provided by urban trees outside North America should greatly assist urban land managers in making a better case for urban forestry and urban greening.

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Figure

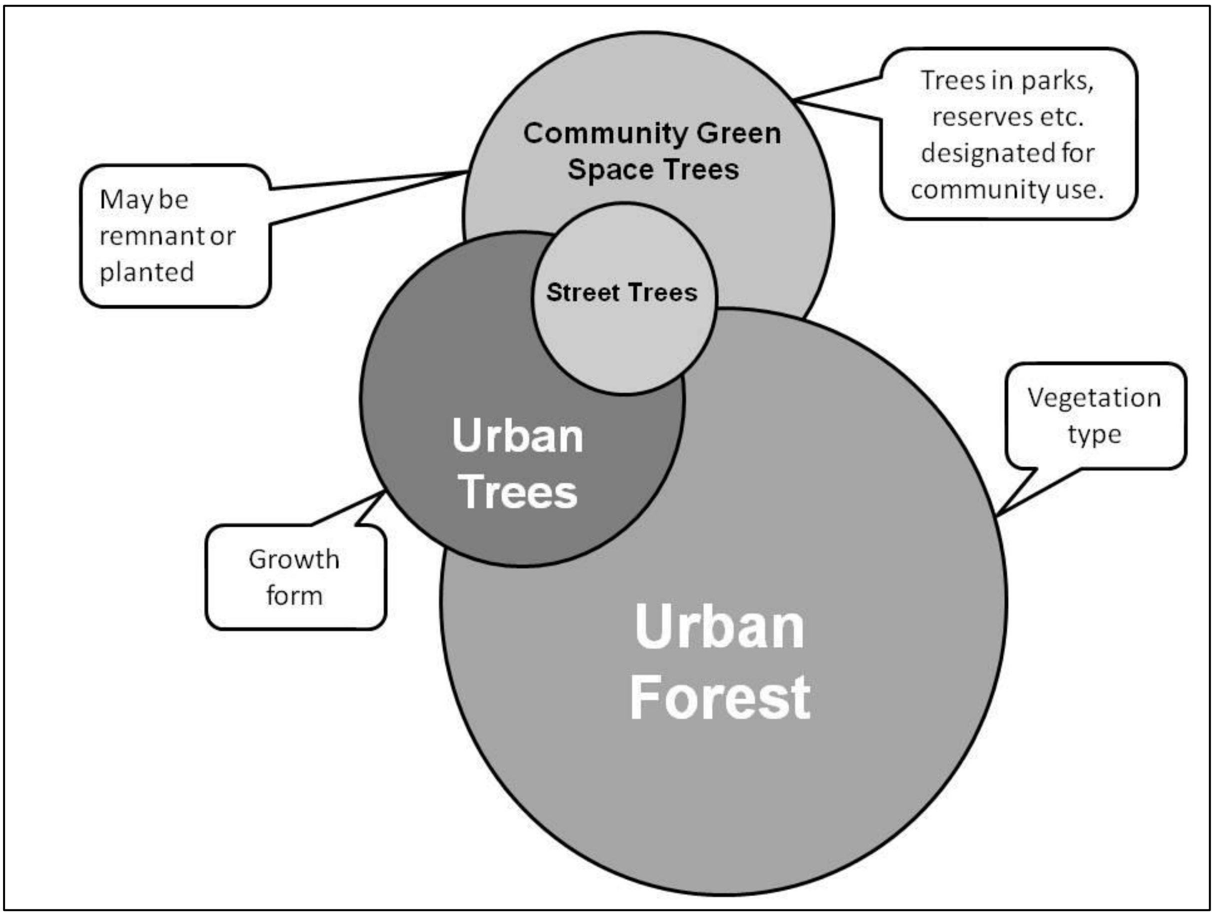

Figure 1 – Conceptual framework explaining the domain of urban trees.

