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URBAN INVASIONS

Alien plants as mediators of ecosystem services and disservices in urban systems: a global review

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Abstract Urban areas have unique assemblages of species which are governed by novel ecological processes. People living in these environments have specific needs and demands in terms of ecosystem services (ES). Urban ecosystems are transformed in many ways by human activities and their floras comprise a high proportion of alien plant species, many of which were intentionally introduced to provide, augment or restore ES. Urban environments also have novel disturbance regimes and provide colonization sites for the establishment, dispersal and proliferation of alien plant species; such conditions often generate biological invasions which may cause marked changes to ES. We review the roles that alien plants play in providing urban ES and ecosystem disservices (EDS) globally. We identify the main ES and EDS associated with alien plants, and highlight the key species involved. A literature search revealed 335 papers, representing studies in 58 cities or urban areas in 27 countries. These studies recorded 337 alien plant species, contributing to 39 different ES and 27 EDS–310 species were recorded as contributing to ES and 53 species to EDS. A small number of alien plant taxa were frequently recorded as providing multiple ES in many urban ecosystems; the 10 most recorded species accounted for 21% of the ES recorded. Some of these species also result in significant EDS; three

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species accounted for 30% of the EDS recorded. Cultural services (notably aesthetics) are the most reported ES provided by alien plants in urban areas of developed countries, while provisioning services (notably food production) are most reported in developing countries. The most commonly studied EDS provided by alien plants is the impact on human health (notably allergic reactions). Eighty percent of studies on alien plants and ES and EDS have been done in developed countries. To elucidate the full range of effects of alien plants, more work is needed in developing countries. Urban planners and managers need to be mindful of both the positive and negative impacts of alien plant species to maximise the provision of ES.

Keywords *Ailanthus altissima* · Biological invasions · Developed and developing countries · Human health · Planning and management · Plant invasions · Tree invasions · Urbanisation · Urban ecosystems

Introduction

Urbanization is influencing the functioning of ecosystems and the services they provide in many ways worldwide. This adds complexity to management activities that are aimed at enhancing the well-being of urban residents by preventing the loss of biodiversity and ecosystem degradation, and maintaining flows of ecosystem services (ES) into and within urban areas (Elmqvist et al. 2015; Luederitz et al. 2015). Acknowledging this global trend, local government leaders and city managers face the challenge of seeking an appropriate balance between the demands of economic development, the provision of ES, and the conservation of biodiversity (Gaston et al. 2013).

Assessments at regional and global scales indicate that human-accelerated environmental changes, including altered land use and escalating biological invasions, are compromising the provision of a range of ES and making them more prone to sudden collapse (Millennium Ecosystem Assessment 2005). Furthermore, the non-sustainable use of ES has caused widespread degradation which now threatens human health and livelihoods in many parts of the world (Millennium Ecosystem Assessment 2005). This is of particular concern in urban areas where ES are in high demand.

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Ecosystem services and disservices in an urban context

The benefits that humans derive from ecosystem functions and processes (i.e. ES) are an important basis for the well-being of society. In this context, well-being is defined as access to secure livelihoods, health, good social relations, security and freedom (Mooney 2005). The concept of ES has been criticized for only considering the beneficial outputs of ecosystems while overlooking the unwanted or harmful effects (termed ecosystem disservices; EDS) (Vaz et al. 2017a). This is partly because different people may perceive the same ecosystem function in different ways (Gaertner et al. 2016; Kueffer and Kull 2017). For example, one person may find a shade tree to be aesthetically pleasing and comforting whereas another person may find it to be a source of allergens, unwanted leaf litter, and obstructed views. Such divergent views vary spatially, temporally and between individuals or societal groups (Chan et al. 2012; Shackleton et al. 2016; Kueffer and Kull 2017), thus complicating management efforts. Management to optimise specific ES exclusively may exacerbate associated EDS, and interventions aiming only at reducing EDS may reduce ES (Shackleton et al. 2016). For example, planting Black Locust (*Robinia pseudoacacia* L., Fabaceae) in urban areas provides many benefits such as aesthetic enhancement (Noe et al. 2008), shade (Moser et al. 2015), and provides resources for honey producing bees (Haussman et al. 2015), but also provides EDS such as altered soil fertility and reduced species richness (Marozas et al. 2015). Integrating ES and EDS in decision making for management may yield better outcomes for human well-being.

Urban ecosystems are those where humans live at high densities and where the built infrastructure covers a large proportion of the land surface (Pickett et al. 2001). The definition of ES in an urban context remains contested due to the spatial and temporal disparities between the physical boundaries of urban areas and the resources drawn into and used within them (Borgström et al. 2006; Luederitz et al. 2015). For example, most of the total annual water supply for the city of Cape Town, South Africa is supplied from outside the municipal boundaries of the city (Anderson and O'Farrell 2012). Valuable services from ecosystems in a city include air filtration, noise reduction, flood prevention, microclimatic regulation, and many cultural services, including recreation (Bolund and Hunhammar 1999; Costanza et al. 2007). Such ES are generated by a diverse set of green spaces (as reviewed by Haase et al. 2014).

Developing countries are now urbanising faster than any group of countries in the past (OECD 2015), while the developed world has already experienced an urban transition, with 80% of people residing in towns and cities (UNFPA 2007). Developing countries face particularly complex challenges as inefficient resource- and land-use directly results in negative environmental consequences and socioeconomic impacts (Piracha and Marcotullio 2003). The per capita resources in developing countries are significantly lower than for developed countries, and growth in developing regions is still concentrated around urban cores rather than in surrounding suburban areas (Pauchard et al. 2006). This unprecedented demographic shift is concentrating pressure on ES in and around urbanizing regions; such higher-density development presents challenges and opportunities for managing ES (Tratalos et al. 2007).

