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RESEARCH PAPER

Vegetation-based ecosystem service delivery in urban landscapes: A systematic review

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Abstract

The use of plants in cities and the ecosystem services they provide has attracted increased attention both publicly and within the research literature. Increasingly, the value of urban green and blue space is being recognised for its multiple benefits to human wellness and ecological integrity.

A quantitative assessment of studies considering nature-based solutions and ecosystem services can identify the current evidence−base for improving the provisioning of plant ecosystem services management and understanding barriers to adoption of nature-based solutions. Here, we provide a systematic review of the literature to characterise the current state of research on ecosystem service provision by urban blue and green space.

We identified 684 relevant studies on urban plant literature and extracted key research themes. Studies were generally focused on terrestrial systems (89%) compared to aquatic systems such as blue space (11%). Geographically most studies were focused on Europe (39%), Asia (23%), and N. America (22%). Trees were the most frequently reported vegetation type studies (29%) followed by generic vegetation (20%), grassland (11%), forest (7%), and aquatic vegetation (5%). Many studies were short (41%), collecting data only over a single year or single field season. Many of the long-term studies are concerning land use/land cover change. Most studies (64%) were conducted for less than five years. The most-reported methodology was remote sensing technology (15%), followed by field surveys (8%), stakeholder surveys (6%), and ecosystem service models (5%). The most-reported ecosystem service types were regulation and maintenance (54%), cultural (28%), and provisioning (16%). Only a small number of studies looked solely at disservice (1%) or discussed ecosystem services in generic terms. Disservices were reported in only 16% of studies with the greatest single category of a disservice being biogenic volatile organic compounds and allergenic potential. Few studies (13%) reported on the use of nature-based solutions and these 80% only focused on a single nature-based solution. There was a lack of detail on plant species, 68% (n = 468) did not list the species studied.

We conclude that there is a broad spectrum of research on urban vegetation services, overall, the focus of the literature is uneven. Research should seek to examine the species-specific responses to urbanisation and counter geographic disparities. There is also a need for longitudinal experimental data to identify the functioning and ecosystem service provision of green infrastructure in both urban green and blue space and factors that influence performance over policy- and management-relevant timescales.

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Introduction

Throughout the latter half of the 20th and early 21st centuries, urban expansion has continued to increase with urban populations and land areas growing rapidly across the world. As of 2008, over half the world's 7 billion people reside in cities (Williams, Hahs & Vesk, 2015) whilst urban land use quadrupled between the 1970s to 2000s and cities grew at a rate greater than population growth (Alberti, 2005; Aronson, La Sorte, Nilon, Katti, Goddard, & Lepczyk, 2014). It is currently predicted that urban populations will double by 2030, while urban areas are expected to triple (Dulal, 2017). This increase in urbanisation impacts both natural and modified environments and continues to exert pressure on the capacity of these systems to support ecosystem services (Gill, Handley, Ennos & Pauleit, 2007). As natural habitats are altered or destroyed, native vegetation is replaced with a mix of homogeneous urban vegetation types which better favour urban environments (Lososová, Chytrý, Tichý, Danihelka, Fajmon, & Hájek, 2012). Aquatic vegetation is an important indicator of ecological condition, and urbanisation often decreased the diversity of macrophyte species present in blue spaces (Ding, Qian, Wu, Zhao, Lin, & Zhang, 2019; Zub, Prokopuk & Pogorelova, 2019). It has been noted that blue-space is less well represented in the research literature than greenspace (Gunawardena, Wells & Kershaw, 2017). It has also been suggested that blue spaces have numerous wellness benefits and may be valuable health resources when managed appropriately (Foley & Kistemann, 2015).

It is evident that human expansion has come at a great ecological and biological cost, while climate and land−use change can have complex interacting, often synergistic, negative effects on species and ecosystems (Powers & Jetz, 2019; Singh, Singh & Singh, 2018). Subsequently, species are going extinct at a much faster rate than historic background extinction events (De Vos, Joppa, Gittleman, Stephens & Pimm, 2015). The physical process of urbanization is also accompanied by increased traffic, air and noise pollution, the urban heat island effect, and a greater prevalence in physical and mental ailments (Depietri, Welle & Renaud, 2013; Kabisch, van den Bosch & Lafortezza, 2017).

Ecosystem services are the processes through which ecosystems and species support and enrich human life. Applied to urban planning, the ecosystem services concept reveals urban populations' dependence on the goods and services appropriated from ecosystems (Elmqvist, Fragkias, Goodness, Güneralp, Marcotullio, & McDonald, 2013; Gómez-Baggethun & Barton, 2013). This concept has now been further developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) as nature's contributions to people, encompassing all contributions, both positive and negative (Díaz, Pascual, Stenseke, Martín-López, Watson, & Molnár, 2018). The three categories of ecosystem services as defined by the Common International Classification of Ecosystem Services (CICES) are: provisioning services are benefits such as food, water, and timber; regulating and maintenance services are those that moderate phenomena such as climate, water quality, and viability of species; cultural ecosystem services are those nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, social infrastructure, and aesthetic experiences (Haines-Young & Potschin, 2012). Within an urban context, regulation and cultural services dominate, although the relative importance of different services varies in cities depending on socioeconomic and geographical dynamics and contexts (Luederitz, Brink, Gralla, Hermelingmeier, Meyer, & Niven, 2015). A quantitative assessment of studies considering nature-based solutions can identify the current evidence−base for improving the provisioning of plant ecosystem services management and understanding barriers to adoption of nature-based solutions to mitigate the impact of urbanisation.

Urbanisation exerts complex pressures on a wide range of species (Czech, Krausman & Devers, 2000). Studies have shown that for several taxonomic groups (vertebrates, invertebrates, and plants) extreme levels of urbanisation nearly always reduce species richness, mostly via the loss of habitat or the degradation of remaining patches due to increased pollution, traffic, or disturbance (McKinney, 2008). McKinney (2008) noted that about 65% of studies indicated increasing species richness with moderate urbanization. Most studies included in McKinney's (2008) analysis focused on animal taxa, with 57 and 31 reporting invertebrates and vertebrates respectively, whilst only 17 focused on plants. This aligns with general trends in ecology and conservation studies, where vertebrate studies are well represented, and other taxa are neglected (Troudet, Grandcolas, Blin, Vignes-Lebbe & Legendre, 2017).

Urbanisation and its impacts have been recorded to homogenise various freshwater taxa, for example, Ding et al. (2019) noted the homogenisation of macrophyte species in urban blue spaces across 35 major Chinese cites whilst Rahel (2002) notes the homogenization often resulted in increased biodiversity faunas via the establishment of new species over the extinction of natives. Some studies have demonstrated that urbanised blue space can host a range of species and may be of value for conservation Perron and Pick (2020). demonstrated stormwater ponds contained a diversity of Zygoptera species comparable to natural ponds whilst Hill, Biggs, Thornhill, Briers, Gledhill, and White (2017) observed that there was a relatively high alpha and gamma diversity of macroinvertebrates in urban ponds compared to non-urban ponds with no evidence of homogenisation.

It is evident there is still much to learn about the different impacts of urbanisation on species, particularly on aquatic plants as despite their ecological significance in urban blue space they may remain overlooked. Iversen et al. note freshwater plants have been neglected in the context of functional biogeography and little attention has been given to identifying their life strategies (Iversen, Girón & Pan, 2021). They argue better identifying aquatic plants, their ecological adaptive strategies, and how global change is impacting urban freshwaters via different species functional responses will aid us in predicting the consequences of global change, which will ultimately enable us to better enhance urban blue space.

Whilst studies of urban vegetation are less common than studies on animal taxa, studies on urban flora, such as those by Qian, Qi, Huang, Zhao, Lin, and Yang (2016), Wittig and Backer (2010), and Pyšek, Chocholousková, Pyšek, Jarošík, Chytrý, and Tichý (2004) have each noted that cites suffer from homogenisation and feature a general decline in floristic diversity compared to non-urban areas Ding et al. (2019) conducted a meta-analysis of aquatic plant distributions in China and found a general trend toward homogenisation in urban cities. In addition to this, Ding et al. concluded that comprehensive studies of urban aquatic macrophytes are lacking, with most research being undertaken in China and the West. This disparity within ecosystem service research was not confined to aquatic macrophytes, this is particularly of concern with the current predicted rate of urbanisation in Africa, South America, and Asia.