Figure

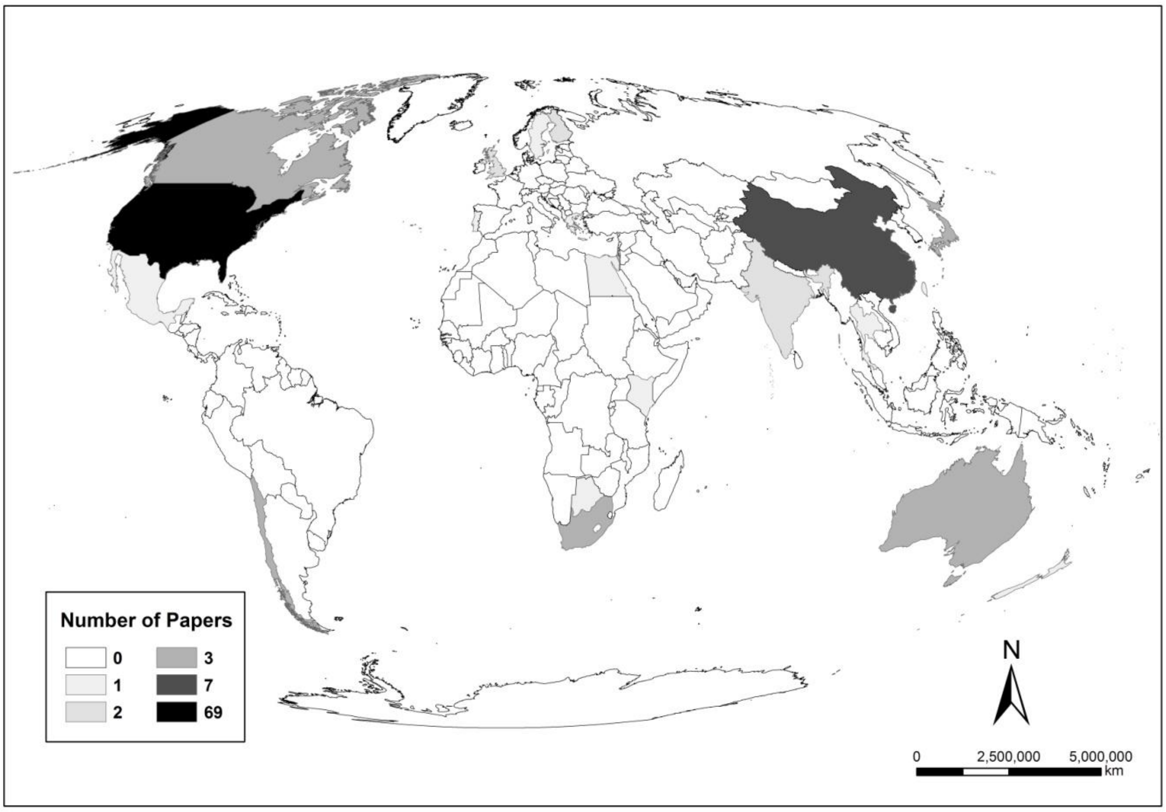

Figure 2 – Geographic distribution of the 115 research papers on urban trees assessed in this study using colour coding that reflects the number of research papers per country.