Importance and consequences of alien plants in urban systems

Urban floras are typically characterized by greater species richness than adjoining natural areas (Kühn et al. 2004; Wania et al. 2006), replacement of native species with alien species (Godefroid 2001; Millard 2008; Cadotte et al. 2017), and increasingly fragmented populations (McKinney 2002). Since alien plant species make up a large proportion of urban floras (Pyšek 1998; Kühn and Klotz 2006), it is important to weigh the detrimental effects of alien species against the ways they enhance local diversity and maintain important functional roles (Elmqvist et al. 2008).

Many alien plants were introduced specifically to create, augment or restore key ES (Pimentel et al. 2001), for example, to provide shade and visual amenity, provide resources for honey producing bees, provide timber and fuel wood, sequester carbon, fix nitrogen, stabilize sands and control erosion (Foster and Sandberg 2004; de Wit et al. 2009; Cilliers and Siebert 2012; Pyšek et al. 2012; Dickie et al. 2014). Yet, some alien plant species introduced for such purposes subsequently spread beyond original plantings and have become invasive, causing negative effects on existing ES (Pysek and Richardson 2010) or creating novel ES or EDS (Hobbs et al. 2013; Shackleton et al. 2014; Vaz et al. 2017a).

Trade-offs arise when the ES provided by alien plants are weighed against the EDS provided by the same species, often creating conflicts over whether to manage for the former or the latter (Gaertner et al. 2016). For example, *Rhus typhina* L. (Anacardiaceae) shows strong invasive behaviour and is cited as a source of allergy-producing pollen (Mao et al. 2013), but this species is also valued for its aesthetics (Dyderski et al. 2015). *Acer platanoides* L. (Sapindaceae) has contrasting effects on the chemical composition of the air: it removes CO_2 (thereby contributing to climate change mitigation) but contributes to the emission of biogenic volatile organic compounds (BVOCs) (Millward and Sabir 2011). BVOCs have a significant influence on air quality by increasing the concentration levels of secondary air pollutants such as ground-level ozone and secondary organic aerosols, which negatively impacts human health (Bogacki and Sygula 2013).

Urban areas are particularly susceptible to invasion by alien plant species as they are important points of entry for the introduction (intentional and inadvertent) and further spread of alien plant species into surrounding areas (Kowarik 1995; Pyšek 1998; Gaertner et al. 2016). Trade, traffic, and horticulture are the most prominent dispersal pathways (Von Der Lippe and Kowarik 2007; Padayachee et al. 2017). Altered disturbance regimes and increased resource availability associated with human activities often differentially improves the performance of alien over native plant species, leading to invasions (Daehler 2003; Cadotte et al. 2017). Furthermore, climatic conditions, hydrology, and soils that have been profoundly altered by human activity play a significant role in urban plant invasion patterns and processes (Klotz and Kühn 2010). Management of invasive alien plants (IAPs) follows very different approaches in different parts of the world, which affects the number and distribution of IAPs within cities. This is often closely linked to the availability of funding and city-planning priorities. For example, some cities may prioritise management of urban green space, while others are mandated to channel limited funding to other departments which are given higher priority (Irlich et al. 2017).

The composition of biotic communities in urban ecosystems affects ES (Kremen 2005; Bennett et al. 2009; Luck et al. 2009) and IAPs are becoming increasingly dominant in many cities around the world. This leads to concerns over the capacity and type of ES that these environments can produce and therefore the potential effects of IAPs on human well-being (Eviner et al. 2012). To respond, managers need a better understanding of the drivers of establishment of the species, how they impact local biodiversity, and their effect on ES and/or EDS. It is therefore imperative to further our understanding of the links between IAPs and ES/EDS so that we can better manage their delivery and to ensure their ability to withstand and recover from disturbances and diverse facets of environmental change (Carpenter et al. 2001).

This paper identifies key ES and EDS associated with alien plants in urban areas around the world, and highlights the key alien plant species affecting these services. We also contrast the role of alien plants in providing ES and EDS in developing and developed country contexts and identify potential research gaps. This study provides important insights on the links between alien plants and ES and EDS in urban areas and may help guide urban managers in prioritizing alien plant species for management and developing appropriate strategies for enhancing ES provision.

Methods

Data collection

We reviewed the literature, using ISI Web of Science, Scopus and Google Scholar, to identify key ES around the world and the most important alien plant species that affect such services. As the term 'ecosystem service' is not always used in the literature, we searched for keywords related to the ES categorisation of the Millennium Ecosystem Assessment (2005) and refined the search to include literature from only urban areas. Examples of keywords used for the search included: "urban*" OR "city" OR "cities" OR "town" OR "metropolitan" OR "built-up" AND "ecosystem service*" OR "environment* service*" OR "landscape service*" OR "ecologic* service*" AND "food" OR "fibre" OR "fuel" (see Online Resource 1 for a full list of keywords searched). Our literature search criteria did yield several non-English publications (with abstracts in English) and these were included in the analysis.