Blue space has also been relatively neglected in urban ecology (Céréghino, Biggs, Oertli & Declerck, 2007), despite many cities having developed around rivers and their fertile floodplains, frequently resulting in the alteration and fragmentation of freshwater ecosystems (Harrison, Green, Farrell, Juffe-Bignoli, Sáenz, & Vörösmarty, 2016). Impacts of urbanisation on water are well documented and are broadly defined as five interacting categories: overexploitation, water pollution, flow modification, invasive non-native species, destruction or degradation of habitats (Dudgeon, Arthington, Gessner, Kawabata, Knowler, & Lévêque, 2006). Currently, three−quarters of inland wetlands have been destroyed, one−third of the 28,000 freshwater species assessed on the IUCN Red List are threatened with extinction, and freshwater vertebrate species are experiencing declines faster than terrestrial and marine counterparts (Darwall, Bremerich, De Wever, Dell, Freyhof, & Gessner, 2018). Experiments have demonstrated that urban streams exhibit increased levels of pollutants, such as nitrogen, phosphorus, and faecal coliform bacteria when compared to reference streams and have lost many clean water taxa and become dominated by pollution-tolerant taxa (Blakely, Harding, McIntosh & Winterbourn, 2006; Carle, Halpin & Stow, 2005; Shoffner & Royall, 2008). These typical environmental responses to urbanisation are so frequently observed in urban streams that it is commonly referred to as “urban stream Syndrome” (Booth, Roy, Smith & Capps, 2016).

Research on the link between neglected habitats (e.g. freshwater) and taxa (e.g. plants), the processes of urbanisation, and the delivery of ecosystem services tend to be place-specific, restricting the application of that knowledge to “nature-based solutions” to urban challenges in a broader geographical context. Nature-based solutions refer to the variety of different engineering and planning interventions to manage various urban planning challenges, defined by the European Commission as “*solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions which are inspired by, supported by or copied from nature*” (Bauduceau, Berry, Cecchi, Elmqvist, Fernandez, & Hartig, 2015; Fusaro, Marando, Sebastiani, Capotorti, Blasi, & Copiz, 2017). There has, in recent years, been considerable investment in green infrastructure and nature-based solutions (Vandermeulen, Verspecht, Vermeire, Van Huylenbroeck & Gellynck, 2011). The EU has made considerable commitments to invest in research into nature−based solutions under Horizon 2020, allocating 140 million euros for this research theme (Faivre, Fritz, Freitas, de Boissezon & Vandewoestijne, 2017). As such, nature-based solutions may provide answers to many problems associated with urbanisation, use of stormwater ponds and vegetated swales for holding and slowing storm surges, vegetated roofs for reducing air conditioning costs, the establishment of hedges to reduce noise pollution are becoming more commonplace (Amir, Katoh, Katsurayama, Koganei & Mizunuma, 2018; Biocca, Gallo, Di Loreto, Imperi, Pochi, & Fornaciari, 2019; Greenway, 2017). Increased greening in cities is not only linked to biodiversity benefits but also in providing social and cultural services such as the aesthetic value and wellness enhancement (Aerts, Honnay & Van Nieuwenhuyse, 2018).

However, despite the longstanding use of nature in cities, the study of nature-based solutions is a relatively new field of research and there are still many research challenges to consider. For example, often studies discussing the role of ecosystem services and nature-based solutions discuss generic vegetation types and lack granularity when discussing how species interactions contribute to ecosystem services (Lavorel, 2013). In the context of the homogenisation of urban vegetation, it is critical to establish a suite of species that are suitable for delivering nature-based solutions, native to the area in which they are being employed, and ecologically and socially suitable for the habitat.

Previous reviews of ecosystem service provision in urban environments have incorporated elements of biodiversity in a broad context rather than exploring links between services and particular taxa (Haase, Larondelle, Andersson, Artmann, Borgstrom, & Breuste, 2014; Luederitz et al., 2015). Other studies have also focused specifically on ecological research or single areas of research. For example, Ziter (2016) comprehensively reviewed ecological studies on the biodiversity-ecosystem service relationship but did not include studies primarily focused on economics or social sciences which still may provide valuable information on ecosystem service provisioning. There is also a wide range of (dis) service-specific reviews dealing with topics from air pollution to invasive non-native species (Branco, Videira, Branco & Paiva, 2015; Gourdji, 2018). Taking urban plants as a focal taxon, we suggest that a greater understanding of vegetation dynamics will enable us to understand key relationships between plants and ecosystem services. Such an understanding would highlight gaps within our current knowledge of which taxa are most appropriate to facilitate ecosystem services within urban areas.

The purpose of this systematic review is to map and categorise our understanding of the role of vegetation in the provisioning of ecosystem services and nature-based solutions with a particular emphasis on the dynamics of ecosystem service provision in urban green and blue space. To gain insight into the scope of current urban plant research, we focus on four broad questions: (i) What is the distribution of research effort across different habitats or plant communities studied? Understanding the mechanisms and services provided by different vegetation types is critical for effectively understanding, managing, and implementing ecosystem services and nature-based solutions within urban areas. (ii) Which services and disservices have been the focus of the urban plant ecology literature? For example, temperate urban areas are often focused on hydrological management (flood or drought), but climate change commitments are likely increasing the use of plants for carbon capture and storage. Understanding where the current focus lies can help to target future research to neglected but promising service enhancement and identifying potential disservices can help minimise disruptions in urban areas. (iii) Which geographic regions are best represented in the literature? Due to the perceived expense of nature-based solutions installation, their use and study are likely to be restricted to wealthier countries. However, countries with lower socioeconomic development may benefit more from the use of nature-based solutions. Geographic patterns could help to identify future opportunities to translate learning among countries. (iv) To what extent are nature-based solutions recognised or utilised in the context of ecosystem services provided by plants? With research and interest increasing in the use and implementation of nature-based solutions what is the current knowledge base for urban planners to draw upon?

Materials and methods

The literature search for the review used the ISI Web of Science database and SCOPUS search engines and the search included records from 1st January 1911 to 1st June 2020. We defined suitable vegetation systems to include in the analysis as based on Kettenring and Adams (2011) who undertook similar work on invasive plants within urban areas. The search terms that we used to identify relevant papers in Scopus were: TITLE-ABS-KEY(macrophyt* OR alga* OR plant* OR seed* OR herb* OR flora* OR veget* OR botan* OR tree* OR shrub* OR bryophyt* OR grass*) AND TITLE-ABS-KEY ("ecosystem servic*" OR "nature-based solut*" OR "nature based" OR nature-based) AND TITLE-ABS-KEY(cit* OR urban*). In Web of Science, the terms were: TS = (macrophyt* OR alga* OR plant* OR seed* OR herb* OR flora* OR veget* OR botan* OR tree* OR shrub* OR bryophyt* OR grass*) AND TS = ("ecosystem servic*" OR "nature-based solut*" OR "nature based" OR nature-based) AND TS = (cit* OR urban*).

Due to the interdisciplinary nature of ecosystem service work we did not limit the database to fields of study. Instead, we included all subjects including medicine, virology, and healthcare. We did not exclude publications based on language and so non-English language publications are included but were not screened. We extracted the following records from both engines: author, title, keywords, publication date, abstract, citations, DOI. Duplicate records were removed using EndNote Online duplicate removal function and then further manually checked. The systematic review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, http://www.prisma-statement.org/) system in Fig. 2 and selected abstracts moved on to the next stage of screening.

Abstract screening

The machine learning program ABSTRAKR, an abstract and systematic review management tool designed to aid researchers in organising and screening large volumes of papers was used by the researchers to aid in screening abstracts (abstrackr.cebm.brown.edu 2020). ABSTRAKR aids researchers by providing them with a web-based annotation tool that allows participants in a review to screen citations collaboratively, and machine learning technologies that prioritise papers in the screening queue according to relevance (Wallace, Small, Brodley, Lau & Trikalinos).

All unique abstracts from both search engines were included for the first screening process by SS (n = 2011). Studies selected for full screening generally featured specific vegetation types, habitats (i.e. semi-natural grassland/floating ecosystem) or plant species. These could be from any urban or peri-urban environment and discussed ecosystem services. We rejected any papers not relevant to ecosystem services provisioned by vegetation or specific plants in urban or peri-urban environments (n = 543). The screening resulted in the final set of full texts (n = 1234) that were used for data extraction (Fig. 1).