Figure

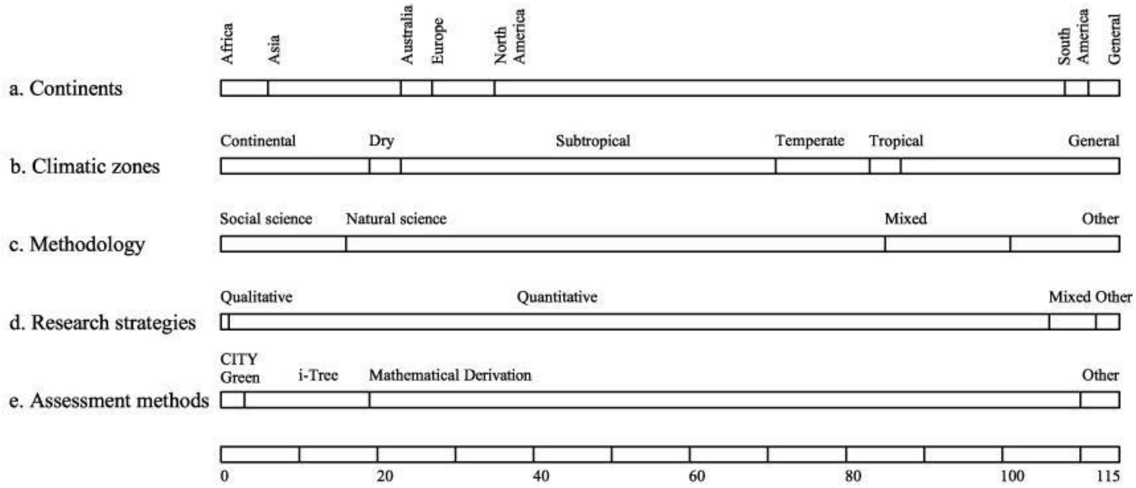

Figure 3 – Aspect wise distribution of the 115 research papers on urban trees assessed in this study.

Tables

Table 1 – Author(s), year, journal and study location of the 115 research papers on urban trees assessed in this study.

Author	Year	Journal	Study location
Akbari, H., et al.	2001	Solar Energy	Los Angeles
Akbari, H.	2002	Environmental Pollution	
Amir, S. and Misgav, A.	1990	Landscape and Urban Planning	Tel Aviv
Anderson, L. M. and H. K. Cordell	1988	Landscape and Urban Planning	Athens
Beatty, R. A. and C. T. Heckman	1981	Urban Ecology	
Benjamin, M.T. and Winer, A.M.	1998	Atmospheric Environment	
Benjamin, M.T., et al.	1996	Atmospheric Environment	
Bolund, P. and S. Hunhammar	1999	Ecological Economics	Stockholm
Brack, C.L.	2002	Environmental Pollution	Canberra
Broadhead, J.S., et al.	2003	Agricultural and Forest Meteorology	
Bruns, D. and N. Fetcher	2008	Journal of Contemporary Water Research & Education	Philadelphia
Carver, A.D., et al.	2004	Environmental Management	Carbondale
Corchnoy, S.B., et al.	1992	Atmospheric Environment Part B-Urban Atmosphere	Los Angeles
Dobbs, C., et al.	2011	Landscape and Urban Planning	Gainesville
Donovan, G. H. and D. T. Butry	2009	Energy and Buildings	Sacramento
Donovan, G. H. and D. T. Butry	2010	Landscape and Urban Planning	Portland
Donovan, G.H. and Butry, D.T.	2011	Urban Forestry and Urban Greening	Portland
Dwyer, J., et al.	1992	Journal of Arboriculture	
Dwyer, J., et al.	2003	Journal of Arboriculture	
Escobedo, F., et al.	2006	Urban Forestry and Urban Greening	Santiago
Escobedo, F., et al.	2010	Environmental Science and Policy	Miami, Gainesville
Escobedo, F.J., et al.	2011	Environmental Pollution	
Escobedo, F. J. and D. J. Nowak	2009	Landscape and Urban Planning	Santiago
Escobedo, F. J., et al.	2008	Journal of Environmental Management	Santiago
Fahmy, M., et al.	2010	Building and Environment	Cairo
Frank, S., et al.	2006	Arboriculture and Urban Forestry	Melbourne
Galvin, M.F.	1999	Journal of Arboriculture	Mount Rainier
Gao, X. and Y. Asami	2007	Landscape and Urban Planning	Tokyo, Kitakyushu
Gómez-Muñoz, V. M., et al.	2010	Landscape and Urban Planning	La Paz
Gorman, J.	2004	Journal of Arboriculture	Philadelphia
Hamada, S. and T. Ohta	2010	Urban Forestry and Urban Greening	Nagoya
Heisler, G.	1986	Urban Ecology	Philadelphia
Heisler, G.	1986	Journal of Arboriculture	