EDS were categorised according to the typology proposed by Vaz et al. (2017a) (namely health, material, safety and security, cultural and aesthetic, and leisure and recreation), but two additional categories (economic and environmental problems) were included based on the categorisation of Roy et al. (2012). Because the concept of EDS (particularly in urban settings) is new, we searched for keywords related to urban areas and the aforementioned EDS categories, and not only to explicit reference to "disservices". Examples of keywords used for the search included: "urban*" OR "city" OR "cities" OR "town" OR "metropolitan" OR "built-up" AND "ecosystem disservice*" OR "environment* disservice*" OR "landscape disservice*" OR "ecologic* disservice*" OR "ecosystem dis-service*" AND "health" OR "safety" OR "security" OR "aesthetic" (see Online Resource 1 for a full list of keywords searched). Additional papers were identified from the reference lists of papers found through the formal literature search (i.e. snowballing).

We acknowledge that our search did not locate all the literature on ES and EDS, but we are confident that the collection of publications that were included in our analysis provides an appropriate sample for a broad overview of the most significant literature and to draw reliable conclusions on recent approaches to urban invasions and ES and EDS research. Importantly, several biases exist in the literature. For example, the invasive species literature is biased in favour of studies that address the negative impacts of a limited number of taxa or plant groups. On the other hand, the literature on landscape architecture, gardening, and urban design is biased towards studies that emphasize the positive roles of alien plants. Similarly, the literature on ES and EDS provided by urban vegetation rarely distinguishes between native and alien species and for the latter seldom address their introduction status (i.e. whether the species is just alien, and naturalized or invasive). The literature on invasive alien species heavily underrepresents social and cultural aspects (Vaz et al. 2017b), which may have lead to a strong underrepresentation of cultural ES and EDS, and especially of non-economic and informal ones. There is also a biased towards few intensively and many little studied species in the invasive species literature (Kueffer et al. 2013).

Analysis

The following information was recorded for each publication retrieved in our search: (i) ecosystem service category (categorised according to the Millennium Ecosystem Assessment 2005); (ii) ecosystem service; (iii) ecosystem disservice category (categorised according to Vaz et al. 2017a); (iv) ecosystem disservice; (v) urban area (city, town, etc.); (vii) country; (viii) world region; (ix) species name; and (x) literature source. The countries in which the research took place were further categorised into developed or developing countries based on the classification of the United Nations (2017). Only studies which referred to alien taxa at the species level were included in the analysis. Where studies did not differentiate between alien and native plant species, we identified the native range of each recorded species using peer-reviewed literature and noted whether it was native or alien at the respective study sites (a list of all publications appears in Online Resource 2). Where possible, we noted from the literature whether the alien plant species was classified as invasive at the study site (following the criteria proposed by Richardson et al. 2011).

Results

The literature search revealed 335 papers, representing studies in 58 cities or urban areas in 27 countries. These studies recorded 337 alien plant species, contributing to 39 different ES and 27 EDS; 307 species were recorded as contributing to the provision of ES and 53 species to EDS. A small number of alien plant taxa were frequently recorded as providing multiple ES and the 10 most recorded species accounted for 21% of the ES recorded. Some of these species also result in significant EDS and three species accounted for 30% of the EDS recorded. There was a clear bias towards studies in Europe (41% of studies from 33 cities in 14 countries) and North America (28% of studies from 17 cities in USA and Canada).

Alien plants and ecosystem services and disservices

Regarding ES, the role of alien plants is most significant in the delivery of provisioning services, with 172 species contributing to the provision of services such as food production (Fig. 1). Next most important were cultural services with 137 species found to be important in delivering services such as aesthetic enhancement. Regulating services have received relatively little attention in the literature and 33 species were found to be important in delivering services such as CO_2 sequestration and improving air quality. The role of alien plants in the delivery of supporting services (e.g., nutrient cycling and soil formation) has received the least attention and only 16 species were identified as being important in this regard.

Our analysis shows that 67% of studies focussed on woody alien plant species, with trees and shrubs providing ES across all service categories (Fig. 1). Herbaceous alien plant species have received less attention in the literature. Of the woody alien plants, the role of *Ailanthus altissima* (Mill.) Swingle (Simaroubaceae) contributing to ES was the most prevalent in the literature, followed by *Platanus x acerifolia* (Aiton) Willd. (Platanaceae), while *Carica papaya* L. (Caricaceae) was the most studied herbaceous plant (Table 1; although this species exhibits a tree-like growth form, it is categorised as herbaceous; Ming et al. 2008).

The most commonly studied EDS provided by alien plants was the impact on human health (Fig. 2), with 53 species contributing to EDS such as allergic reactions or the emission of BVOCs, followed by the creation of environmental problems, with 21 species providing EDS such as the alteration of soil fertility and reducing species diversity. Other EDS included infrastructural damage, reduction in property value, and threats to safety. Woody alien plant species resulted in the greatest proportion of EDS with 78% of the most harmful species being woody and only 19% being herbaceous (Fig. 2).

There is a strong connection between the species that are important for the provision of ES and those that result in EDS—27% of all recorded species provided both ES and EDS. *Ailanthus altissima*, although important for the provision of ES (see Box 1), results in several EDS such as infrastructural

