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REVIEW

A review of drivers of tree diversity in suburban areas: Research needs for North American cities

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Abstract: Tree diversity is crucial to urban forest management. More diverse urban forests provide habitat for a wider range of organisms, increase resilience to pests and disease and, in cases where native tree species are well represented, contribute to local biodiversity protection. Studies have shown that tree diversity can peak in the low- to mid-density neighbourhoods found in suburban and peri-urban areas, emphasizing the potential for biodiversity enhancement during and after subdivision development. Most studies quantifying tree species composition in suburban areas focus on one or two major drivers of tree diversity, such as land use, socioeconomics and demographics, or the presence of natural features like parks or greenways. Furthermore, relatively little attention has been paid to the drivers of diversity for the variety of land types that make up the entire urban forest, which represent differences in tree planting and establishment practices, ownership, and maintenance. This paper presents an overview of drivers of tree species composition based on the literature, as well as factors that require further study because they play a role in determining the structure of the (sub)urban forest. These factors are examined in the context of four land types: street, residential property, park, and remnant woodland, and are organized under the following major themes: biophysical characteristics, community design, historical paradigms and influences, municipal management, and demographics and cultures. Based on what is known so far, a research agenda is also presented outlining major gaps in research on urban tree diversity in North America (USA and Canada). The information presented in this paper can thus serve as a guideline to inform urban forest management practices and strategically enhance tree diversity.

Key words: diversity, urban forest, subdivision development, suburbs, urbanization.

Résumé : La diversité des arbres est cruciale à la gestion forestière urbaine. Les forêts urbaines plus diversifiées procurent un habitat à une plus large gamme d'organismes, augmentent la résistance aux parasites et aux maladies, et, dans le cas où les espèces d'arbres indigènes sont bien représentées, contribuent à la protection de la biodiversité locale. Les études ont montré que la diversité des arbres peut atteindre un niveau maximal dans les voisinages de basse et de moyenne densité que l'on retrouve dans les zones suburbaines et périurbaines, mettant en évidence le potentiel d'amélioration de la biodiversité pendant et après les projets de subdivision. La plupart des études quantifiant la composition des espèces d'arbres dans les zones urbaines sont axées sur un ou deux principaux facteurs influant sur la diversité des arbres, tels que l'utilisation des terres, la socioéconomie et la démographie, ou la présence d'éléments naturels comme des parcs ou des couloirs de verdure. En outre, relativement peu d'attention a été portée sur les facteurs de la diversité pour une variété de types de terre composant la forêt urbaine dans son ensemble; ces facteurs représentent des différences dans les pratiques de plantation et d'établissement d'arbres, la propriété, et l'entretien. Cet article donne un aperçu des facteurs de la composition des espèces d'arbres d'après la littérature, ainsi que des facteurs qui ne sont pas bien étudiés, mais qui devraient l'être, car ils jouent un rôle dans la détermination de la structure de la forêt (sub)urbaine. Ces facteurs sont examinés dans le cadre de quatre types de terre (la rue, la propriété résidentielle, le parc, le terrain boisé) et sont organisés sous les principaux thèmes suivants: les caractéristiques biophysiques, la conception de la communauté, les paradigmes et les influences historiques, la gestion municipale et les démographies et les cultures. D'après ce qui est connu jusqu'à présent, on présente aussi un programme de recherche décrivant les principaux domaines où il y a des lacunes en matière de recherche sur la diversité des arbres en milieu urbain en Amérique du Nord (aux É.-U. et au Canada). L'information présentée dans cet article peut servir comme ligne directrice afin d'informer sur les pratiques de gestion de la forêt urbaine et pour stratégiquement améliorer la diversité des arbres. [Traduit par la Rédaction]

Mots-clés : diversité, forêt urbaine, projet de subdivision, banlieues, urbanisation.

1. Introduction

Over the last twenty years, biodiversity conservation and improvement has gained traction among researchers and policymakers given rapid rates of global biodiversity loss (Alvey 2006). Efforts to protect biodiversity have made headway in urban ecosystems, as evidenced by research and urban planning strategies (Savard et al. 2000; Dearborn and Kark 2010; Goddard et al. 2010; Marzok et al. 2014). Urban forests can contain a significant number of tree species native to a particular locale, and have been targeted for diversity enhancement in many cities (Cornelis and Hermy 2004; Alvey 2006; Ordóñez and Duinker 2013). Despite this, biotic homogenization has been identified as a challenge to biodiversity improvements in urban areas, as the same exotic and human-adapted species become more abundant in anthropogenic landscapes (Tait et al. 2005; McKinney 2008).

The purpose of this paper is to review the literature on factors influencing tree species composition in urban areas, organize findings based on general themes and pertinence to suburban

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areas, and present research needs for forest diversity assessment and management. Our definition of tree species composition includes species richness and numbers (or proportions) of native and non-native species. The suburbs were chosen for study because research has shown that residential developments in particular have the potential to house a large amount of native and non-native plant species on private properties, and could thus be effectively targeted for biodiversity enhancement (McKinney 2002; Turner et al. 2005). Suburban areas often exhibit greater landscape heterogeneity compared to dense urban cores and commercial or industrial strips (McKinney 2002), and could therefore be subjected to a wider range of factors influencing tree diversity, and more opportunities for biodiversity gains. Finally, suburban areas are found around the world and, in many cases, represent the regions where the most urban growth is occurring (Gordon and Shirokoff 2014).

The following sections discuss the importance of urban forest diversity and characterize the "suburban forest" and neighbourhood. Our definition of suburban neighbourhood is not an official one, but it is accessible and relevant enough to apply to a broad spectrum of areas found in North American cities. A suburban neighbourhood is a primarily residential area developed between an urban centre and its periphery, characterized by a relatively homogenous grouping of detached or semi-detached houses and green space that were constructed around the same time.

The list of factors influencing suburban tree diversity was generated by consulting studies on urban forest management, urban ecology, and biodiversity in urban and suburban areas. The papers referenced include meta-analyses (Kendal et al. 2012*b*; Beninde et al. 2015), empirical studies (Doody et al. 2010; Bourne and Conway 2014), conceptual frameworks (Steenberg et al. 2015), and other review papers (Chalker-Scott 2015). In addition to a broad literature survey, the authors consulted with an urban planner, an urban forester, and an arborist from the city of Halifax, Nova Scotia, to identify and elucidate factors that are not well studied in the literature. Factors are organized into five main categories or themes, with sub-categories and descriptions accompanied by references to the literature to establish a connection between the driver in question and its influence on suburban forest diversity. Most of the drivers identified were gleaned from studies carried out in Europe, Australia, and North America; this information was then used to inform influences on tree species composition in suburban land types in the North American context, as well as research needs.

2. Diversity in the urban forest

Biodiversity loss has been identified as one of the world's most pressing ecological problems, and is predicted to have long-lasting global effects. The implementation of international treaties like the Convention on Biological Diversity, as well as the passing of national and regional laws (e.g., Species at Risk Act 2003), reflects a growing interest in understanding the causes and consequences of declines in biodiversity, as well as the need to develop solutions (Turner et al. 2005; Cardinale et al. 2012). Among many repercussions, biodiversity loss can hamper ecosystem functioning and stability, decrease ecosystem resilience to environmental perturbations, and reduce ecosystem services (Cardinale et al. 2012). Research and policies aimed at preserving biodiversity often involve protecting large, untouched expanses of natural landscapes. However, improving diversity in urban environments, particularly if native species are prioritized, can have many benefits at both local and global scales by slowing rates of biotic homogenization (Alvey 2006; McKinney 2008).