Hildebrandt, E.W. and Sarkovich, M.	1998	Atmospheric Environment	Sacramento
Jaenson, R., et al.	1992	Journal of Arboriculture	
Jim, C. Y. and W. Y. Chen	2008	Journal of Environmental Management	Guangzhou
Jim, C. Y. and W. Y. Chen	2009	Applied Geography	Taipei
Jim, C. Y. and W. Y. Chen	2009	Cities	
Jo, H. K. and E. G. McPherson	1995	Journal of Environmental Management	Chicago
Johnson, A. D. and H. D. Gerhold	2003	Urban Forestry and Urban Greening	
Jonsson, P.	2004	International Journal of Climatology	Gaborone
Jutras, P., et al.	2009	Computers and Electronics in Agriculture	Montreal
Kaya, L. G.	2009	Scientific Research and Essays	
Kirkpatrick, J.B., et al.	2011	Landscape and Urban Planning	
Kong, F., et al.	2007	Landscape and Urban Planning	Jinan
Kooten, G. C. v., et al.	2002	Land Economics	
Liu, C. and Li, X.	2011	Urban Forestry and Urban Greening	Shenyang
Lohr, V., et al.	2004	Journal of Arboriculture	~
Longcore, T., et al.	2004	Urban Geography	Los Angeles
Maco, S. and E. McPherson	2002	Journal of Arboriculture	Davis
Maco, S. E. and E. G. McPherson	2003	Journal of Arboriculture	Davis
Mansfield, C., et al.	2005	Journal of Forest Economics	
Martin, C., et al.	1989	Journal of Arboriculture	Austin
McPherson, E.	2003	Journal of Arboriculture	Modesto
McPherson, E., et al.	1997	Urban Ecosystems	Chicago
McPherson, E. and R. Rowntree	2008	Landscape Journal	
McPherson, E. G.	2010	Arboriculture and Urban Forestry	
Mcpherson, E.G., et al.	1998	Atmospheric Environment	Sacramento
McPherson, E. G., et al.	2011	Landscape and Urban Planning	Los Angeles
Mcpherson, G., et al.	2005	Journal of Forestry	
Millward, A.A. and Sabir, S.	2011	Landscape and Urban Planning	Toronto
Morani, A., et al.	2011	Environmental Pollution	New York
Myeong, S., et al.	2006	Remote Sensing of Environment	Syracuse
Nagendra, H. and D. Gopal	2010	Urban Forestry and Urban Greening	Bangalore
Ng, E., et al.	2012	Building and Environment	Hong Kong
Nowak, D.	1990	Journal of Arboriculture	Syracuse
Nowak, D.	1993	Journal of Arboriculture	Oakland
Nowak, D.	1996	Forest Science	Chicago
Nowak, D.	2008	Arboriculture and Urban Forestry	~
Nowak, D., et al.	2000	Atmospheric Environment	
Nowak, D., et al.	2007	Arboriculture and Urban Forestry	
Nowak, D., et al.	1990	Journal of Arboriculture	Oakland
Nowak, D., et al.	2001	Journal of Forestry	