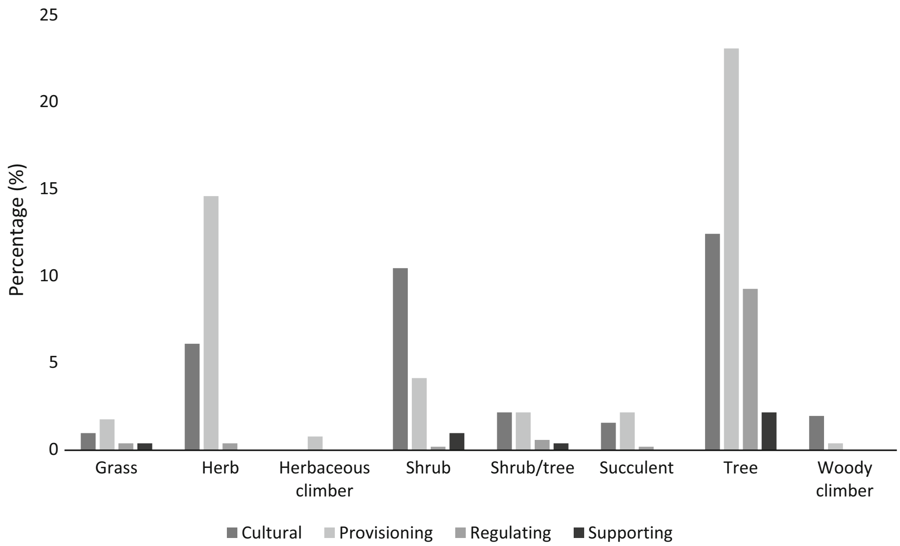

Fig. 1 Percentage of alien plant species recorded as providing urban ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005), classified according to growth form

Table 1 Number of records in the literature of urban ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005) provided by the ten most recorded alien plant species (see Online Resource 3 for the full list of records)

Species	Family	Growth form	Ecosystem service category				Total
			Cultural	Provisioning	Regulating	Supporting	
Acer platanoides L.	Sapindaceae	Deciduous tree	1	2	4	0	7
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	4	15	6	7	32
Carica papaya L.	Caricaceae	Evergreen herbaceous tree	0	9	0	0	9
Jacaranda mimosifolia D. Don	Bignoniaceae	Deciduous tree	3	1	1	0	5
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	1	0	4	5
Morus alba L.	Moraceae	Deciduous tree	2	4	1	0	7
Opuntia ficus-indica Mill.	Cactaceae	Succulent shrub/tree	3	2	0	0	5
Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	3	2	5	0	10
Psidium guajava L.	Myrtaceae	Evergreen shrub/tree	1	4	1	0	6
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	2	1	3	0	6

damage, pollen allergies, and loss of biodiversity (Casella and Vurro 2013; Table 2). Similarly, *Platanus x acerifolia* contributes to the provision of ES such as CO_2 sequestration, but also generates EDS such as the emission of BVOCs. The allergenic *Ambrosia artemisiifolia* L. (Asteraceae) was most harmful of the herbaceous species given its impacts on human health in many European cities (Table 2).

Alien plants in the developing world

Research on the roles that alien plants play in providing ES is largely confined to urban areas in developed countries (Fig. 3a). Of the 310 species recorded in the literature, 60% occurred in urban areas of developing countries and 40% in developed countries. The cities with the greatest number of records were Niamey (Niger) and Poznań (Poland) (Fig. 3b),

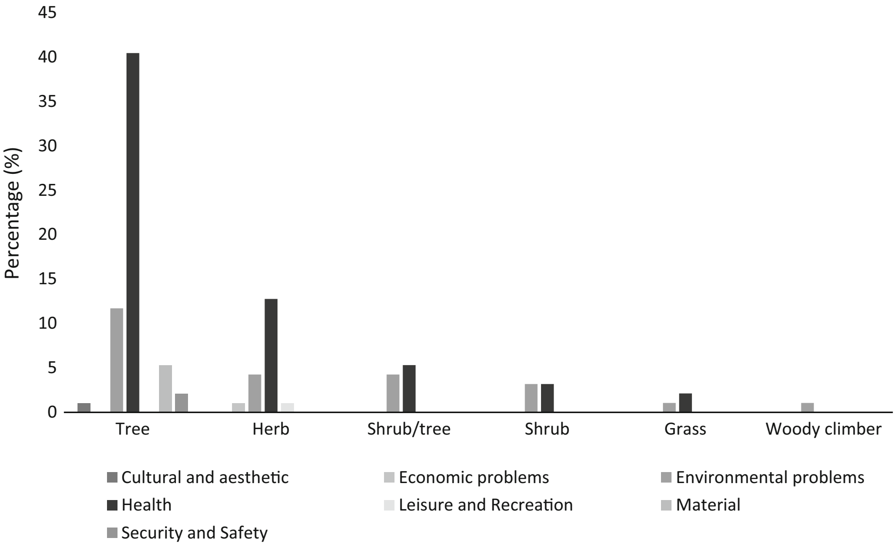

Fig. 2 Percentage of alien plant species recorded as providing ecosystem disservices (categorised according to the Vaz et al. 2017a; Roy et al. 2012), classified according to growth form

though high numbers in these cities as well as some others (e.g., Bujumbura, Burundi, and Seshego, South Africa) resulted from one publication for each city that compiled comprehensive species lists and corresponding uses.

Table 3 shows that cultural services provided by alien plants are most recorded in urban areas of developed countries while provisioning services are most often recorded in developing countries. Alien plants used for aesthetic/ornamental purposes are most significant in developed countries, while food production is the most important ES in developing countries (Fig. 4).

There is a dearth of literature on the role of alien plants in providing EDS in urban areas of developing countries (Table 3). Of the 95 studies recording EDS provided by alien plants in urban areas, only one was from a developing country—an increase in density of *Acacia saligna* H. L. Wendl. (Fabaceae) was found to reduce avian species richness in urban and peri-urban areas of Cape Town, South Africa (Dures and Cumming 2010).