Consistent with these trends, the concept of diversity has grown increasingly popular in urban forest research and management. Many studies have explored the benefits of enhancing biodiversity in urban areas, and diversity metrics have been incorporated into core tenets and goals for urban forest management plans (UFMPs) (Ordóñez and Duinker 2013). Indeed, more diverse urban forests tend to have greater ecosystem productivity, as well as increased resilience to environmental changes related to climate, invasive species, and diseases (Alvey 2006; Ordóñez and Duinker 2012; Bourne and Conway 2014). It has been shown that the dominance of a single species generally increases the vulnerability of the urban forest to pest and disease outbreaks and increases mass mortality rates of affected trees (Alvey 2006; Lacan and McBride 2008), although there are exceptions in urban areas (Berland and Elliott 2014). Species-rich forests also allow for the establishment of other organisms (birds, insects, mammals, microbes) that contribute to food webs and local ecosystem dynamics (Halifax Regional Municipality (HRM) 2013). A diverse assemblage of fruit-bearing trees can be a convenient and valuable food source for urban communities (Clark and Nicholas 2013). The maintenance of structural diversity is essential in avoiding even-aged conditions, when trees along one street or in one neighbourhood reach the end of their life cycle at roughly the same time (Steenberg et al. 2013). Diverse urban forests can also encourage positive conservation attitudes and educate residents about natural features and processes (Bourne and Conway 2014).

Similar arguments can be made for conserving native biodiversity in urban settings. Increasing numbers of native tree species can promote native bird, mammal, and insect diversity by providing suitable wildlife habitats within the city (Kendle and Rose 2000; Ikin et al. 2013; Barth et al. 2015), although studies have found that an abundance of non-native plants may increase resource availability for some bird species (Davis 2011). From an ethical standpoint, one can argue for the importance of preserving the uniqueness of local and regional ecosystems, particularly if some native species are threatened or otherwise at risk (HRM 2013). Finally, the dominance of non-native and (or) naturalized species over native species is a sign of decreasing ecological integrity due to the potential for non-native species invasion events and endemic species extirpation (Turner et al. 2005; Alvey 2006). It is thus worthwhile to examine the various relationships that can elucidate the *how* and the *why* underlying urban forest structure and diversity.

Although tree diversity can be defined in a number of ways, the most common diversity metrics used in the context of urban forests relate to age- or size-classes, richness (the count of tree species), and evenness (the representation of a given species within the total number of individuals). Most papers quantifying tree species composition in suburban areas focus on one or two major drivers of tree diversity, such as land type and use, residents' education and income, and the presence of natural features like parks or greenways (Hope et al. 2003; Cornelis and Hermy 2004; Godefroid and Koedam 2007; Kendal et al. 2012*a*; Bourne and Conway 2014). Although some studies on plant diversity have identified a wide variety of biophysical drivers of diversity in suburban areas (Čepelová and Münzbergová 2012), they fail to capture relevant socio-political and economic dimensions, including resource availability, administrative decisions, and management traditions. Other studies have examined both habitat-related and socioeconomic drivers of biodiversity in urban areas (McKinney 2008; Kowarik 2011), but do not refer explicitly to the urban forest or to varying temporal factors involved in suburban development. Furthermore, North American urban forest research has paid relatively little attention so far to the range of different influences on tree diversity in the land types making up the suburban forest, such as streets, residential properties, parks, and naturalized areas.

3. Characterizing the suburban forest

This paper characterizes the suburban neighbourhood fairly broadly for the purpose of envisioning its urban forest and the factors that might influence forest structure. There is no universal definition for "suburbia," and the literature contains many conceptions of what constitutes the suburbs (Forsyth 2012). Different forms of

Table 1. The land types on which trees are found in suburban residential areas.

Land type	Ownership	Description
Street	Public	Along roads and boulevards, usually in a straight line; on tree lawns, medians; planted by developer (contractor) or municipality, and maintained by the municipality.
Property	Private	In front and back yards; can be planted in a row (hedges) or more randomly; either established naturally or planted; trees individually maintained by the property owner.
Park	Public	In parks and other open spaces otherwise dominated by lawn or impervious surfaces; planted and maintained by the city or municipality.
Remnant and/ or regenerated	Private or public	In naturalized areas; includes forest buffers and patches in parks, between houses and/or residential developments; the trees are generally not individually maintained.

subdivision development have been described based on street design and patterns, land use, buildings, and the presence of green and grey infrastructure (Wheeler 2015). Other factors, like commuting distance, access and location, modal transport, demographics, and culture have also been used to define suburbia (Forsyth 2012; Gordon and Shirokoff 2014). Various manifestations of suburban development are pervasive worldwide and, in many urban areas, represent the primary land-use type (Wheeler 2015).

Canadian research has identified three types of suburbs: exurbs, which are low density rural areas; auto suburbs, the more "classical" suburban neighbourhoods where most dwellers commute via personal automobile; and transit suburbs, often found in larger metropolitan areas with more advanced public transit systems (Gordon and Shirokoff 2014). For our purposes, the suburbs can include any of these three types. More simply, these areas are primarily residential, parceled into individually owned lots that include detached or semi-detached dwellings and green space (e.g., lawn or garden). When initially developed, suburban neighbourhoods are located between the urban centre and the "countryside," often at the periphery of cities (Forsyth 2012; Turcotte 2008).

Any tree found within a city boundary, whether planted or naturally occurring, can be considered part of the urban forest (Duinker et al. 2015). Urban forests are generally composed either of remnants of natural habitats, or are intentionally planned and created for the purpose of increasing forest cover in cities (Turner et al. 2005; Ordóñez and Duinker 2014). In suburban areas, one might find trees planted along residential streets, in back or front yards on private residential property, and in public open spaces like parks. One might also find trees in areas that were either untouched during development or have naturalized since, including patches of woodland and forest buffers running along property lines. Where suburban communities are gated, all trees found within the community, whether along streets or in open spaces, would be considered private. However, for the purpose of this paper, we are interested in neighbourhoods that are open to the public. We find that trees in suburban areas generally grow on one of four land types that represent differences in development patterns, establishment practices, ownerships, and maintenance: street trees, property trees, park trees, and trees found in remnant stands (Table 1).

Studies have shown that, compared to the countryside and the highly built-up urban core, tree species richness is often greatest in suburban and peri-urban areas (McKinney 2008), although there are exceptions (Dobbs et al. 2013). Researchers have attributed this pattern to the heterogeneity and diversity of suburban landscapes, where multiple habitats (e.g., gardens, streetscapes, public green spaces, remnant woodland, agricultural land) occur in fairly close proximity (McKinney 2002; Hansen et al. 2005). Additionally, private gardens reflect individual planting preferences; diverse ornamental species are planted for horticultural purposes, which often attract a wide range of organisms (Henderson et al. 1998; McKinney 2002; Turner et al. 2005). Evidently, suburban areas can exhibit greater landscape and species diversity compared to other urban areas despite the potential homogeneity of suburban housing design and development.

Suburban population growth is outpacing urban growth in many North American cities. In many regions of the world, suburban development accounts for the largest urban land area (Gordon and Shirokoff 2014; Wheeler 2015). Given that suburban areas have the potential to include a range of landscapes and species, identifying the factors that shape the composition of trees found on various land types can provide insight on biodiversity enhancement in urban areas for planners and policymakers (Dobbs et al. 2013).