Nowak, D., et al.	1996	Landscape and Urban Planning	~
Nowak, D., et al.	2005	Journal of Forestry	
Nowak, D. J. and D. E. Crane	2002	Environmental Pollution	
Nowak, D. J., et al.	2002	Journal of Arboriculture	
Nowak, D. J., et al.	2006	Urban Forestry and Urban Greening	
Nowak, D. J., et al.	2008	Arboriculture and Urban Forestry	
Nowak, D. J., et al.	2002	Journal of Arboriculture	
Nowak, D. J., et al.	2008	Arboriculture and Urban Forestry	
Pandit, R. and D. N. Laband	2010	Ecological Economics	Auburn
Pandit, R. and Laband, D.N.	2010	Arboriculture and Urban Forestry	Auburn
Pataki, D., et al.	2006	Global Change Biology	
Peper, P. J., et al.	2001	Journal of Arboriculture	Modesto
Poudyal, N.C., et al.	2011	Urban Forestry and Urban Greening	
Profous, G. V.	1992	Journal of Arboriculture	Beijing
Richards, N. A.	1983	Urban Ecology	Syracuse
Roloff, A., et al.	2009	Urban Forestry and Urban Greening	~
Rowntree, R. and D. Nowak	1991	Journal of Arboriculture	
Sander, H., et al.	2010	Ecological Economics	Minneapolis
Sanders, R. A.	1981	Urban Ecology	Syracuse
Shashua-Bar, L. and M. E. Hoffman	2000	Energy and Buildings	Tel Aviv
Shashua-Bar, L. and M. E. Hoffman	2004	Building and Environment	Tel Aviv
Simpson, J. R. and McPherson, E. G.	2011	Environmental Pollution	Sacramento
Soares, A.L., et al.	2011	Urban Forestry and Urban Greening	Lisbon
Stoffberg, G. H., et al.	2008	Urban Forestry and Urban Greening	Tshwane
Stoffberg, G. H., et al.	2009	Southern Forests	Tshwane
Stoffberg, G. H., et al.	2010	Urban Forestry and Urban Greening	Tshwane
Sudha, P. and N. H. Ravindranath	2000	Landscape and Urban Planning	Bangalore
Sun, W.-Q. and N. L. Bassuk	1991	Landscape and Urban Planning	Ithaca
Taha, H., et al.	1997	Energy and Buildings	
Tallis, M., et al.	2011	Landscape and Urban Planning	London
Thaiutsa, B., et al.	2008	Urban Forestry and Urban Greening	Bangkok
Tiwary, A., et al.	2009	Environmental Pollution	London
Todorova, A., et al.	2004	Landscape and Urban Planning	Sapporo
Tsiros, I. X.	2010	Renewable Energy	Athens
Tyrvainen, L.	1997	Landscape and Urban Planning	Joensuu
Tyrvainen, L., et al.	1998	Landscape and Urban Planning	Joensuu
Tzilkowski, W. M., et al.	1986	Urban Ecology	
Vesely, E.-T.	2007	Ecological Economics	
Walton, J., et al.	2008	Arboriculture and Urban Forestry	Syracuse
Watson, G.	2002	Journal of Arboriculture	~
Welch, J. M.	1994	Landscape and Urban Planning	Boston

Table

Table 2 – Discipline and journal distribution of the 115 research papers on urban trees assessed in this study.

Discipline	Journal titles	No. of Papers	Discipline total
Arboriculture and Forestry (6)	Agricultural and Forest Meteorology	1	48
	Arboriculture and Urban Forestry / Journal of Arboriculture	28	
	Forest Science	1	
	Journal of Forestry	3	
	Southern Forests	1	
	Urban Forestry and Urban Greening	14	
Economics (3)	Ecological Economics	4	6
	Journal of Forest Economics	1	
	Land Economics	1	
Energy (3)	Energy and Buildings	3	5
	Renewable Energy	1	
	Solar Energy	1	
Environment and Ecology (10)	Atmospheric Environment	5	28
	Atmospheric Environment Part B-Urban Atmosphere	1	
	Building and Environment	3	
	Environmental Management	1	
	Environmental Pollution	7	
	Environmental Science and Policy	1	
	Journal of Environmental Management	3	
	Remote Sensing of Environment	1	
	Urban Ecology	5	
	Urban Ecosystems	1	
Geography (2)	Applied Geography	1	2
	Urban Geography	1	
Landscape (2)	Landscape and Urban Planning	19	20
	Landscape Journal	1	
Other (6)	Cities	1	6
	Computers and Electronics in Agriculture	1	
	Global Change Biology	1	
	International Journal of Climatology	1	
	Journal of Contemporary Water Research & Education	1	
	Scientific Research and Essays	1	
Total		115	115

Table

Table 3 - Research methods used in the 115 research papers on urban trees examined in this study.