Kappa analysis

Cohen's Kappa is a commonly used statistic that measures inter-observer reliability, sometimes called interobserver agreement (McHugh, 2012). A Kappa analysis was performed between two authors (SS and CH) on a subset (n = 150) of randomly selected abstracts from the two

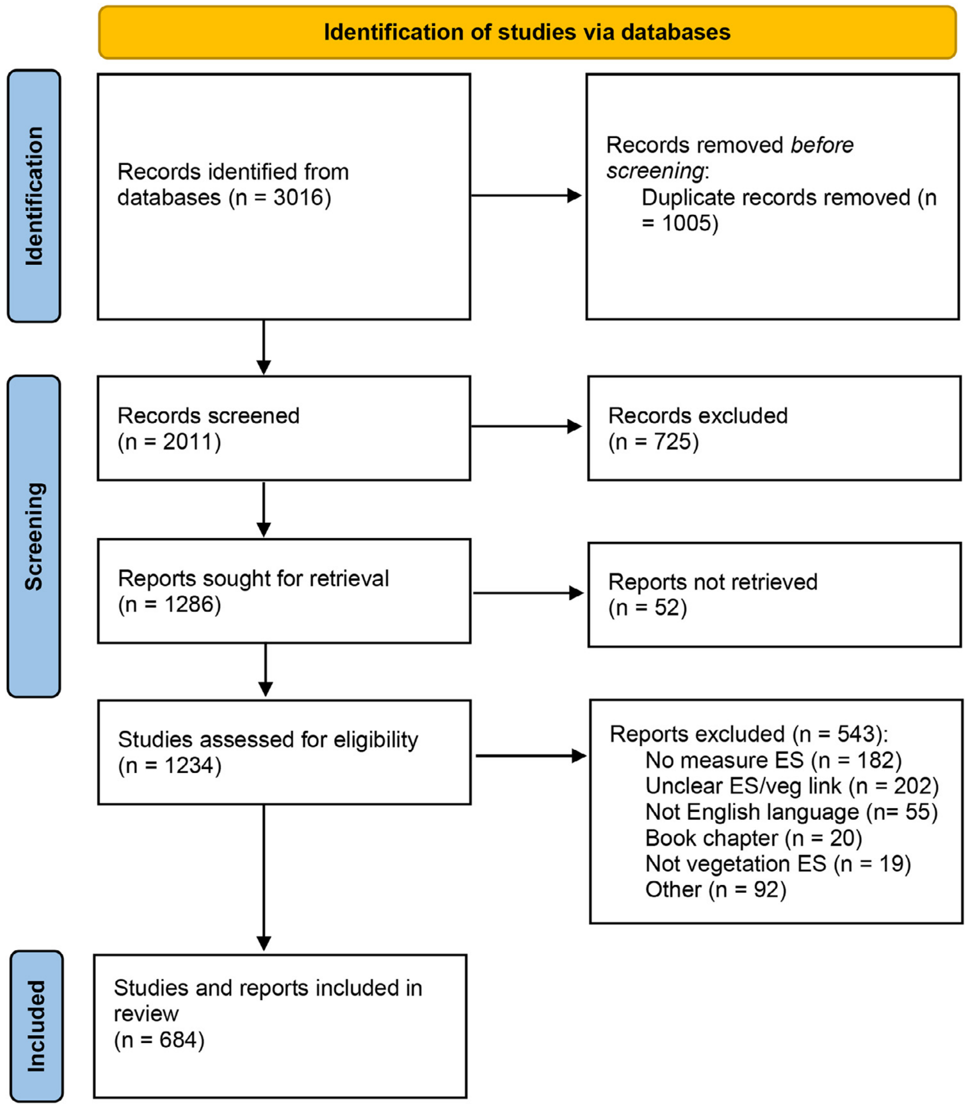

Fig. 1. PRiSMa flow chart detailing the process of study and abstract collection and elimination for the systematic review (prisma-statement.org).

literature databases. Within our study, the Kappa statistic measures the level of agreement between two authors on the eligibility of papers for the final analysis. The authors reached a substantial agreement with Cohen's Kappa measured equal to $K = 0.7$.

Data extraction

When reviewing studies, authors considered relevant studies as those concerned with a fundamental and applied understanding of plant biology in urban environments, biological invasions, ecosystem services, horticultural sciences, ecological economics, management of plants, policy and governance of ecosystem services or urban vegetation management, the social and cultural value of vegetation, social and health impacts of plants, mapping of urban vegetation or greenspace change and urban agricultural systems. All recorded were extracted by SS. We also included remote sensing and monitoring studies with a focus on generic vegetation/greenspace if there was a clear ecosystem service or disservice focus. Studies were then categorized by the authors via the type of vegetation systems featured, geographic details, methodological and research methods, economic outputs, and details of nature-based solutions featured.

Studies or categories where there was a degree of uncertainty were discussed between SS and CH until a conclusion was reached. The final set of variables extracted from papers can be seen in Table S1. Proportions of urban plant studies were calculated from the total average volume of ecosystem services research papers published for each relevant year from the Web of Science and SCOPUS databases. This value was identified by searching "ecosystem service", then averaging the output of both databases each year from and calculating the proportion represented by our featured studies.

The studies screened for this review only contain published research articles and do not include grey literature. Reports on some important systems may be found in the grey literature (e.g., government reports) rather than solely in publications included in the Web of Science and SCOPUS databases. Research themes were based on a published classification of research perspectives (Luederitz et al., 2015), ecosystem services were identified as defined by CICES (Haines-Young et al. 2012), and disservices categories as per (von Döhren & Haase, 2015).

Results

Geographic, temporal and spatial, descriptive

The initial search resulted in 3016 retrievals, of these 1005 were duplicates. After the initial screening of titles and abstracts, the number of remaining papers was 1286. We further excluded 602 studies for lack of either clear ecosystem service or vegetation links. Some studies were not included because they were not in English. We have included these within the appendix should others with the linguistic skills wish to build upon this work. A visual representation can be seen in the PRiSMa flow chart below (Fig. 1). For full details of PRiSMa terminology see Page, McKenzie, Bossuyt, Boutron, Hoffmann, and Mulrow (2021).

Most studies we identified were not open access, only 32% (n = 218) were open access and the remaining 68% (n = 466) were behind journal paywalls. The number of published studies reporting on the ecosystem services associated with urban vegetation has been steadily increasing throughout the last two decades, the largest number of studies reported was in 2019 (n = 150). The percentage of studies featuring urban vegetation and ecosystem services and disservice relative to total published research in the field of ecosystem services can be seen in Fig. 2 below. We note a steady increase in the proportion of papers that are being published in the field of vegetation ecosystem services since 2004. We found only a single study before 2004, due to the novelty of the term prior to the early 2000s. If we consider the whole field of ecological research, “ecosystem services” are first featured in a 1983 paper by Ehrlich and Mooney (Ehrlich & Mooney, 1983), whereas by 2005 there were approximately 100 papers in the field (West, 2015), it is therefore not unsurprising to note few studies during this period.

Studies tended to be carried out over short timescales, with 41% collecting data over a single year or field season. Most studies (64%) were conducted for a period of fewer than five years (Fig. 3). Many of the longer-term studies examined land use or land cover change using remote sensing methodologies such as (Mugiraneza, Ban & Haas, 2019) work on ecosystem service supply, urban land cover dynamics and multitemporal Landsat data.

We were able to identify 513 locations from 82 different countries, although literature reviews or metanalyses may not list countries and regions of origin. While this research was very widely distributed with publications reporting data from each continent, studies were clustered in Europe, Asia, North America, and Oceania, with fewer studies in Africa, South America, Central America, and southern, western, and central Asia (Fig. 4). There were fewer research articles from plant ecosystem services developing regions such as South America, South Asia and Africa. Almost a third of studies (29%) were conducted in the USA (n = 137) and China alone (n = 92), with 39% of the remaining studies focused on European countries (n = 251). Within Europe, most studies came from Germany (n = 52), Italy (n = 48) and the United Kingdom (n = 39). Regarding individual cities, the single most featured city was Beijing, (n = 18), then Rome (n = 17), followed by New York (n = 16), Berlin (n = 15), and Helsinki (n = 15).