4. Drivers of tree species composition

4.1. Biophysical characteristics and natural features

The tree species composition on all land types is influenced in part by ecological factors like climate, geology, weather, and topography, and other natural features. Trees located in areas with potentially high anthropogenic influence, like residential properties and parks, or with high impervious surface cover, like streets, are more likely to feel the effects of biophysical urban stressors (Table 2). Some tree species may be more suitable for street plantings due to higher tolerances to urban stressors like soil compaction, vehicular traffic and pollution, road maintenance, and construction. The success of planted and naturally established tree species can also depend on tolerances to site-specific characteristics like heat and light exposure, soil type and moisture, and topography.

4.1.1. Geography and climate

Like non-urban vegetation communities, the species assemblage of trees that can thrive in cities depends on the local climate, temperature, and rainfall (Kendal et al. 2012*b*, 2014). Dwyer et al. (2000) and Ramage et al. (2013) determined that the composition of urban trees was linked to the native ranges of tree species in the surrounding biome, which is in turn determined largely by temperature and precipitation. The type of soil, rock formation, topographic position, and other site-specific characteristics can also serve as a predictor for tree species composition, particularly in more natural remnant or regenerated areas (Keys et al. 2010). According to Kühn et al. (2004), the number of geological types found within a city is positively correlated with native and overall plant species richness. The authors attributed this trend to other biophysical factors shaped by geology, like soil, relief, and natural habitats, a diversity of which promotes species richness.

4.1.2. Forest patches and habitat edges

The presence of natural features like forest remnants, patches, green corridors, and naturalized spaces can influence suburban tree composition at the neighbourhood level (Jim and Chen 2008). Forest stands located close to urban and suburban areas create transition zones, known as "forest edges," along the perimeters of the contrasting habitat types (Godefroid and Koedam 2003*a*). Forest edges have the potential to house species that are generally not found in forest interiors, emphasizing the potential for these microhabitats to increase both native and non-native tree species (Godefroid and Koedam 2003*a*; Čepelová and Münzbergová 2012). Areas that have undergone rapid and significant anthropogenic alteration are known to facilitate the invasion and propagation of

Table 2. Biophysical drivers of tree diversity related to land type.

Factor	Influence on land type: Remnant	Park	Residential	Street	Key reference(s) and location
Geography and climate	●	●	◐	◐	Kühn et al. (2004, Germany); Ramage et al. (2013, USA); Kendal et al. (2014, Australia)
Forest patches and habitat edges	●	●	◐	○	Honnay et al. (1999, Belgium); Godefroid and Koedam (2003*a*, Belgium); Čepelová and Münzbergová (2012, Czech Republic)
Extreme weather events	◐	◐	◐	●	Roloff et al. (2009, Central Europe); Ordóñez and Duinker (2014, Canada)
Urban site-specific conditions	○	●	●	●	Sæbø et al. (2003, Northern Europe); Vogt et al. (2016)
Tree-species traits and nuisances	◐	◐	●	●	Pearce et al. (2015, Australia); Lyytimaki et al. (2008, Finland)

Note: Filled symbols (●) indicate a strong relationship between driver and tree diversity; half-filled symbols (◐) indicate weak, indirect, or mixed relationship where different studies present conflicting results; open symbols (○) indicate that no relationship has been found to date.

non-native species (Byers 2002; Tait et al. 2005), which can in turn alter the species composition of remnant woodlands by promoting the establishment of exotic species in suburban areas.

Although edges along remnant woodland can serve as habitat for non-native species, studies have shown that preserving remnant patches can conserve native species more effectively than anthropogenic landscapes like planned parks (Gong et al. 2013). Results like these indicate that "near-natural" habitats that have not been subjected to anthropogenic disturbance could mitigate the effects of biotic homogenization by preventing the establishment of non-native species (LaPaix and Freedman 2010; Gong et al. 2013). Larger naturalized areas tend to hold more tree species than smaller ones (Hobbs 1988), and smaller forest patches may be more susceptible to anthropogenic disturbance and species invasions, potentially reducing overall species richness (Honnay et al. 1999).

4.1.3. Extreme weather events

Extreme weather events are predicted to increase in frequency and intensity in the near future due to climate change, and urban planners and foresters need to consider which tree species should be prioritized (Roloff et al. 2009; Ordóñez and Duinker 2014). The range of native tree species is predicted to shift in many parts of the world due to climate change, which could also influence the distribution of these species in city environments (Kendal et al. 2012*b*). Although species traits are important considerations when planning future suburban forests, developers and planners may also be influenced (or constrained) by resource availability, planting traditions, and costs.

Tree species composition can be influenced by the constraints of neighbourhood management due to weather, particularly in colder and wetter climates where street trees are affected by maintenance activities related to stormwater control, snow removal, and road salt applications for de-icing purposes. Some tree species are more sensitive than others to the effects of de-icing salt (including reduction in leaf necrosis and photosynthesis) (Palludan-Müller et al. 2002). With this in mind, municipalities may constrain species selection for street trees based on salt tolerance (Dirr 1976; Sæbø et al. 2003). Snow removal techniques may also cause damage to street trees, which could alter species composition if trees require removal and replacement.

4.1.4. Urban site-specific conditions

Trees found in more urbanized habitats like streets and residential properties are subject to more severe urban stressors than trees in naturalized areas, which likely influences species selection and tree species composition (Table 2). Underground physical stressors relate to the abundance of impervious surfaces, limited planting space, water supply, and soil volume and compaction, while aboveground factors include heat, light, and pollution (Sæbø et al. 2003; Sjöman and Nielsen 2010; Ghao et al. 2016; Vogt et al. 2016). Heat stress can influence all trees in areas where the urban heat island effect (UHIE) significantly increases air temperatures. The UHIE is more often felt in heavily urbanized landscapes dominated by grey infrastructure, emphasizing the importance of choosing tree species capable of adapting to predicted environmental changes related to climate and temperature (Lanza and Stone 2016). Street-tree root and crown growth is often constrained due to existing above- and belowground urban infrastructure, soil availability and quality, and vehicular pollution, influencing species selection decisions (Sæbø et al. 2003). Tree species may also be chosen strategically based on their effectiveness in particulate pollution uptake, depending on the location of the planting site (Freer-Smith et al. 2004). Similarly, residential property owners may select species based on the conditions of their yard. Motivating factors include contributions to the aesthetics of the space, the degree of maintenance required, the amount of space available, site-specific environmental concerns (e.g., drainage, water availability), local climatic conditions, and landscaping priorities (St. Hilaire et al. 2010; Van Heezik et al. 2014; Avolio et al. 2015; Conway 2016).

4.1.5. Tree species traits and nuisances

Although trees provide a multitude of benefits in the urban setting, they can also create problems for urban dwellers and influence species selection due to perceived nuisance or risk (Duinker et al. 2015). Some trees produce more pollen and other allergens (Almas and Conway 2016). Some residents may prefer to plant smaller trees to avoid shading gardens and flower beds (Fraser and Kenney 2000), while others want to avoid damage to infrastructure (Pearce et al. 2015) and habitat provisioning for undesirable wildlife (Pearce et al. 2015). Less severe nuisances include detritus caused by the dropping of leaves or fruit, which requires management and removal (Lyytimaki et al. 2008).