Discussion

The role of alien plants in urban ecosystem service provision

Alien plant species have been introduced to urban centres around the world where they play an important role in providing ES. A select number of alien plant taxa are widely recorded as providing multiple ES (Table 1). Cultural and provisioning services have received the most research attention, while few studies have addressed how alien plants affect regulating and supporting services, either positively or negatively (Fig. 1)—a trend also observed by Charles and Dukes (2007). This may be due to the relative insignificance of their impact on these functions in urban areas. Provisioning services are the easiest to assess, since their effects occur over shorter time scales and are often felt more acutely, at least initially, than for other ES (Charles and Dukes 2007). Moreover, good data are available on provisioning services and such information is often highly relevant for decision-makers (van Wilgen et al. 2008). Regulating services are the benefits obtained through the natural regulation of habitats and ecosystem processes (Millennium Ecosystem Assessment 2005). Such ES may be characterized as being of indirect use because they provide the conditions that allow other directly used ES (e.g., provision of food) to exist (Abson and Termansen 2011). Similarly, supporting services do not directly benefit people, but are essential to the functioning of ecosystems and are therefore indirectly responsible for all other services (Haines-Young and Potschin 2010). Consequently, these services are more difficult to quantify (Rodriguez et al. 2006), particularly in urban settings, though it is also noteworthy that many IAPs may be significant providers of regulating and supporting services.

Table 2 Number of records in the literature of urban ecosystem disservices (categorised according to Vaz et al. 2017a and Roy et al. 2012) provided by the ten most recorded alien plant species (see Online Resource 4 for the full list of records)

Species	Family	Growth Form	Ecosystem Disservice Category							Total
			Cultural and aesthetic	Economic problems	Environmental problems	Health	Leisure and recreation	Material	Security and safety	
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	1	0	5	6	0	5	2	19
Ambrosia artemisiifolia L.	Asteraceae	Annual herb	0	0	0	9	0	0	0	9
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	0	0	3	2	0	0	0	5
Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	0	0	0	4	0	0	0	4
Rhamnus cathartica L.	Rhamnaceae	Deciduous shrub/tree	0	0	3	0	0	0	0	3
Vincetoxicum rossicum (Kleopow) Barbar.	Asclepiadaceae	Perennial herbaceous vine	0	0	3	0	0	0	0	3
Cedrus deodara (Roxb. ex D.Don) G.Don	Pinaceae	Evergreen tree	0	0	0	2	0	0	0	2
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	0	2	0	0	0	0	2
Myriophyllum spicatum L.	Haloragaceae	Aquatic perennial herb	0	1	0	0	1	0	0	2
Rhus typhina L.	Anacardiaceae	Deciduous shrub	0	0	0	2	0	0	0	2