The most common location for studies was either *temperate broadleaf and mixed forest biomes* (41%), then *Mediterranean forests, woodland, and scrub* (19%), *tropical and subtropical moist broadleaf forests* − mostly China (16%), *temperate coniferous forests* (6%) and *taiga* (4%). The remaining 10 biomes featured made up less than 14% of represented studies. We found around 8% of studies featured some form of urban blue-space, such as floating ecosystems or sustainable urban drainage systems (Fig. 6).

Research perspectives and methods

Of the six ecosystem service research perspectives as defined by Luederitz et al. (2015), *ecology* was largest with 50% of studies having an environmental science focus. *Social* perspectives were the second largest with 22% of studies dealing with social behaviour, perceptions, and health. The remaining perspectives were much less commonly featured. *Methods/tools/guidelines* was the focus of 14% of studies, *governance* 6%, *planning* 5%, and *economics* 4%. Study designs were overwhelmingly *descriptive* (50%), with the remaining studies being evenly split between *reviews* (13%), *applied* (13%), *experimental* (12%), and *observational studies* (11%).

In total, we identified 202 research methods, with a total of 1479 instances of these methods being used across reviewed studies. The most employed method was *remote sensing* (15%), *field survey* (9%), *modelling* (9%), *literature review* (9%), *stakeholder engagement* (8%) and *ecosystem service assessment* (4%) (Fig. 5). Some of the novel methods recorded were VR technologies to identify restorative impacts of different vegetation types on participants (Nejati, Rodiek & Shepley, 2016), the use of scanning electron microscopy to identify leaf micromorphology for particulate pollution capture (Sgrigna, Baldacchini, Dreveck, Cheng & Calfapietra, 2020), and the use of biomass digestion experiments to access the potential of greenspace to

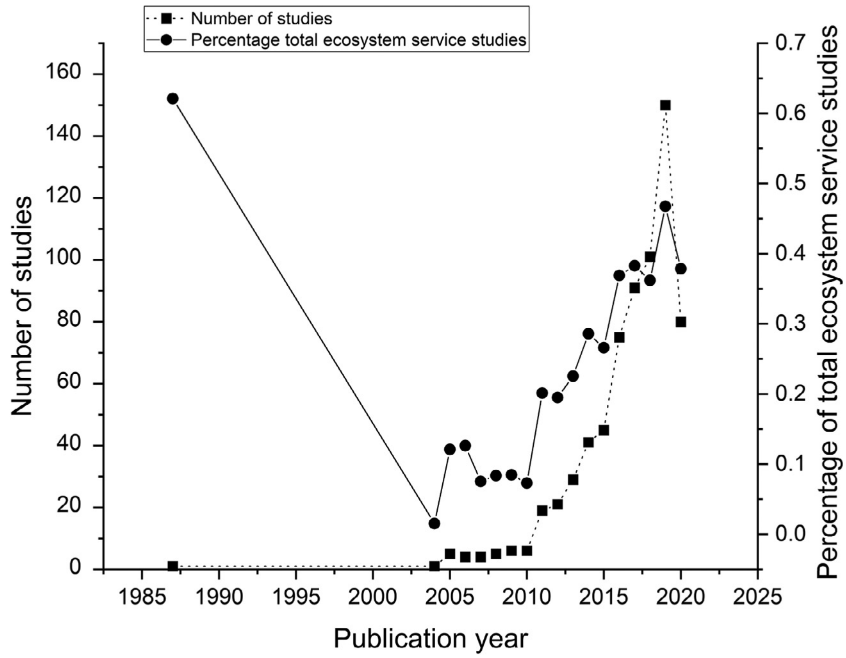

Fig. 2. Percentage of publications (n = 684) integrating urban vegetation ecosystem services research relative to the total scientific production in the field of ecosystem services annually as calculated from averages of the two databases used in this study, Web of Science and SCOPUS. The increased percentage of studies in 1987 is due to the rarity of the term ecosystem services before the 2000s.

produce biofuel (Piepenschneider, Buhle, Hensgen & Wachendorf, 2016). The variety of different research methods reflects the broad scope of our review. Notably, we identified few studies (2.5%) with a framework and policy focus, i.e. studies which discuss actions or decision-making to direct a detailed set of policies or strategies for ongoing maintenance and goals. However, we did not explicitly include a search term that included frameworks or policy and these documents may be less likely to be published in academic literature.

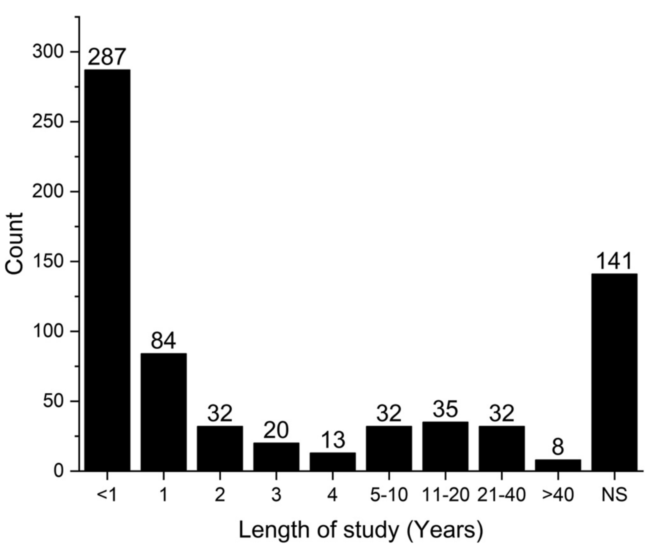

Fig. 3. Timescale of studies featured within the ecosystem service literature (n = 684), majority of studies collecting data only over a single year or single field season and most studies were conducted for less than five years. The number on top of the bars represented the total incidence of study length. Most literature-based studies (reviews and meta-analyses), were categorised as either thematic or not stated regarding study length, other review papers reported respective dates of data sources. NS = not stated.

Vegetations and habitats

In total, we identified 21 different vegetation and habitat types from 1301 different instances across the literature. The majority of studies focused on either *forest habitats* (15%), followed by *generic greenspace* (11%), *urban parkland* (8%), *urban trees* (6%), *urban agricultural or food-producing land* (8%), *green infrastructure* (5%), *urban blue space* (4%) and *urban grassland* (4%) (Fig. 6). For additional vegetation systems see Appendix S4. Studies were generally focused on terrestrial systems (87%) rather than aquatic systems (13%).

In total, we identified 54 different vegetation types featured 1023 times across the literature. Many studies focused on trees or forests (37%), followed by generic vegetation (20%), grasslands (11%), aquatic vegetation (6%), crop plants (5%), shrubs (4%) herbaceous vegetation (4%) and riparian vegetation (2%) (Fig. 7). For additional vegetation details see Appendix 5.

Out of the 684 studies in the dataset, 68% (n = 468) did not list the specific species studied. In total there were 879 unique species or genera reported. The most frequently mentioned species were *Robinia pseudoacacia* (L.) and *Tilia cordata* (Mill.), with both being featured in 28 studies, closely followed by *Acer platanoides* (L.) (n = 27). Other commonly featured species were *Acer negundo* (L.)

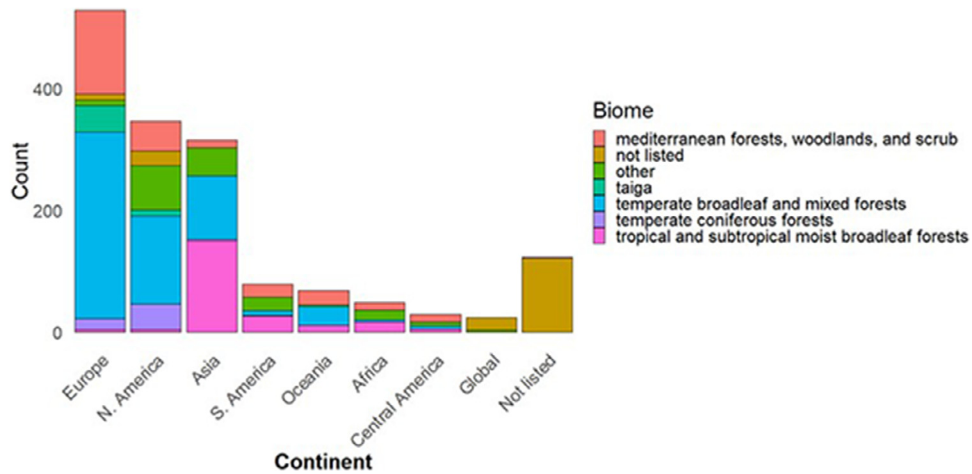

Fig. 4. Location of studies included in the systematic review that was explicitly specified in the publications looking at ecosystem services and disservices provided by plants globally (n = 684). Note more than one location could be specified per study and some review articles may not contain locations.