4.2. Neighbourhood and community design

Development patterns and techniques that alter the ecological characteristics of an area, including soil, geology, and natural contours, can shape the composition of both remnant areas and trees located on residential and public properties (Florgård 2000). Factors relating to neighbourhood design include development history and traditions, which influence forest composition on all land types; park and green space creation; and subdivision and housing arrangement (Table 3).

4.2.1. Development patterns, history, and age

How suburban developments are created can play a role in how their urban forest is shaped (Hahs et al. 2009; Cook et al. 2011; Fahey et al. 2012). One factor that distinguishes development patterns is the landscape present immediately prior to urbanization, also known as the pre-urbanized or pre-settlement landscape. It has been shown that urban tree cover, overall tree species richness, and the proportion of native species is greatest in urban areas developed in naturally forested regions when compared to prairie land (Nowak et al. 1996; Fahey et al. 2012), suggesting that remnant and regenerating forest stands significantly influence urban forest composition. Occurrences of native tree species in

Table 3. Neighbourhood and community design as drivers of tree diversity related to land type.

	Influence on land type				
Factor	Remnant	Park	Residential	Street	Key reference(s) and location
Development patterns and history	●	●	●	◐	Hope et al. (2006, USA) Hahs et al. (2009); Fahey et al. (2012, USA); Nitoslawski and Duinker (2016, Canada)
Design of parks and remnant areas	●	●	◐	○	Godefroid and Koedam (2003*a*, 2003*b*, Belgium); Doody et al. (2010, New Zealand); LaPaix and Freedman (2010, Canada)
Urban design, morphology, and land use	○	◐	●	●	Turner et al. (2005, Canada); Tratalos et al. (2007, UK); Bigsby et al. (2014, USA); Bourne and Conway (2014, Canada)

Note: Filled symbols (●) indicate a strong relationship between driver and tree diversity; half-filled symbols (◐) indicate weak, indirect, or mixed relationship where different studies present conflicting results; open symbols (○) indicate that no relationship has been found to date.

the urbanized landscape are spatially correlated with previously forested areas housing these species (Fahey et al. 2012). In a similar vein, Hope et al. (2003) found that urban developments on previously farmed land housed fewer woody plant species compared to areas that had not been cultivated. Residential development encroaching onto once-forested farmland or prairie and desert land will likely require more reforestation than similar types of development encroaching onto woodland (Nowak et al. 1996; Heynen and Lindsey 2003). The tree species composition of subdivision development that occurs in non-wooded areas may therefore be influenced more by the preferences of developers, planners, and residents.

The age of a suburban neighbourhood may also explain its tree species composition, particularly as landscapes mature and residents settle into their homes and plant (or remove) trees according to their own preferences (Hope et al. 2006). The date on which a subdivision was developed may also reflect a particular development pattern or trend that could influence the type and amount of green space it holds, as well as its urban forest structure. Hope et al. (2003) found that newer residential property lots correlated with higher plant species richness, which could reflect changes in technology and preferences related to water use, landscaping, and environmental values. These results illustrate that planting fashions and changing values could explain differences in urban forest composition between neighbourhoods located in the same city, but developed at different times. Similarly, the species composition of trees in the public right-of-way reflects municipal diversity targets enacted at the time of neighbourhood development. Nitoslawski and Duinker (2016) found that streetscapes in newer subdivisions (<15 years) exhibit greater species richness, evenness, and proportions of native species compared to older subdivisions (>40 years), illustrating how neighbourhood age can reflect changes in municipal policy and targets.

4.2.2. Design of parks and remnant areas

Research has shown that forest patches and green spaces can help protect native tree species and enhance overall species richness (Alvey 2006; LaPaix and Freedman 2010; Beninde et al. 2015). Parks found in urban and suburban areas generally support both native and non-native tree species, which could explain why planned green spaces are typically species-rich (Gong et al. 2013; Nock et al. 2013). However, larger parks and remnant areas tend to exhibit higher species richness than smaller green spaces (Godefroid and Koedam 2003*a*, 2003*b*). The shape of a forest patch and habitat edges can also influence its tree species composition, as non-native species are generally found around forest boundaries (Godefroid and Koedam 2003*a*; LaPaix and Freedman 2010; Pennington et al. 2010). Remnant woodlands with a long perimeter and wide recreational trails could therefore increase species richness by promoting the establishment of exotic, opportunistic species, but possibly at the expense of native ones (LaPaix and Freedman 2010). The effectiveness of parks in protecting native tree species may therefore depend on their ecological integrity. Parks and green spaces with a high degree of hemeroby related to intensive landscaping and the presence of impervious surfaces typically do not reflect the natural history of a region, and may not encourage the establishment of native species that are vulnerable to urban stressors (LaPaix and Freedman 2010).

The presence of remnant woodlands adjacent to residential neighbourhoods can present an opportunity for native species establishment on private properties, as species can disperse and become established in lawns and gardens (Doody et al. 2010; Nitoslawski and Duinker 2016). Given this phenomenon, it can also be argued that species in residential gardens may also disperse and become established in adjacent parks or remnant areas. Green space connectivity within a neighbourhood can thus promote tree species diversity by providing sufficient habitat for species to disperse and become established (Rudd et al. 2002). Interestingly, research has also shown that the amount of public green space in a particular neighbourhood can positively correlate with the amount of green space on surrounding private residential properties (Troy et al. 2007). These trends indicate that native tree species richness can be promoted on properties close to parks or remnant woodlands, depending on the planting and maintenance preferences of homeowners (Doody et al. 2010).

The recreational use of parks and other public green spaces may also result in changes in plant and tree diversity. Vakhlamova et al. (2016) found that park visitors influenced overall plant species richness as well as the abundance of exotic species due to anthropogenic disturbances like trampling and waste disposal. Generally, species richness was positively correlated with recreational influence and disturbance.

4.2.3. Urban design, morphology, and land use

The various forms of subdivision development differ in terms of size, street and lot design, land use, building types, and the presence of green and grey infrastructure (Wheeler 2015). The spatial design of a suburban neighbourhood can influence urban forest structure and composition (Bigsby et al. 2014). For starters, the total land area of a neighbourhood can correlate with the amount of land available for tree planting. One might expect that with fewer trees, one would also generally find fewer species. Higher housing and population density has been shown to positively correlate with the extent of impervious surfaces, and negatively correlate with tree abundance as well as native species richness (Luck et al. 2009). These trends may be associated with the size of lots and gardens on residential properties, as well as the type of housing (Tratalos et al. 2007). Studies have shown that larger gardens hold more species than smaller ones (Kendal et al. 2012*a*), and larger gardens are generally positively correlated with vegetation cover and number of large tree species (Smith et al. 2005). Studies have shown that tree species richness is high on residential land (Turner et al. 2005; Dobbs et al. 2013; Bourne and Conway 2014), suggesting that a primarily residential neighbourhood with larger lots may house more tree species on private property.

Neighbourhood design likely has a strong influence on street-tree planting and selection (Table 3). The presence of tree lawns, medians, or road verges along residential streets allows for street-tree planting by the municipality as well as by neighbourhood residents who participate in "guerilla gardening" in front of their

Table 4. Historical influences and paradigms as drivers of tree diversity related to land type.