Details of the methods	Nos.
Surveys	17
Interviews	5
Questionnaires	9
Observations	-
Content / text analysis	-
Case study	3
Focus groups	-
Field surveys & samples	45
Field experiments	25
Existing data base & records search	28
Geographic Information Systems (GIS), remote sensing & satellite imagery	14
Other / literature analysis / simulation	37

Table

Table 4 - Tree valuation methods used to value tree species in the 115 research papers on urban trees examined in this study.

Tree valuation methods	Nos.
Valuation using market prices	0
Surrogate market approach	11
Travel-cost method	0
Hedonic pricing method	11
Substitute goods approach	0
Production function approach	6
Stated preference approach	3
Contingent valuation method	3
Contingent ranking method	0
Choice experiments	0
Participatory methods	0
Cost based valuation method	8
Replacement cost method	5
Preventative expenditure method	3
Opportunity cost of labour method	0
Cost-benefit analysis method	18
Ecosystem services goods indicator	1

Table 5 - Urban tree benefits reported in the 115 research papers on urban trees examined in this study.

Benefits	Discussed	Demonstrated
Social benefits	7	5
making urban environment more pleasant to live, work and spend leisure time	3	2
providing significant outdoor leisure / recreation opportunities	3	2
providing nature in the city	1	1
enhancing quality of urban life	5	3
promoting environmental responsibility and ethics	1	-
building stronger sense of community	1	-
enhancing community's sense of social identity and self esteem	1	-
providing settings for significant emotional and spiritual experiences	1	-
providing opportunities for inner city children to experience nature	1	-
Economic benefits	28	27
saving substantially on fuel expenditure	1	-
increasing land value	3	3
increasing property value	13	12
Increasing rental price	1	1
increasing neighbouring property value	2	1
reducing 'time on market' for selling property	1	1
increasing property taxes	1	-
increasing tourism revenue	1	-
increasing business activity	1	-
contributing to the economic vitality of the city	1	-
providing annual returns on municipal investments	2	1
alleviating the hardships of inner city living for low - income groups	1	-
reducing expenditure on air pollution removal	7	6
reducing expenditure on storm water infrastructure	4	3
saving annual heating and cooling costs	2	2
savings on electricity costs	1	1
avoiding investment in new power supplies	3	2
providing potential for future carbon offsetting trade	2	2
Health benefits	5	2
fewer complications and faster recovery at hospital having windows with tree view	2	-
reducing stress	3	-
improving physical health	2	-
creating relaxed psychological states	3	1
averting premature death	1	1
averting respiratory hospital admissions	1	1
Visual and aesthetic benefits	6	5
providing a sense of place & identity	2	1
creating seasonal interest by highlighting seasonal	1	1

Benefits	Discussed	Demonstrated
changes		
improving scenic quality	6	5
providing privacy	2	2

Table

Table 6 - Urban tree ecosystem services reported in the 115 research papers on urban trees examined in this study.

Ecosystem services	Discussed	Demonstrated
Carbon related ecosystem services	30	27
Storing / sequestering carbon	30	27
Air quality related ecosystem services	38	34
producing oxygen	2	2
filtering air	11	9
removing ozone	18	16
removing carbon monoxide	12	10
removing sulphur dioxide	17	15
removing nitrogen dioxide	15	14
removing airborne particle matters / suspended particles	22	20
removing dust	1	1
reducing smog	3	3
reducing carbon dioxide emissions	9	8
Storm water related ecosystem services	10	9
reducing rate of storm water runoff	10	9
reducing volume of storm water runoff	8	7
reducing flooding damage	4	3
reducing water quality problems	3	2
recharging ground water	1	1
Energy related ecosystem services	20	18
reducing annual energy use	14	11
reducing summer time energy use	5	5
reducing seasonal cooling energy	4	4
reducing carbon dioxide emission from power plants	3	2
Habitat related ecosystem services	7	5
providing habitat for wildlife	7	5
enhancing biodiversity	1	-
providing stability to urban ecosystems	1	-
Noise related ecosystem services	8	5
reducing noise	8	5
reducing apparent loudness	2	1
Micro climate related ecosystem services	25	25
providing shade	16	16
reducing solar radiation	4	4
modifying microclimate	9	9
reducing relative humidity	1	1
reducing air temperature	15	15
reducing heat island effect	10	10
reduction of glare / reflection	3	3
controlling wind	6	6