(n = 17), *Aesculus hippocastanum* (L.) (n = 15), *Quercus ilex* (L.) (n = 13), *Betula pendula* (Roth.) (n = 12), and *Quercus robur* (L.) (n = 12). For those studies that give species-level data, the five most frequently featured species make up 50% of all records.

When accounting only for genera there was a different spread, in total 464 different genera of plants were reported. The single most frequently reported genus of plants were *Acer* spp. (6% of genera reported), *Quercus* spp. (5%), and *Pinus* spp. (4%). *Tilia* spp., which dominated species-level data made up only 4% of total reported genera, whilst *Robinia* sp. Accounted for <2%. Full species and genera lists can be found in Appendix 2.

Ecosystem services

The evaluation of ecosystem services themes was highly uneven. Regulation and maintenance were evaluated by most studies (54%), followed by cultural (28%), and provisioning (16%) (Fig. 8). Disservices and “generic” ecosystem services (i.e., those which used a model to create a generic ES value) were the focus of a small number of studies.

A total of 57 regulation and supporting ecosystem services were reported in the literature with a total of 1285 individual service examples across 529 studies (Fig. 8A). The most studied regulation and supporting ecosystem service classes were

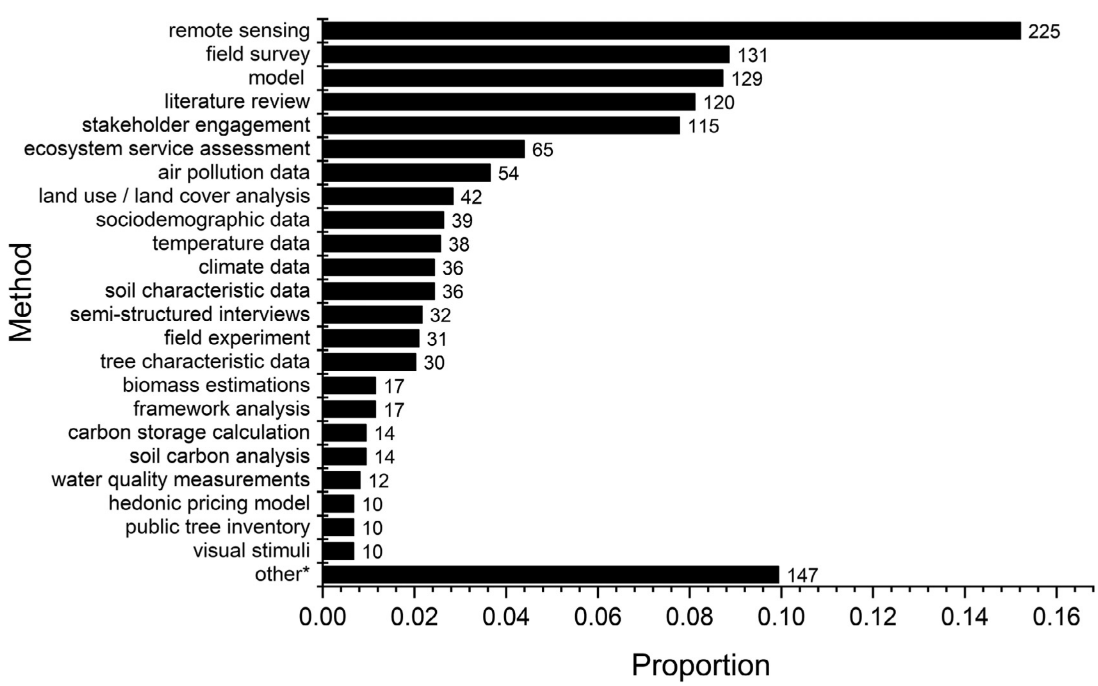

Fig. 5. methodology of studies included in the systematic review (n = 684). Numbers of top of bars represented total times methods were featured and studies may feature multiple methods.

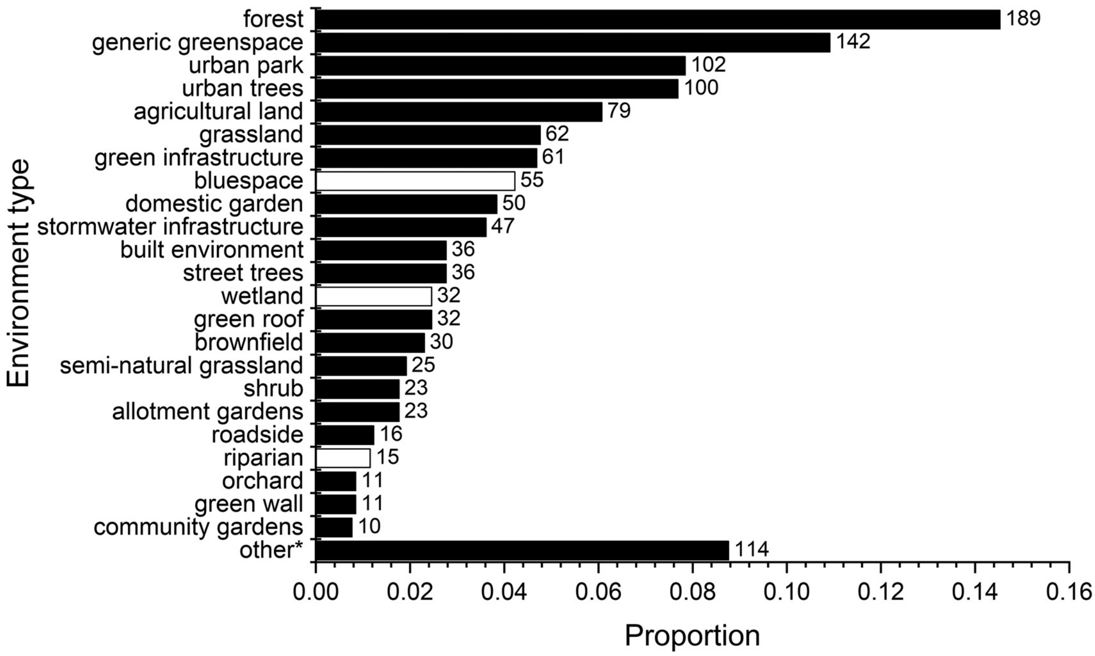

Fig. 6. The type of ecosystem that was principally investigated or discussed in each publication (*n* = 684). Figure showing only those environments with more than 10 instances of occurrence, publications may have multiple investigated ecosystems. Numbers on top of bars represent total number of times environments were featured, and studies may feature more than one environment. Bars in white represent aquatic or riparian systems.

focused on the *regulation of chemical composition of atmosphere and oceans* (28%), *regulation of temperature and humidity* (15%), followed by *hydrological cycle and water flow regulation* (12%) and *maintaining nursery populations and habitats* (9%) (Fig. 8A). It should be noted *regulation of chemical composition of atmosphere and oceans*, was split between several unique classes, namely *carbon sequestration* (9%), *air pollution management* (8%), and *generic air quality regulation* (5%) whereas other regulation groups generally comprised of only a single class of services.