Factor	Influence on land type: Remnant	Park	Residential	Street	Key reference(s) and location
Colonial influences	◐	◐	◐	◐	Stewart et al. (2004, New Zealand); Dobbs et al. (2013, Australia); Kirkpatrick et al. (2013*a*, Australia)
"Naturalness" agenda	○	●	◐	●	Ranta and Viljanen (2011, Finland); Conway and Vecht (2015, Canada); Toni and Duinker (2015, Canada)
Climate change	◐	●	◐	●	Rostami (2011, Canada); Leichenko and Solecki (2013, USA); Ordóñez and Duinker (2014)

Note: Filled symbols (●) indicate a strong relationship between driver and tree diversity; half-filled symbols (◐) indicate weak, indirect, or mixed relationship where different studies present conflicting results; open symbols (○) indicate that no relationship has been found to date.

house but in the public right-of-way. Depending on the development history, the majority of the canopy in some suburban developments is found on private properties and "pedestrian corridors" between residential lots (Nitoslawski and Duinker 2016). These neighbourhoods may have lower tree species richness simply due to the lack of street trees. Infrastructure may also restrict species selection in the public right-of-way. The presence of overhead power lines is an important consideration when planting along streets, as height restrictions and crown shape may constrain species selection. Neighbourhoods with buried power lines may therefore exhibit greater species richness and size diversity, as smaller and larger species can be planted without risk of damage from and to lines. Similarly, narrower streets and verges may constrain species selection to favour smaller trees with narrow crowns (Sæbø et al. 2003).

4.3. Historical paradigms and influences

Given the multidisciplinary nature of managing trees in the city, the field of urban forestry has piqued the interest of academics, scientists, policymakers and practitioners. These groups reflect a multiplicity of values, priorities, influences, trends, and challenges that shape the conceptualization and management of urban forests. The definition of "urban forestry" itself is highly contextual and may depend on language, land-use history, and research traditions (Konijnendijk et al. 2006). Tree species composition, particularly that found on public land, is therefore inevitably influenced by historical and contemporary trends as well as the cultures and priorities of the many professionals who engage in urban tree care and management (Table 4).

4.3.1 Colonial history and influence

Cities located in countries with colonial histories may display European influences on tree species composition on both public and private properties. In Canada, tree species in cities have traditionally been chosen from a pool of primarily European species, reflecting the country's colonial history and landscape influences (Turner et al. 2005; Ordóñez and Duinker 2013). Some species have since naturalized and grow in parks and remnant woodland (NIPpaysage Landscape Architects et al. 2008). In Melbourne, Australia, Dobbs et al. (2013) discovered that most non-native tree species planted in the city are endemic to Europe, and dominate residential properties and streets. Colonial settlers may also have influenced species choices for planting for pragmatic purposes. Large, native shade trees were often seen as a nuisance to builders and farmers, a perspective that some researchers argue has pervaded Australian society to the point where native tree species are generally disliked (Kirkpatrick et al. 2013*a*). Christchurch, New Zealand, was designed as an "English garden city," and non-native species have traditionally outnumbered native species in residential gardens (Stewart et al. 2004). These trends may be changing as some citizens begin to recognize the importance of protecting native species in urban areas (Kirkpatrick et al. 2013*a*). In Christchurch, urban dwellers are increasingly promoting the natural heritage of the area by planting native species on public and private residential properties and restoring woodland habitat.

4.3.2. "Naturalness" in the urban forest

The concept of naturalization has become an important component of urban forest management in recent years, as researchers and practitioners recognize the importance of preserving ecological integrity in urban ecosystems (Kendle and Rose 2000; Ordóñez and Duinker 2012; Toni and Duinker 2015; Almas and Conway 2016). However, the naturalness agenda is still hotly debated as some researchers question the ecological benefits of prioritizing native tree species for planting, and argue that the presence of non-native, non-invasive species is vital for urban biodiversity enhancement (Kendle and Rose 2000; Chalker-Scott 2015; Sjöman et al. 2016). Despite the lack of consensus, frameworks for naturalizing urban woodlands have been conceptualized and applied (Toni and Duinker 2015). Furthermore, many UFMPs, which present a set of principles, guidelines, targets, and implementation strategies meant to promote a healthy and sustainable urban forest, have set guidelines and targets for native species plantings and species-at-risk protection (HRM 2013; Ordóñez and Duinker 2013). It has been shown that the conservation and enhancement of remnant woodlands can protect native tree species and encourage the retention, dispersal, and establishment of species in adjacent residential areas (Doody et al. 2010; Ranta and Viljanen 2011). The trend towards increasing the naturalness of the urban forest, and the incorporation of concrete targets in municipal planning, could increase native species representation in streets and other public spaces where planting occurs (Conway and Vecht 2015).

Monocultures in street-tree plantings, which reflect distinctly "unnatural" tree establishment processes, are now widely recognized as detrimental to the resilience of the urban forest (Raupp et al. 2006). This is in part due to the mass tree mortality rates from diseases and insects experienced in North America over the last century (Poland and McCullough 2006; Ordóñez and Duinker 2013). Dutch elm disease has devastated urban forests throughout the United States and Canada, especially in cities where stately elms were predominantly planted in the streets for shade purposes (Steenberg et al. 2013). Ash trees were also commonly planted together alongside roads and in residential developments; these have been decimated with the arrival of the emerald ash borer (Poland and McCullough 2006; Herms and McCullough 2014). As a result, urban foresters have diversified municipal street tree planting lists and have included more native species (Raupp et al. 2006). Although tree species diversification in city streets will likely occur primarily in newer developments, the tree species richness in the streetscapes of older suburban neighbourhoods may increase when trees are removed and replaced due to decline and death.

It is not clear whether targets regarding native species prioritization and species diversification will influence the planting preferences of residents on private properties. Conway and Vecht (2015) found that some retail garden centres only stocked native tree species, citing customer demand and the influence of native plantings in the public right-of-way. However, despite apparent support for native species, residents may not be knowledgeable enough to recognize a native tree or its ecological importance,

Table 5. Administrative and municipal drivers of tree diversity related to land type.

	Influence on land type				
Factor	Remnant	Park	Residential	Street	Key reference(s) and location
Resource availability	○	●	●	●	Sydnor et al. (2010, USA); Pincetl et al. (2013, USA); Conway and Vecht (2015, Canada)
Targets and policies	◐	◐	○	◐	Santamour (1990, USA); Ordóñez and Duinker (2013, Canada); Almas and Conway (2016)
Management and operations	●	●	◐	●	Jim and Liu (2001, China); Pauleit et al. (2002, Europe); Steenberg et al. (2013, Canada); Almas and Conway (2016)
Professional cultures and priorities	○	●	●	●	Kirkpatrick et al. (2013*a*, Australia); Conway and Vecht (2015, Canada)

Note: Filled symbols (●) indicate a strong relationship between driver and tree diversity; half-filled symbols (◐) indicate weak, indirect, or mixed relationship where different studies present conflicting results; open symbols (○) indicate that no relationship has been found to date.

emphasizing the importance of education and local community engagement (Doody et al. 2010). Interestingly, research on urban dweller attitudes about green space management priorities found that park visitors valued more natural settings, including native tree species selection and more haphazard planting (Jennings et al. 2016).