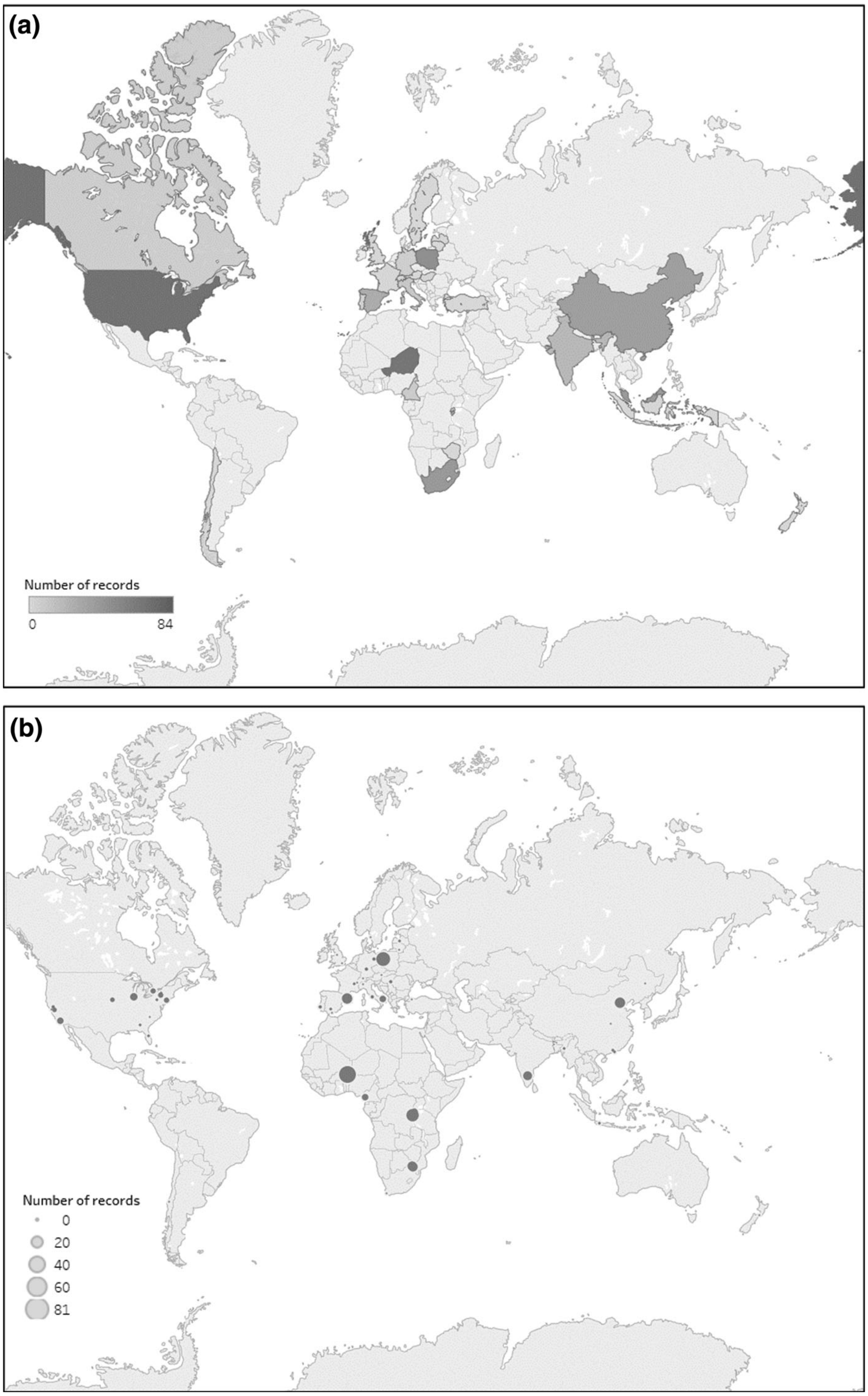

Fig. 3 Geographic distribution of literature records included in the analysis for **a** countries and **b** urban areas around the world

Cultural services such as ornamentation or aesthetics are significant in urban areas in both developed and developing countries (Table 3). Some alien plants are an important source of food in urban areas, particularly in developing countries where many alien plant species (e.g., *Carica papaya*, *Ipomoea batatas* (L.) Lam; Convolvulaceae) are cultivated in domestic gardens to produce fruits and vegetables for household

Table 3 Percentage of records (of a sample of 335 papers) linking alien plants with ecosystems services (categorised according to the Millennium Ecosystem Assessment 2005) and ecosystem disservices (categorised according to Vaz et al. 2017a; Roy et al. 2012) in urban ecosystems in developed and developing countries around the world

	Developed	Developing
Ecosystem service category		
Cultural	18.6	17.2
Provisioning	12.1	37.2
Regulating	9.1	2.0
Supporting	4.0	0
Ecosystem disservice category		
Cultural and aesthetic	1.1	0
Economic problems	1.1	0
Environmental problems	24.5	1.1
Health	63.9	0
Leisure and recreation	1.1	0
Material	5.3	0
Security and safety	2.1	0

consumption or for selling (e.g., Andersson et al. 2007; Hynes and Howe 2004; Bigirimana et al. 2012; Guitart et al. 2012). While the importance of utilising alien plant species in allotment and garden food production in developed countries has received little attention in the literature, studies in developing countries, where alien plants are utilized more extensively for urban food production, suggest that urban agriculture can provide additional food and nutrition security for households (Maxwell et al. 1998; Drescher 2004).

Although important for the provision of ES in cities, the flora of public and domestic urban gardens are an important source of potentially IAPs (Smith et al. 2006; McLean et al. 2017), as many alien plant species grown in gardens have escaped cultivation and become invasive within urban areas and surrounds (Williamson and Fitter 1996; Alpert et al. 2000; Alston and Richardson 2006; Guo et al. 2006). For example, *Catharanthus roseus* regia (L.) G. Don (Apocynaceae) is a common garden ornamental in Bujumbura, Burundi, but has consequently spread and is now listed as invasive (Bigirimana et al. 2012). Although the introduction of new plant species for aesthetic reasons is still an important pathway worldwide (Hulme et al. 2017), the major contribution by which ornamental horticulture facilitates plant invasions may be through repeated local introduction of alien plants, and the selective breeding of traits which increase the likelihood of successful establishment (Kowarik 2003).

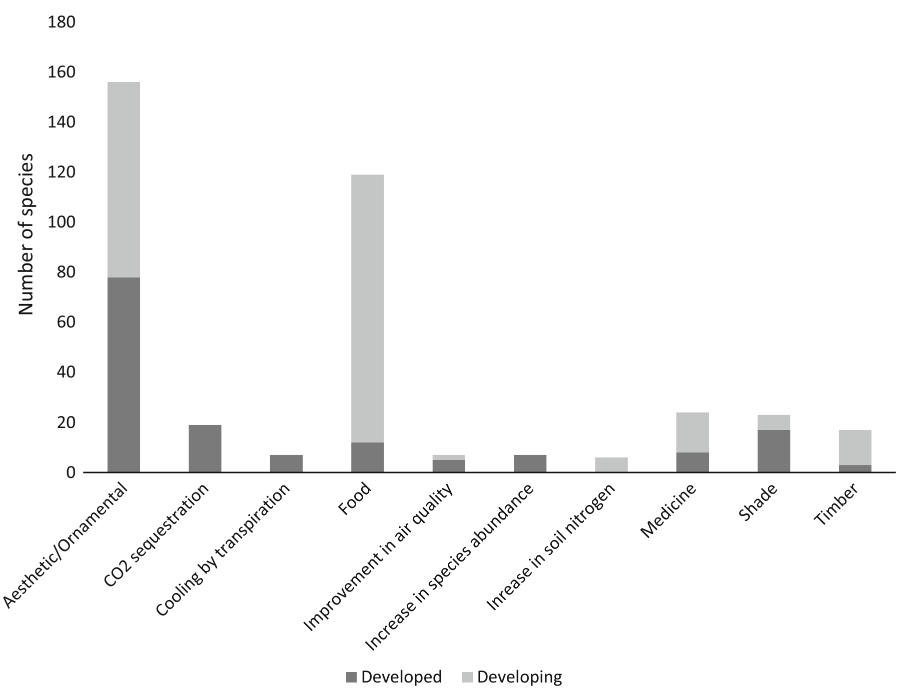

Fig. 4 The ten most recorded urban ecosystem services provided by alien plant species for developed and developing countries