We identified 38 different cultural ecosystem services from 647 individual service examples across 283 studies

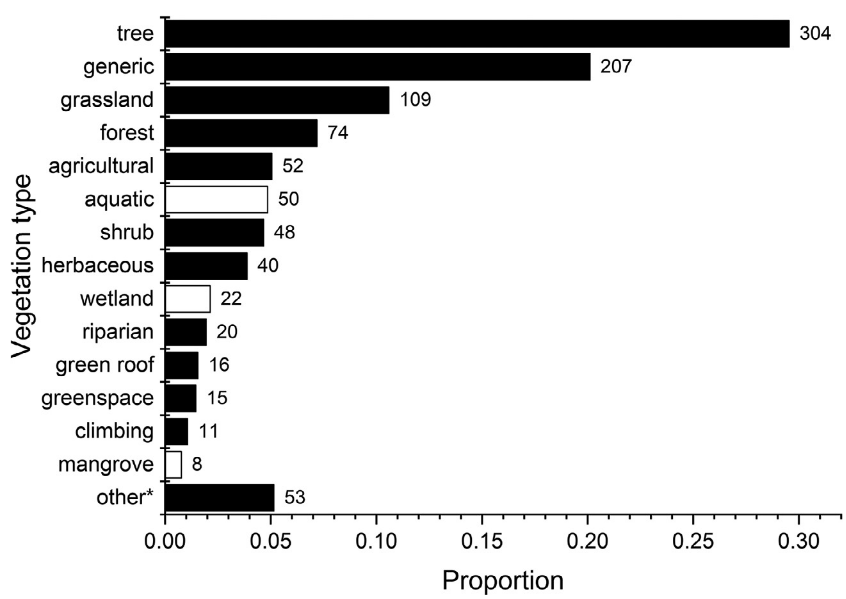

Fig. 7. Vegetation focuses of each of the 684 studies from this review. Showing only vegetation types with more than five instances of occurrence. Numbers represent the total number of times vegetation types were featured, and studies may feature more than one vegetation type. Generic vegetation refers to the non-specific study of green spaces in cities, usually derived from satellite mapping based on NDVI or nondescript descriptions of sites with few details of vegetation types featured. Bars in white represent aquatic or riparian systems.

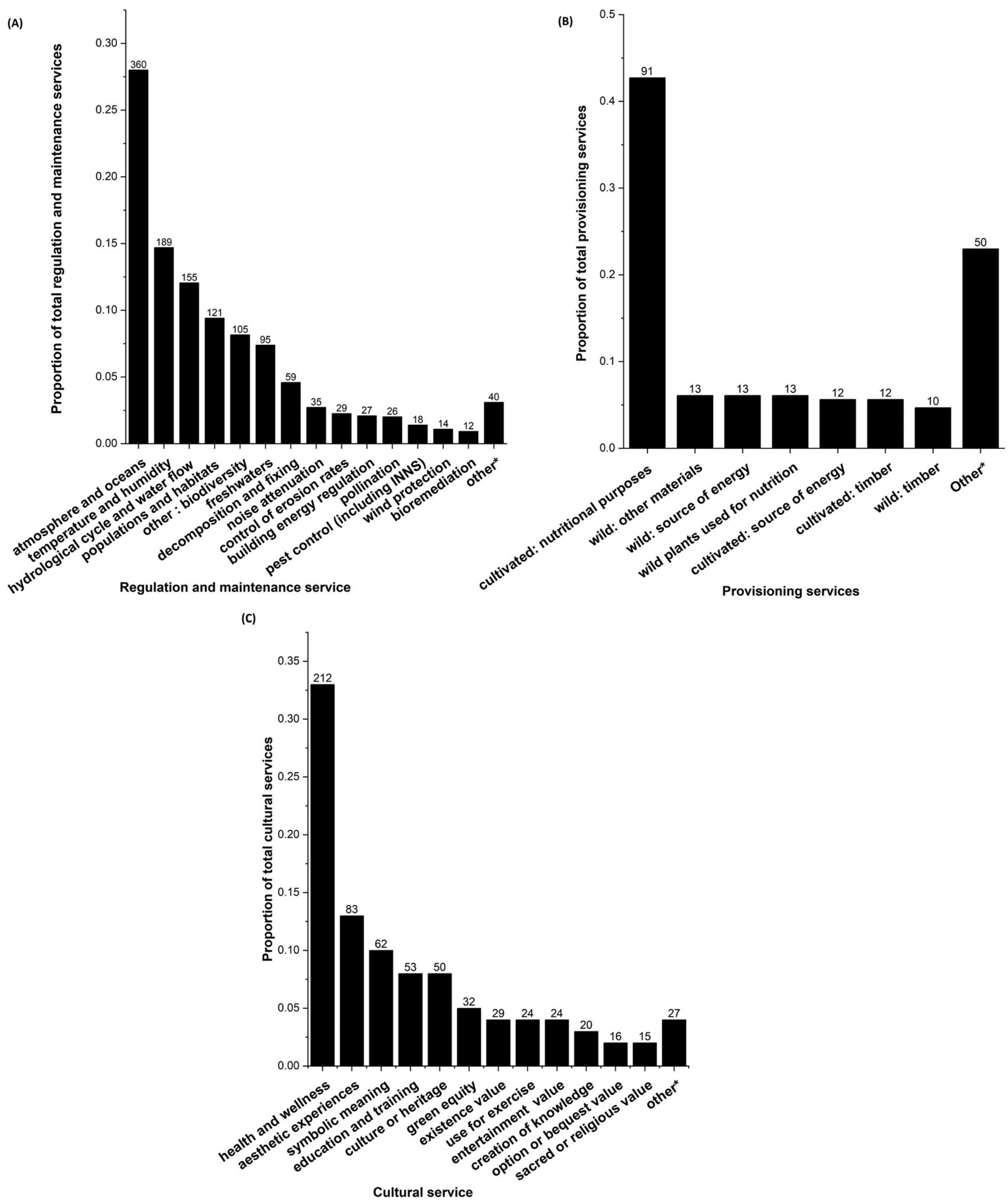

Fig. 8. The distribution of ecosystem services examples produced by vegetation in urban and peri-urban areas examined throughout the research literature ($n = 684$). The services were assigned to the CICES categories. Only ecosystem services with more than 10 instances of occurrence are shown. On top of the bars are the total numbers of studies mentioning an ecosystem service and studies may feature more than one ecosystem service.

(Fig. 8C). The most featured cultural ecosystem service classes were overwhelmingly *the characteristics of living systems that enable activities promoting health, recuperation, and enjoyment* (33%) followed by *aesthetic experiences* (13%) and *elements of living systems that have symbolic meaning* (10%). Other cultural services which featured were *education and training* (8%), *living systems that are resonant in terms of culture or heritage* (7%), and *green equity* (6%) (Fig. 8C). The single largest specific cultural ecosystem service group was *physical and experiential interactions with natural environment* ($n = 237$) followed by *intellectual and representative interactions with natural environment* ($n = 217$)*, spiritual, symbolic and other interactions with natural environment* ($n = 88$)*, Other biotic characteristics that have a non-use value* ($n = 46$), and *other* ($n = 59$). There was a variety of novel services reported such as the use of urban gardens for the staging of disaster relief and memorialization.

Provisioning ecosystem services were the least frequently reported ecosystem services within the literature, reported in 136 studies. In total there were 26 reported provisioning ecosystem services, with 214 individual service examples (Fig. 8B). The most-reported provisioning ecosystem service class was *the use of cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes* (43%) whilst the use of *wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition* accounted for 6% of provisioning services. *Timber from either wild or cultivated plants* was featured 22 times (11%), with *fibres and other materials from cultivated plants, fungi, algae and bacteria* accounting for 6% and *fibres and other materials from wild plants for direct use or processing* for 5% of provisioning services (Fig. 8B). The remaining 15 provisioning services all featured fewer than 10 times though accounted for 23% of those reported. These include services such as wild plants used for fibres, livestock fodder, and the creation of non-timber wood products. The two main groups of provisioning services were *Cultivated terrestrial plants for nutrition, materials or energy* (57.5%) and *Wild plants (terrestrial and aquatic) for nutrition, materials or energy* (37%), other provisioning groups accounted for only 5% of services.

Disservices

We identified a broad range of 52 unique disservices provided by urban vegetation with a total of 283 occurrences from 95 studies. The most commonly occurring disservice themes involved health impacts (n = 56), material impacts (n = 36), and cultural or aesthetic impacts (n = 30), followed by ecological (n = 19), then safety and security (n = 17). The least reported disservices were leisure and recreational (n = 13) and generic (n = 4). The single largest specific disservices were those involving *biogenic volatile organic compound emissions and allergenic potential* (16%), followed by *aesthetical appeal of vegetation* (10%), *cost of management* (7%), *potential to encourage pests* (7%). The most-reported vegetation types within disservices were *trees* (45%) or *forests* (14%), *generic vegetation* (14%), and then grassland (9%). Disservices were also associated with aquatic and riparian vegetation, herbaceous vegetation, green roofs, and green walls (Fig. 9).