4.3.3. Contemporary challenges

Climate change is predicted to directly affect trees in urban and suburban areas. The occurrence of temperature fluctuations, wildfires, extreme weather events, and species invasions threaten the stability and productivity of urban forests (Ordóñez and Duinker 2012). Tree species that are adapted to warmer climates will likely tolerate increasing temperatures, and as such may become more common in urban environments that also experience the UHIE (Leichenko and Solecki 2013). Climate change will therefore pose challenges for some non-adaptive native tree species (Ordóñez and Duinker 2014). Remnant woodlands adjacent to suburban neighbourhoods may be vulnerable to drought and wildfire (Leichenko and Solecki 2013). As mentioned above, a more homogenous urban forest dominated by few tree species will probably be less resilient to the effects of climate change and experience higher tree mortality rates, especially due to pests and diseases (Ordóñez and Duinker 2014).

It is to be expected that some tree species will fare better than others in the face of environmental change (Rostami 2011). Urban foresters can anticipate stressors related to climate change to which trees will be exposed (e.g., wind, drought), and choose species accordingly. Species with southern ranges but higher tolerances to stressors in northern environments (e.g., frost) may also be selected, thus shaping future tree species composition (Ordóñez and Duinker 2014; Lanza and Stone 2016). Furthermore, foresters and managers can mitigate potential climate impacts on tree diversity by protecting remnant forest patches, enhancing habitat connectivity in the urban forest, and increasing the population sizes of vulnerable tree species (Ordóñez and Duinker 2014). Some municipalities have also entertained the notion of assisted migration, or the intentional planting of species outside their natural range in anticipation of biodiversity loss and other climatic changes (Almas and Conway 2016; Chagnon Fontaine and Larson 2016).

4.4. Administration and municipal management

The drivers of urban forest structure related to administration and municipal management primarily influence trees planted on public land, namely streets and parks. However, the procurement and administration of tree resources can play a large role in influencing tree species composition on private properties. Residents often buy trees from local nurseries and garden centres, thus dictating the types of trees available for planting (Summit and McPherson 1998; Zipperer 2008; Conway and Vecht 2015). Municipal factors affecting street and park trees also relate to the availability and cost of tree species (and cultivars) in nurseries and larger wholesalers (Table 5). Although municipal goals and policies may guide and inform decision-making for species selection and diversification, it is inevitably the implementation and operationalization of UFMPs that will shape species composition on public land.

4.4.1. Resource availability

The types of trees that residents choose to plant depend partly on cost and personal preferences, but also on the availability of species at local nurseries and retailers. In the city of Toronto, Canada, Conway and Vecht (2015) found that ornamental tree species like the non-native Japanese maple (*A. palmatum*) are most favoured by homeowners buying trees from these stores; garden centres also identified the popularity of container gardening as a deterrent for stocking larger tree species. Customer demand thus influences tree species availability in nurseries a great deal (Conway and Vecht 2015, p. 6). Despite buyers' propensity towards ornamental species, half of the nurseries examined in this study stated that they were more likely to stock and recommend native tree species to customers, which also may be linked to store location and customer demand, as well as a shift in planting fashions towards prioritizing native species. On a neighbourhood level, the age of development may also correlate with the types of trees found on private properties due to nursery availability. In Los Angeles, the number of tree species, particularly non-native ones, offered in local stores increased significantly from 1990 to 2011 (Pincetl et al. 2013). This trend could be occurring due to changes in customer demand, suggesting that neighbourhoods established more recently may exhibit rather different species composition patterns on residential properties when compared to older neighbourhoods.

Although landscapers and contractors sometimes buy trees from local nurseries, planting projects occurring at the neighbourhood or municipal level for streets, parks, and other public areas often have greater access to regional wholesalers due to the sheer number of trees needed (Conway and Vecht 2015). Disparities can exist between what urban foresters (or contractors) request for large-scale plantings and the availability of tree species in nurseries, leading to substitutions or sourcing of trees from another region (Sydnor et al. 2010; Conway and Vecht 2015). Depending on the planting priorities of the contractor or project, more ecologically favourable species (that are perhaps limited in quantity due to low demand) could be replaced with species that are already common in the cityscape or are not as well adapted to the climate and physical environment (Conway and Vecht 2015).

4.4.2. Urban forest targets and policies

Given the diverse benefits that urban forests provide, cities are recognizing the importance of engaging in strategic urban forest management. One of the ways in which municipalities can do so is to create a UFMP. In most cases, UFMPs outline policies and rules to enhance the diversity of the public urban forest, often according to established standards (Santamour 1990; Ordóñez and Duinker 2013). These biodiversity guidelines, if implemented effectively and followed correctly by multiple actors (e.g., contractors, landscapers, foresters, community planting groups), play an important role in determining the species composition of trees planted on public land. For example, Almas and Conway (2016) found that municipalities adhering to a UFMP were more likely to enhance native species representation in the canopy compared to municipalities without a UFMP.

The content and specificity of UFMP goals for urban forest diversity may vary among cities. Many targets are inspired by the pervasive "10–20–30" rule, where no more than 10% of any species, 20% of any genus, and 30% of any family should be planted in a neighbourhood (Santamour 1990). Others are more ambitious, and incorporate goals for native and heritage species representation (Ordóñez and Duinker 2013). Some municipalities will inevitably have a wider palette of native tree species to choose from for planting due to ecological factors, which could be reflected in diversity targets. However, in a review of 14 Canadian UFMPs, Ordóñez and Duinker (2013) found that although all plans sought to promote naturalness in the urban forest, their objectives were vague and there was little mention of actual numerical targets. Imprecise or ambiguous targets for tree species selection may reflect a lack of knowledge about the composition of urban trees, and can result in disorganized and inefficient management practices.

The species richness and abundance of remnant trees in suburban areas may also be influenced by the lack of regulations surrounding suburban development, particularly if encroachment into woodland is an ongoing problem (McWilliam et al. 2014). For example, provisions for retaining forest buffers and riparian woodland in Halifax, Canada were introduced in municipal bylaws in 2006, but only apply to current projects and newer subdivision developments (HRM 2013). Although laws were recently passed granting the municipality the right to protect remnant woodlands in older suburban areas, implementation is hampered by a lack of resources. This illustrates how newer suburban developments may benefit more than older neighbourhoods from recent regulations aiming to protect native tree stands and tree canopy.

4.4.3. Urban forest management and operations

The decisions made and strategies used in the operationalization of UFMP goals are imperative to the shaping of urban forest composition (Almas and Conway 2016). For streets and parks, factors that may influence the selection and success of planted trees can relate to the content of tree planting bids and contracts (including budgets), the seasonal planting schedule and time of contract completion, planting and aftercare practices and standards, and the stipulations of warranty provisions for damaged or dead trees (Pauleit et al. 2002; J. Charles, personal communication, 2016).

Tree ownership and land tenure also influence the management of tree diversity. Trees in suburban areas grow on multiple land types, reflecting differences in planting practices and ownership (Nowak 2012). Regulations and bylaws related to jurisdiction and oversight responsibilities for tree planting, removal, replacement, and maintenance vary across cities and countries, and can reflect potential differences in tree species assemblages (Jim and Liu 2001). For example, some municipalities have private tree protection bylaws, where the removal of large trees on private property is regulated and requires a permit (City of Toronto 2013).

In some cities, subdivision bylaws require a development officer's approval for street-tree species to be planted in new developments. However, it is difficult to determine whether these are enforced, and subsequently whether diversity targets are being met (J. Charles, personal communication, 2016). For cities that do not have established species diversity policies, tree species selection and composition on public property generally falls into the hands of arborists, developers, and landscape architects (J. Simmons, personal communication, 2016). In this case, the species composition of trees on both public and private land will likely depend on the preferences and priorities of practitioners.