Box 1 *Ailanthus altissima* – an urban invader

Urbanization can result in 'biotic homogenization' (McKinney 2006). One reason for this is the intentional planting of a relatively small number of alien plant species and cultivars in gardens and landscaping schemes (McKinney and Lockwood 1999; Reichard and White 2001; Sullivan et al. 2005). Species adapted to highly modified built habitats at the urban core are ''global homogenizers'' and are found in cities worldwide (McKinney 2006). As cities expand across the world, biotic homogenization increases as the same ''urban-adaptable'' species become more widespread and locally abundant (McKinney 2006)

Ailanthus altissima (tree of heaven) is native to Southeast Asia but has been introduced to urban centres around the world, primarily for ornamental purposes (Kowarik and Säumel 2007; Walker et al. 2017). Sladonja et al. (2015) review the impacts of *A. altissima* on ecosystems and ecosystem services (ES). They highlight the trade-offs associated with this species as positive influences on some ES are weighed against the negative effects on the environment and human health

Urban populations of *A. altissima* can cause significant damage to infrastructure and archaeological sites with its roots, and cause allergic reactions, respiratory problems, and skin rashes (Derrick and Darley 1994; Ballero et al. 2003; Celesti-Grapow and Blasi 2004; Luz-Lezcano Caceres and Gerold 2009; Burrows and Tyrl 2013). Although the species clearly has significant negative impacts, it also provides key cultural, provisioning, regulatory and supporting services, particularly as a source of active compounds and environmental restoration. Its tolerance of a broad range of site conditions and of most pollutants enables further functional uses as an ornamental, shelterbelts, and for erosion control (Kowarik and Säumel 2007). However, such traits enable this species to thrive in urban environments, and ineffective management approaches coupled with high levels of propagule pressure have allowed *A. altissima* to spread rapidly, resulting in significant impacts on the environment and human health (Sladonja et al. 2015)

Sladonja et al. (2015) suggest that in environments altered by human activities, *A. altissima* does not present any major threats and its invasive properties are outweighed by its potential ES. In areas where it has spread into natural ecosystems, it compromises ecological stability, and must be controlled. However, they also suggest that all the potentially positive effects of *A. altissima* presence may be outweighed by the significant costs associated with controlling the species should it continue to spread and densify

While propagule pressure affects the range of introduction and the success of certain introduced species (e.g., Castro-Diez et al. 2011; Potgieter et al. 2014), the ability of species to escape cultivation and establish new populations relies largely on their life-history characteristics (Aronson et al. 2007); although the relevant life-history traits may differ between natural and man-made landscapes such as urbanised areas (Kueffer et al. 2013). Life-history characteristics associated with human importation, such as large showy flowers, colourful fruits and adaptation to disturbed areas can also be associated with reproductive success and efficient dispersal, thus allowing species to establish and spread into new environments (Aronson et al. 2007; Moodley et al. 2013). This trend in human preference for particular plant traits has led to an increase in the proportion of alien trees and shrubs in many urban areas due to escaped woody ornamentals (see Figs. 1, 2) and has been reported for cities in Italy (Celesti-Grapow and Blasi 1998), Germany (Kowarik 2005) and the Czech Republic (Chocholoušková and Pyšek 2003).

Alien plants and urban ecosystem disservices

As found by Shackleton et al. (2016), our analysis showed that very little is known about the role of alien plants in providing EDS in urban environments, specifically in developing countries (Table 3). Von Döhren and Haase (2015) also note that most studies on EDS focus on Western Europe or the USA. Given the trend of urbanisation in developing countries and the ever-increasing dependence on the provision of ES for human well-being, the degradation of these services is a growing concern for city managers. Improved understanding of the drivers of these EDS is thus crucial.

The emphasis in the literature on certain alien plant taxa and the EDS they provide may have been initiated in response to their abundance in urban landscapes due to high levels of widespread plantings and/or invasion. Certainly, there is evidence of spatial clustering of IAPs in urban environments that leads to concentrations of EDS in certain urban landscape types (Štajerová et al. 2017). Thus, the EDS associated with more 'benign' alien species may be overlooked. Moreover, the role of woody plant species in providing both ES and EDS may be more obvious than that of the less conspicuous herbaceous species (Figs. 1, 2), and this trend may continue given the increasing shift in the distribution of trees and shrubs resulting from human preference for particular plant traits (see Williams et al. 2015).

Disparity between developed and developing countries

Developed countries were much better represented than developing countries in publications located in our literature search. This is probably partly because there are many more publications on issues relating to ES and EDS from developed countries overall (Luederitz et al. 2015; Grêt-Regamey et al. 2016). We recognize that our review has almost certainly missed some important contributions and insights from more obscure journals and from the grey literature, especially such publications in languages other than English.

The trend of urbanisation in developing countries has resulted in an increased demand for planning and the provision of basic services (such as water, waste disposal, regulation of climate and air quality, and food production), many of which are provided by ecosystems (Elmqvist et al. 2013). This demand is particularly high in the peri-urban poor communities of developing countries. This is partly due to the provision of such basic services being significantly lower in peri-urban zones than in urban centres. Therefore, planting species which can provide such services can relieve some of these pressures in these less economically stable areas.

A greater number of low- to middle-income people live in urban areas in developing countries, and this disparity in urban versus nonurban populations is growing (Cohen 2004). Owing to a reduction in income differentiation, urban areas of developing countries may be more homogenous than urban areas of developed countries, but native habitats continue to be transformed as the urban core expands (Huebner et al. 2012). This means that fewer remnants of native habitats are likely to persist in urban areas in developing countries, and fewer new alien (and potentially invasive) plant species are likely to be introduced (Huebner et al. 2012). This may ultimately result in urban areas with relatively low plant-species diversity, which may contain already established IAPs, but not act as a source of IAPs. The implications of this trend for the provisioning of ES and EDS requires further research, as the links between urban biodiversity (e.g., native vs alien plant taxa) and ES/EDS provisioning are still emerging (Dearborn and Kark 2010).