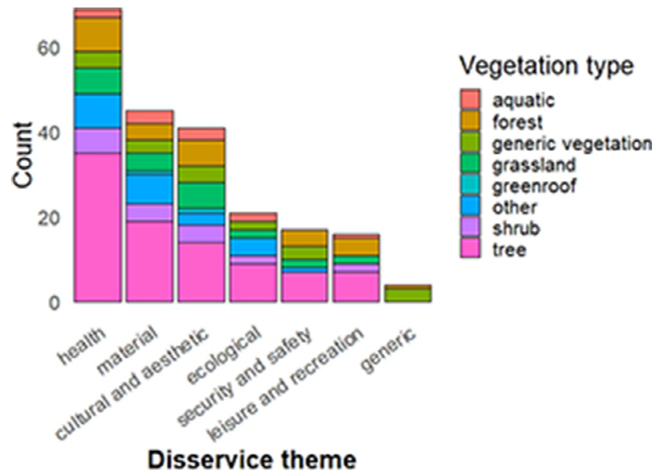

Fig. 9. Ecosystem disservice themes featured and their associated vegetation types (n = 95). On top of the bars are the total of studies mentioning an ecosystem disservice (studies may feature more than one disservice).

Nature-based solutions

Only 20% of screened studies (n = 192) mentioned nature-based solutions. From these studies, we identified 20 unique nature-based solutions, and of these most studies focused on a single nature-based solution (80%). Nature-based solutions were mostly focused on terrestrial systems (78%) whilst aquatic or riparian solutions accounted for 22% of those featured. In total, we identified 21 different contexts within which vegetation was used in a nature-based solution with 187 different instances across the literature. Most commonly, studies featured green roofs (19%), followed by trees (18%), bioretention areas (11%), generic green infrastructure (11% - papers discussing benefits of green infrastructure without identifying specific vegetation), green walls (10%), and generic urban vegetation (7%; generic vegetation refers to the non-specific study of green spaces in cities, usually derived from remote sensing technologies or descriptions of sites with minimal details of vegetation). Other nature-based solution types make up the remaining 25%. Further details can be found with Appendix table S6.

Discussion

We present an overview of the literature on ecosystem services and disservices provided by plants in the urban environment, and nature-based solutions facilitating those services. We note that there are fewer studies on aquatic plants and their associated ecosystem services as most studies in our sample focused on terrestrial ecosystems rather than urban blue space. There has been continuous growth in the proportion of papers discussing vegetation in relation to the total output of ecosystem services research since the early 2000s. Research was generally conducted under short timescales with many studies utilising only a single field season of data. The results from our sample show that studies in the temperate and tropical regions of North America, China, and Europe are well represented. Research frequently focused on large vegetation structures such as trees, parks, and forests, and had a strong terrestrial focus. We noted a distinct lack of species-level data and taxonomic biases within published studies, with 68% of studies not listing species-level data. Ecosystem services classes were dominated by regulation and maintenance services, followed by cultural and provisioning. Reported disservices frequently focused on health, material, and cultural and aesthetic impacts and were associated strongly with trees and forests.

Vegetations, habitats, and species

One finding from our research was the lack of taxonomic detail in studies discussing vegetation. Of the studies, we screened almost two-thirds did not identify vegetation beyond broad habitat or generic terms. This lack of data on species-level function, response, and uses within urban areas leads to challenges in the practical development and design of greenspaces. We noted few studies focusing on several neglected groups, namely bryophytes, pterophytes, but also lichens and fungi. Incomplete taxonomic detail may result in the selection of species inappropriate or ill-suited to supplying ecosystem services which could lead to wasted municipal funds and ultimately cause disservices (Sjoman, Hirons & Bassuk, 2015). What should be noted is for some groups there were comprehensive management considerations, for example, the allergenic impacts of fruit tree species (Carinanos, Grilo, Pinho, Casares-Porcel, Branquinho, & Acil, 2019b; Carinanos, Delgado-Capel, Maradiaga-Marin & Benitez, 2019a). Without investment into either research or the harnessing of local or traditional ecological knowledge to identify the function of urban plant communities, it will be challenging to develop policies to enhance ecosystem system services in understudied regions. There are some notable examples of where research has been well utilised. China has spent considerable sums on green infrastructure and research on projects such as the Sponge Cities Program (Chen & Warren, 2011; Li, Ding, Ren, Li & Wang, 2017). This program has been focused predominantly on urban water management by restoring historic water features and the inclusion of nature-based solutions (bioswales, vegetated retention ponds) in Wuhan, and has been successful in alleviating flooding (Chan, Griffiths, Higgitt, Xu, Zhu, & Tang, 2018).

Blue-green space

Whilst we did see some studies focus on aquatic habitats, this was small (8%) (Fig. 4), most literature focused on terrestrial environments and species. As such, there was relatively poor reporting of aquatic species-level data. The most frequently reported genus of aquatic or wetland plants was *Salix* spp. (n = 17), followed by *Typha* spp. (n = 4) and *Phragmites* spp. (n = 4). Freshwater ecosystems are some of the most threatened globally, particularly in urban areas due to the extensive local and landscape-scale modifications (Hassall, 2014; Hill et al., 2017; Waltham, Burrows, Wegscheidl, Buelow, Ronan, & Connolly, 2019). Without a clear understanding of the ecosystem services provided by aquatic ecosystems, their benefits may be overlooked, or habitats used inappropriately. In studies that discuss the benefits of urban waters and vegetation, it is evident that these habitats not only represent crucial refugia for aquatic biodiversity but also provide a range of ecosystem services. One study estimated the value of wetland services in Jiangbei in China to be USD 1016.46 million (Tang, Wang & Wu, 2019), whilst others have demonstrated the ability of urban riparian vegetation to be highly effective at denitrification of urban stormwaters (Groffman & Crawford, 2003). Addressing global inequalities in aquatic systems research to understand the roles individual species perform in these regions, and how these may best be utilised to protect and enhance urban freshwaters and spaces is critical (Garcia, Barcelo, Comas, Corominas, Hadjimichael, & Page, 2016; Maes & Jacobs, 2017). Without knowing the effectiveness of species for use in nature-based solutions and how they facilitate ecosystem services, there is a risk that inappropriate plants will be used that do not enhance areas and lead to species invasion and/or disservices (Rai & Singh, 2020).

It is well established that most human settlements and cities are located close to the coast, with 40% of the world's population living in coastal areas (Barragán & de Andrés, 2015). Despite this, we found little focus on the regeneration of estuarine and coastal vegetation systems in relation to ecosystem service. The notable exception to this theme is a body of work on the regeneration of mangrove systems, generally undertaken in Asia, which noted the significance of mangrove forests in coastal protection and disaster mitigation (Avtar, Kumar, Oono, Saraswat, Dorji, & Hlaing, 2017; Lee, Tay, Ooi & Friess, 2020).

Geographic, temporal and spatial, descriptive

The study of vegetation within urban systems is rapidly expanding (Fig. 2), which is unsurprising considering the relative novelty of the field, the amount of investment being made in research and infrastructure on ecosystem services. One reason for the increase in publications is investment from research institutions such as the EU, these research funds have been made available to reduce public expenditure through increasing the effectiveness of management interventions with the additional benefits of increasing the ecological quality of urban areas (Faivre et al., 2017). Our results match similar trends in the distribution of ecological studies globally (Fig. 4) Martin, Blossey and Ellis (2012). mapped the global distribution of ecological studies and found the geographic distribution of studies was uneven with the overrepresentation of protected areas, temperate regions, and wealthier countries. Concerningly, many of the world's biodiversity hotspots are not featured within the ecosystem services literature, with few studies being reported from South America, Africa, and Asia, although our findings demonstrate that China is well represented (Fig. 4). With increasing urbanisation globally it is vital to understand how native species can contribute to people's health, sustainable urban design, and maintaining viable ecosystems and their services whilst mitigating against the negative impacts of urbanisation (Cobbinah, Erdiaw-Kwasie & Amoateng, 2015). Only a few studies in this review looked at services based on native vegetation in the Global South, such as Basu and Nagendra (2020) and Khan, Jhariya, Yadav and Banerjee (2020) which both discussed urban green equity and ecosystem services. As such, future work should focus on accessing, identifying, and funding the research needs of the Global South, as it is clear that economics drive the abundance of research in the West and China (Leimu & Koricheva, 2005).