Table

Table 7 – Urban tree disservices (problems, hazards costs and expenditures) reported in the 115 research papers on urban trees examined in this study.

Disservices	Discussed	Demonstrated
Social problems / hazards	1	-
causing fears of crime	1	-
causing fears of disease	1	-
causing fears of insects and other animals	1	-
causing fears of trees, forests and associated environments	1	1
Economic problems / hazards	1	1
cost too much for the city to maintain	1	1
Health problems / hazards	4	3
increasing allergy attacks by plant pollens	4	3
increasing attack by associated insects and other animals	2	1
Visual and aesthetic problems / hazards	4	3
darkness	2	1
displeasure of messiness and clutter	3	2
obscuring good views	4	3
drip sap or sticky residue on parked cars	1	1
trees look ugly if not maintained	1	1
Environmental problems / hazards	19	17
increasing water and energy consumption for tree maintenance	1	-
generating pollens	2	1
generating green waste	1	-
releasing carbon through landscape management and tree management practices	3	3
generating and releasing volatile organic compounds	15	12
displacing native species	1	-
reducing solar access	4	3
dropping branches, leaves, flowers and seeds	2	2
tree roots crack the sidewalks	2	2
causing drainage problems	1	1
can fall across power lines	1	1
Costs and expenditures	7	6
cost of planting and establishment	7	6
cost of irrigation	3	2
cost of maintenance, pruning, crown thinning, removal etc.	5	4
cost of management / administration	4	3
cost associated with maintaining urban wildlife	1	-
cost associated with forest induced repairs of urban infrastructure	4	3
cost associated with blocked solar collectors	1	-

Table

Table 8 - Urban tree ecology (including tree selection, tree growth and population characteristics) reported in the 115 research papers on urban trees examined in this study.

Other special aspects	Nos.
Studied & discussed other special aspects	42
Demonstrated other special aspects	42
Population characteristic	29
analysis of street tree population	2
assessing and managing the biodiversity of street tree population	1
diversity and stability in street tree population	4
assessment of urban forest structure	11
diversity and distribution of landscape trees	3
comparing urban forest structure of street and park trees	1
measuring and analyzing urban tree cover / urban forest canopy cover	2
comparing formula methods of tree appraisal	1
comparing formula methods for determining leaf area in tree rows	1
estimating forest stand characteristics	1
temporal and spatial variation in garden and street trees	1
shades of green as a measure of greenness of urban forest	1
Selecting trees	5
street tree selection process	1
sampling of urban tree population	2
selecting tree species by accounting their usability after predicted climate changes	1
attitude towards trees and flowers as an element of street vegetation	1
Tree Growth	10
urban forest structure and air pollution removal	1
predicting diameter, height, crown width, and leaf area of street trees	3
tree growth and mortality	1
height diameter relation	1
estimating leaf area and leaf biomass	1
assessing canopy cover over streets and sidewalks in street tree populations	1
planning and management of urban tree	1
predicting street tree morphological parameters using artificial neural networks	1
Other ecological issues	4
relationships between street-tree characteristics and use by urban birds	1
influence of urban environments on forest	1
stressful environment of street tree	1
quality of carbon credit	1
sustainability indicators of urban forests	1