Scaling down to the city level, wealthier neighbourhoods tend to have increased numbers of perennial plant species, due to the higher disposable income of landowners (Hope et al. 2006). In their study of the developed city of Beijing, Clarke et al. (2014) found that species diversity and abundance shifts according to a hierarchy of need from ornamental species (cultural ES) to edible species (provisioning ES) with increasing distance from the city centre. Gardens in cities of developing countries contain species that are selected based on their food or medicinal value (Blanckaert et al. 2004; Winklerprins and de Souze 2005). Cilliers et al. (2013) found that plant species providing provisioning services such as food, medicine and shade were more common in the gardens of lower income residents than in those of more affluent areas. Gavier-Pizarro et al. (2010) found that richness of alien plants was positively correlated to mean income and low-density residential areas. These studies suggest that income may function as a proxy measure of socioeconomic activities that favour alien plant introductions and potential invasions, although importance of other socioeconomic factors such as lifestyle behaviour and housing age (Grove et al. 2006) should not be discounted.

Knowledge gaps

While the composition of urban floras and the associated spatial and temporal changes have been well studied, there is a dearth of information on the role of alien plants in providing and mediating ES and EDS. Another gap is that many impacts (both positive or negative) are described qualitatively rather than measured, making it difficult to determine 'net' outcomes, and complicating synthetic analyses that seek to determine benefit: i.e. cost ratios. Indeed, researchers have struggled to develop a general approach for the quantification of invasion impact in urban areas (Kumschick et al. 2014). A diverse range of terminology describing ES in urban areas exists in the literature. For example, ES provided by urban green space (urban floras) are increasingly discussed in the context of "green infrastructure" or "nature-based solutions" in "sustainable cities" (Kabisch et al. 2016; Scott et al. 2016; Hui et al. 2017). A unified lexicon within an ES context would be useful.

There has been a strong research focus on certain ES (e.g., air quality), but the species affecting such services are seldom mentioned. Moreover, the literature on ES or EDS provided by urban vegetation rarely distinguishes between native and alien species (and the introduction status for the latter is seldom clearly stated). For example, Barau (2015) presents comprehensive lists of common urban household plants used for ornamental purposes in Malaysia, but does not specify whether the species are native or alien. There is also a clear disparity in the ES and EDS literature between urban areas in developed and developing countries, with a strong focus on the former. There is a need to further our understanding of the role of alien plants on ES in urban areas in developing nations, especially given the importance of effective ES delivery.

Several species are repeatedly mentioned in studies of urban plant invasions around the world, but little mention is made of their role in ES or EDS. For example, although *Robinia pseudoacacia* (25 hits in our literature search) is referred to in many studies of urban floras (e.g., Song et al. 2005; Cierjacks et al. 2013; Kowarik et al. 2013), the role of this species in mediating ES and EDS is seldom addressed. Such species often have high levels of propagule pressure, long residence time, and life-history traits suited to proliferation in urban environments. Further research is required to elucidate the impact of such species on ES and EDS.

Another important question is whether native plant species can provide the same (or more) ES than are currently provided by urban alien plant taxa and if so, whether there are associated EDS. Johnston et al. (2012) argue that a preference for native plants species may lead to urban landscapes with limited environmental, economic and social benefits. Dickie et al. (2014) describe several examples where attempts to remove alien trees were delayed or halted due to their perceived importance in providing ES such as food or habitat for charismatic or endangered native fauna. From a biodiversity conservation perspective, alien tree species can provide ES in support of other biodiversity (Johnston et al. 2012; Chalker-Scott 2015). For example, Gariola et al. (2013) found that the alien tree species *Melia azedarach* L. (Meliaceae) was a common host for native mistletoes in urban parks in Durban, South Africa. Alien plants are culturally embedded in urban landscapes around the world and have strong ties to ES provision. Much more work is needed to compare the role of native and alien plant species and the ES and EDS they provide in urban environments. Such research might become more pertinent in the context of the adaptation of cities to climate change (Sjöman et al. 2016).

Conclusions

Our review indicates that knowledge about ES and EDS provided by alien plant species to urban areas is still relatively limited and is biased in several ways. Overall, few alien species have been comprehensively studied in terms of ES and EDS provision, and for many species only data on either ES or EDS is available. Most research on the role of alien plants in ES provision has been done in developed countries, and more work is needed to elucidate the importance of alien plants in developing countries. There is also an imbalance in the study of different ES/EDS. While provisioning services are well studied there is little information on regulating services. Among cultural services, mostly aesthetics has been studied with a lack of studies on other cultural services such as psychological, social, symbolic, and religious roles that are known to be important for the perception of alien species (Kueffer and Kull 2017). Among EDS, many studies focused on few mechanisms such as pollen allergies affecting human health and emissions of BVOCs reducing air quality.

This review however shows clearly that alien plants can provide key ES and EDS in urban landscapes. Consequently, urban planners and managers need to be mindful of both the positive and negative impacts of alien plant species to maximise the provision of ES. Our findings suggest that alien plants are firmly embedded in urban landscapes and have complex social and economic ties. In the face of rapid urbanization and changing climates, the role and importance of these in delivering ES will change. Elucidating the role of alien plants in providing ES and EDS in urban areas can guide management prioritization and facilitate communication with various stakeholders.

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