Resource availability is a major consideration in the operationalization of urban forest diversity objectives (Almas and Conway 2016). Partnerships between municipalities and universities, industry, and community groups not only encourage resource and knowledge sharing, but also foster public stewardship of the urban forest. UFMP goals for urban forest diversity that are defined and implemented at the neighbourhood level may also encourage citizen engagement, which can be important for achieving diversity targets (Steenberg et al. 2013, 2015). Neighbourhoods that do not hold many trees on municipal land would benefit from community-based strategies geared towards enhancing tree diversity on both public and private properties. For example, initiatives encouraging residents and community groups to plant trees in the road verge or in public spaces can enhance neighbourhood tree species diversity if implemented according to municipal guidelines and urban forest composition targets, and if citizen preferences are taken into account (Jennings et al. 2016). If neighbourhood diversity targets are set and citizens are educated and consulted about tree species selection, it is more likely that appropriate species will be planted on both public and private property, enhancing overall tree diversity.

4.4.4. Professional cultures and priorities

Many practitioners are involved in the research, planning, and management of urban forests. Differences in priorities and agendas can influence species selection and overall species richness in neighbourhoods, and can vary depending on where trees are being planted (Conway and Vecht 2015). Kirkpatrick et al. (2013*b*) found that urban planners did not prioritize biodiversity conservation as much as arborists do when selecting street trees, indicating that planners may not consider street trees as an important contribution to wildlife habitat compared to trees on other land types. In comparison, municipal forestry staff in Toronto, Canada, prioritize native species and largely base their tree planting decisions on the species composition of nearby trees, looking to increase "both neighbourhood and district-wide diversity" (Conway and Vecht 2015, p. 6).

When selecting a tree species to plant, landscape architects tend to prioritize available space, aesthetics, sun exposure, slope, and intended use before both species diversity and native status (Conway and Vecht 2015). This indicates that the landscape architect, whose work is not necessarily tree-focused, may not consider the contribution that their selected trees make to the overall diversity of the neighbourhood canopy.

4.5. Neighbourhood demographics and cultures

Socioeconomic and cultural drivers of suburban tree diversity manifest themselves mainly at the residential property level (Conway and Bourne 2013), although some studies have examined similar relationships pertaining to street and park trees (Pedlowski et al. 2002). Many of the trees found on residential properties are planted by homeowners and reflect personal planting priorities, maintenance preferences, and environmental values. These factors can be shaped by demographic characteristics such as education, income, ethnicity, and gender. The tree species composition on private properties can also be influenced by factors determined at the street or neighbourhood scale that relate to fads and social norms (Table 6).

4.5.1. Income and economic status

Household income seems to influence homeowner decisions regarding tree planting and removal on residential properties. Researchers have found that higher income earners are more likely to plant trees to enhance the aesthetic beauty of their garden or home, and to choose tree species according to fashion. They also value trees based on the ecosystem services that they provide, including food and habitat for wildlife (Kirkpatrick et al. 2012). According to Kinzig et al. (2005), groups with similar socio-

Table 6. Social, cultural, and economic drivers of tree diversity related to land type.

	Influence on land type				
Factor	Remnant	Park	Residential	Street	Key reference(s) and location
Income	○	◐	●	◐	Pedlowski et al. (2002, Brazil); Hope et al. (2003, USA); Martin et al. (2004, USA); Kinzig et al. (2005, USA); Kirkpatrick et al. (2012, Australia)
Property ownership	○	○	◐	○	Heynen et al. (2006, USA); Landry and Chakraborty (2009, USA); Kendal et al. (2012*a*, Australia)
Ethnicity and nationality	○	○	●	○	Fraser and Kenney (2000, Canada); Kinzig et al. (2005, USA)
Education	○	◐	●	◐	Luck et al. (2009, Australia); Kirkpatrick et al. (2012, Australia)
Gender and age	○	○	◐	○	Kendal et al. (2012*a*, Australia); Kirkpatrick et al. (2012, Australia)
Fads and social norms	○	○	●	○	Julien and Zmyslony (2001, Canada); Nassauer et al. (2009, USA); Goddard et al. (2013, UK)

Note: Filled symbols (●) indicate a strong relationship between driver and tree diversity; half-filled symbols (◐) indicate weak, indirect, or mixed relationship where different studies present conflicting results; open symbols (○) indicate that no relationship has been found to date.

economic and cultural status tend to group together, suggesting that the median household income of a particular suburban neighbourhood could reveal trends related to planting preferences on private and public land. Some researchers suggest the existence of a "luxury effect," whereby wealthier groups either favour diverse landscapes for settlement or create and maintain their own (Hope et al. 2003). According to Hope et al. (2003) and Martin et al. (2004, USA), perennial plant species richness is generally greatest in urban areas with higher family incomes and socioeconomic status. Pedlowski et al. (2002) also discovered that wealthier neighbourhoods contain more street and private property tree species than poorer neighbourhoods. In this case, the authors surmised that tree species composition is influenced by homeowner planting and involvement, as well as by municipal policies that may favour wealthier groups for public plantings (Pedlowski et al. 2002).

4.5.2. Property ownership

Little empirical research has been carried out regarding the influence of property ownership on tree species composition. Kendal et al. (2012*a*) discovered that neighbourhoods with more renters had a greater number of tree species on private properties. The authors attributed this pattern to the fact that different renters might plant different species in the same yard, contributing to overall species richness over time. However, studies have also shown that higher proportions of renters can also correlate with lower canopy cover in residential areas, due to lower-income renters having fewer resources and less authority to plant and maintain trees on private property (Heynen et al. 2006; Landry and Chakraborty 2009). In a similar vein, neighbourhoods with more renters may have fewer planted trees and lower overall species richness.

4.5.3. Education

The education level of homeowners in suburban areas can also correlate with species richness on private property, although it is important to note that education often co-varies with income and socioeconomic status (Luck et al. 2009). According to Kirkpatrick et al. (2012), groups with both higher education and income levels were more likely to perceive trees as positive contributions to the urban landscape and understand the benefits of trees, which could influence tree species choices and shape tree species diversity on private properties (Luck et al. 2009; Meléndez-Ackerman et al. 2014).

4.5.4. Gender and age

Research has shown that, along with income and education, gender and age may also shape tree species choices on private properties. Kirkpatrick et al. (2012) found that females were more likely to value trees for a wide range of reasons, including intrinsically and pragmatically, and be most knowledgeable about tree species. Homeowner age can also play a role; studies have shown that older, retired people spend more time tending to their garden, which could increase species richness depending on gardening priorities (Kendal et al. 2012*a*).

4.5.5. Ethnicity and nationality

Demographics related to culture, nationality, and ethnicity can also correlate with neighbourhood tree species composition through variability at the household level. Homeowners with different cultural backgrounds can internalize contrasting perceptions of the urban forest, which are demonstrated through their preferences related to tree planting and yard maintenance (Fraser and Kenney 2000). Research in Toronto has shown that homeowners of British origin gravitated towards shade and ornamental trees, Italian and Portuguese community members tended to favour fruit trees, and those of Chinese origin generally planted the fewest trees (Fraser and Kenney 2000). These results indicate what different cultural groups value in urban trees. Some plant trees for practical purposes like shade or food, while others choose species based on aesthetics and level of maintenance. The authors draw a connection between current urban landscaping practices and traditional land use and histories; people tend to value the natural features and processes associated with their cultural heritage. A suburban neighbourhood inhabited by a diverse group of people with distinct cultural values and traditions could thus create a more diverse landscape with high species richness, driven by "bottom-up" planting decisions (Kinzig et al. 2005).

4.5.6. Fads and social norms

Landscape elements and maintenance activities that could influence the tree species composition of the neighbourhood forest include gardening, lawn mowing, trampling, encroaching onto remnant woodland, planting location and, evidently, species choices (Hobbs 1988; McWilliam et al. 2014). Although individual ethnic and cultural norms can significantly influence preferences for yard maintenance and tree planting, social rules operating at the neighbourhood level can also play a role in determining urban forest structure. It is well documented that homeowners are either directly or indirectly influenced by the landscape, gardening, and planting practices of their neighbours (Nassauer et al. 2009; Goddard et al. 2013). Researchers have proposed that replication or mimicry can occur at the street level, when particular landscape elements in front or back yards are "perceived and interpreted as a case or rule," and subsequently are adopted by other residents (Julien and Zmyslony 2001, p. 347). Residents who do plant trees may (unintentionally) encourage neighbourhood homogeneity related to planting location and tree species choice, potentially limiting overall tree species richness (Jim 1993). Summit and McPherson (1998) found that homeowners tended to plant trees within five years of residency, suggesting that in the case of a new subdivision, the tree species composition of private properties in suburban neighbourhoods could be determined fairly soon after development and initial settlement.

Homeowner values about landscapes and tree species choices are also driven by dominant environmental paradigms and planting traditions. Kirkpatrick et al. (2013*a*) found that residents in Australian cities often made a conscious effort to remove non-native trees from their property, suggesting a backlash against outdated colonial landscape influences and a propensity towards intrinsically valuing "indigeneity" more than non-native tree species (Kirkpatrick et al. 2013*a*, p. 175). Increasing pressure for urban dwellers to adopt more environmentally responsible behaviour may result in a newfound appreciation for nativeness in the urban landscape.

5. Research needs

While this paper has presented a breadth of factors that could influence tree diversity in suburban areas, it is evident that some drivers are better studied and more relevant than others for trees in North American cities. Nevertheless, considering differences in land types and spatial contexts within suburban residential areas is vital for revealing and understanding patterns in tree species composition at the neighbourhood level. Although it is useful to examine drivers of tree species diversity separately for the purpose of identifying the degrees of influence and importance for different land types, these factors are not necessarily disconnected. Interactions between drivers should be kept in mind when assessing tree diversity, particularly where household-level and neighbourhood-level factors come into play.

It would be worthwhile to carry out qualitative studies exploring the value of native tree species for residential homeowners, particularly because it has been shown that native species can disperse from remnant woodland and establish on residential properties (Doody et al. 2010). Urban dwellers experience and contribute to the private urban forest in a variety of ways (Avolio et al. 2015; Pearce et al. 2015). It is therefore difficult to extrapolate or generalize patterns between demographic factors and manifestations of tree diversity. Exploring links between homeowner values, management decisions, and resulting species selection and composition in different neighbourhoods and cities can elucidate more contextual and place-specific considerations (Conway 2016). Furthermore, determining the role of education and community engagement regarding native species protection and overall diversity enhancement can highlight important factors that shape how private gardens might contribute to urban biodiversity. Given the lack of consensus on whether property ownership influences tree diversity, future studies examining urban forest values of renters and homeowners could be carried out to identify barriers to biodiversity enhancement and to decouple the influence of other socio-demographic variables from property ownership.

Few studies have examined how land-use design and planning could influence tree species selection and urban forest diversity. Examining the extent to which urban morphology plays a role in determining tree arrangements and composition is vital for creating suburban neighbourhoods that integrate green infrastructure effectively to maximize its benefits. One can argue that the presence of road verges and tree lawns encourages street-tree planting, yet there is little to no empirical evidence about how the size, shape, and design of sidewalks and roads could influence tree diversity. It would also be worthwhile to test how specific neighbourhood and residential property design could increase green-space connectivity and promote biodiversity (Cerra and Crain 2016). In doing so, priorities for urban planners, foresters, and developers can be identified to inform plans for future subdivision developments where citizens will benefit from effective green and grey infrastructure design.

Exploring how municipalities, developers, urban foresters, and other stakeholders communicate and cooperate during subdivision development can shed light on policies, operations, and compliance issues related to tree species selection, planting, and maintenance. Determining whether discrepancies exist between tree species planting lists and targets developed by municipalities, and the trees being chosen and planted by contractors and developers, can shed light on barriers to diversity enhancements in the public right-of-way. Now that many cities have developed UFMPs, which often include targets and policies for species diversification (Ordóñez and Duinker 2013), more research is needed to ascertain whether these targets are measured and monitored effectively. Are tree species lists and diversity targets being consulted appropriately? Are there consequences for non-compliance? Tree diversity is shaped by both policy and its implementation, so it is vital to consider the priorities and practices of professionals involved in the planning (and planting) process.

Finally, determining how the influence of factors changes over time is useful for planning and forecasting the composition of the suburban forest. As cities expand around and beyond suburban areas, landscape changes could alter tree cover and tree species composition. It is thus crucial to understand and consider temporal contexts when determining drivers of urban diversity (Luck et al. 2009). As suburban developments age, new drivers of tree diversity may come into play. For example, the availability of nursery species at a given point in time influences the composition of planted trees during the early stages of development (Pincetl et al. 2013; Conway and Vecht 2015), while elements of community design (e.g., the presence of remnant woodland adjacent to residential properties) can influence tree diversity as a neighbourhood ages and the canopy becomes more mature. More research is needed to identify factors that are pervasive throughout the development process and as neighbourhoods age.

6. Conclusion

Enhancing tree diversity should be a priority for urban forest managers, particularly given concerns about biodiversity loss as well as the many benefits and services that diverse urban forests provide. Despite the recognition that biodiversity management in the urban forest context is important, it is also fraught with uncertainty. Debate persists about the contributions of native and non-native species to tree diversity, and in many cases municipal diversity targets are lackluster and ill-defined. Disturbances like pests, diseases, extreme weather events, and other climatic changes are likely to impinge on the success of growing trees in urban environments, especially species that are already vulnerable to urban stressors. These difficulties reinforce the utility of adaptive management; not all trees nor plantable spaces should be considered equal. Instead of blindly aiming for *more* biodiversity, managers and practitioners might be better off envisioning the *right* kind of biodiversity.

In this paper, we have outlined ecological, socioeconomic, cultural, and administrative drivers of tree diversity in suburban areas. We recognize that this list is neither exhaustive nor inflexible; other factors will likely be identified and studied as urban forest research continues, while some factors and their influence will be more relevant in specific contexts. We intend for the drivers described in this paper to serve as a guideline that can be used to inform urban forest management practices and to develop strategic diversity targets. In doing so, it is worth considering how the urban forest itself is perceived to contribute to our cities. Are trees in the city prioritized during and after urban development? Do we consider forests to be an integral component of the urban landscape, retained and designed with purpose, or more of an afterthought dependent on available resources? Biodiversity enhancement and the maximization of its benefits are most effective when the green infrastructure takes precedence over the grey, and when the city is built with the trees firmly in mind.

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