Disservices

Relatively few studies featured disservices, with only a handful directly looking at ecosystem disservices as their focus (Fig. 9). Trees were the most reported vegetation associated with disservices followed by generic vegetation, forests, and grasslands. It has been noted that there is a culture of unsuitable tree planting, particularly in urban greening projects, which may not acknowledge that trees and their management can have environmentally negative impacts (Roman, Conway, Eisenman, Koeser, Barona, & Locke, 2021). These associated management challenges include risks to people by falling trees or limbs, and to buildings through the action of their roots or limbs breaking, though it has been noted that the majority of tree or branch failure can be detected and thus risk mitigated with appropriate maintenance (Klein, Koeser, Hauer, Hansen & Escobedo, 2019). They also produce large quantities of organic debris which can be unsightly and disrupt drainage systems (Cherqui, Belmeziti, Granger, Sourdril & Le Gauffre, 2015; Graca, Queiros, Farinha-Marques & Cunha, 2018). Various compounds produced by trees are harmful or irritable to human health such as volatile biogenic organic compounds which induce allergies, thus tree planting needs appropriate selection, management, and planning (Chen & Liang, 2020; Fernandez-Rodriguez, Cortes-Perez, Muriel, Tormo-Molina & Maya-Manzano, 2018; Ren, Qu, Du, Xu, Ma, & Yang, 2017). Health impacts (both negative and positive) are likely commonly featured due to detailed socioeconomic and health data for municipal areas with public tree inventories (Carinanos, Casares-Porcel, de la Guardia, Aira, Belmonte, & Boi, 2017, 2019a; Escobedo, Kroeger & Wagner, 2011). Cultural and aesthetic disservices featured prominently in the literature including, unattractive vegetation, perception of increasing crime, and perception of increasing litter (Delshammar, Östberg & Öxell, 2015; Graca et al., 2018). What is clear from many of these studies is the role cultural values and norms play in perceptions of disservices of vegetation. For example, one study in the US found that pondside and garden vegetation was frequently managed with neighbourhood aesthetic expectations as a key motivation rather than sympathetic management for environmental quality (Monaghan, Hu, Hansen, Ott, Nealis, & Morera, 2016). Future work should continue to build upon methods to address and reframe urban and sub-urban landscaping practice towards ecologically sympathetic norms, particularly around homogenous areas which could be utilised for multiple service supply (Southon, Jorgensen, Dunnett, Hoyle & Evans, 2017).

Some studies did note the conflicts of management of non-native invasive species in developing regions: where native species have been excluded, invasive species may now supply vital services to local populations (Dickie, Bennett, Burrows, Nunez, Peltzer, & Porte, 2014). Non-native species occupy an unusual space within urban areas. Frequently we see a common suite of non-native species utilised for their aesthetic popularity, resilience, and management (Bayón, Godoy, Maurel, van Kleunen & Vilà, 2021). One propagule pressure is the horticultural trade which had resulted in the widespread movement and homogenisation of urban floras, worrying invasive non-native species remain for sale even post-control legislation is enacted (Beaury, Patrick & Bradley, 2021). Gardening and urban landscaping have long been considered significant players in global change and as such greening projects and green infrastructure should, wherever possible, focus on utilisation of native species including avoiding seed mixtures of cultivars or introduced provenances of native species (Fischer, von der Lippe, Rillig & Kowarik, 2013; Kiehl, Kirmer, Donath, Rasran & Hölzel, 2010; Niinemets & Peñuelas 2008).

Reliance on remote sensing methodologies

Large green spaces, such as urban forests, parks, and other generically defined green spaces, were a key focus of studies from our sample and other marginal habitats were less well represented (Fig. 6). This is not unsurprising considering that these are probably the most frequently encountered areas of vegetation by people in urban areas (Elmqvist et al., 2004). However, this emphasis fails to account for the variety of different ecosystems which are encountered throughout urban areas and their contribution to ecosystem service supply. Several studies did focus on marginal habitats such as road verge vegetation, vegetation under power lines, and spontaneous vegetation (Mathey, Arndt, Banse & Rink, 2018; Seamans, 2018). For example, the carbon sequestration capacity has been evaluated in roadside vegetated filter strips and swales and findings demonstrated that wetland swales are better stores of carbon than dry swales (Bouchard, Osmond, Winston & Hunt, 2013) whilst other studies have explored public understanding, values, and perceptions of wild roadside vegetation and found the public associated a variety of values whilst demonstrating a high awareness of ecosystem services supply (Weber, Kowarik & Saumel, 2014). There was a small set of papers discussing the integration of more natural habitats into green spaces. There should be a greater emphasis on the potential use of more natural vegetation types in urban areas to provide a range of services across different provisioning types (Gardiner, Burkman & Prajzner, 2013; Kowarik, 2018).

The prevalence of studies featuring large green spaces may be attributed to the frequency of remote sensing methodologies within the literature that use spectral features (reflectance or emission regions) to identify vegetation. Feld, da Silva, Sousa, de Bello, Bugter, and Grandin (2009) concluded that such remote sensing of ecosystem services may be limited to indirect, generic indicators, while other services may be completely invisible to remote sensing approaches. For example, many indicators of regulating and maintenance services operate at very local scales, such as floral resources for invertebrates, food plants for pollinators and habitat for predators or pests, which are below the resolution of satellite imagery (30−100 m). Meanwhile, indicators of provisioning services operate at regional scales that are more amenable to study using remote sensing technologies. Methods such as Normalised Difference Vegetation Index (NDVI) (Tucker, 1979) are well-documented and frequently used indicators of vegetation biomass, which has been used to map vegetation health, carbon sequestration and forest canopy cover on a variety of scales and is still a valuable tool in understanding vegetation dynamics over large scales (Avtar et al., 2017). However, care needs to be taken when translating into practice a body of literature that relies heavily upon phenomena only studied at broad scales. Remote sensing was utilized in novel mixed methods such as the use of the Danish Civil Registration System to assess the impacts of childhood greenspace exposure on adult psychiatric disorders (Engemann, Pedersen, Arge, Tsirogiannis, Mortensen, & Svenning, 2019) and the relationships between green land cover and life expectancy (Tsai, Leung, McHale, Floyd & Reich, 2019). Work in the US has demonstrated that within urban areas most land is private residential, and it is here where the majority of urban tree canopy is located (Grove, Locke & O'Neil-Dunne, 2014). Thus, these coarse resolution land cover analyses in heterogenous urban areas may favour large blocks of green and blue space but may fail to detect smaller vegetation dynamics in private gardens and land which may be a significant contribution to the local ecosystem service economy but remain undocumented within much remote sensing literature. Work by MacFaden, O'Neil-Dunne, Royar, Lu and Rundle (2012) has demonstrated this granular level of tree cover in New York using high-resolution LIDAR and multispectral imagery technology.

Often, remote sensing technologies are featured in studies that utilised data from across several years. Other research methods had a distinct lack of long-term studies. Most studies featured within this paper were short with 42% (n = 287) being sampled for less than 1 year and 12% (n = 84) sampled for only 1−2 years. In total, of all screened studies 64% (n = 436) had a study period of fewer than 5 years, further highlighting a lack of long-term experimental data. A lack of longitudinal experimental studies leaves gaps not only in the knowledge of long-term functioning and impacts of nature-based solutions but also in the development of societal attitudes towards green infrastructure. This insight is vital to understanding and reaching long-term management and policy goals. We noted no studies which clearly disentangled ecosystem service supply and age of vegetation. Long-term studies would feed into a broader understanding of efficiency, cost, and risk. Importantly assessment of public perception across seasons and ages, vegetation condition (in flower/dieback) is critical in educating and gaining public support for nature-based solutions against hard infrastructure projects. The relationship between vegetation development and age seems to be a relatively neglected research topic within ecosystem services. Forest age has been shown to be positively associated with the multifunctionality of forests and their capacity to provide multiple ecosystem services to society (Jonsson, Bengtsson, Moen, Gamfeldt & Snäll, 2020).

Lack of longitudinal experimental data

We also noted no experimental studies comparing interactions among nature-based solutions, as the majority focused on a single nature-based solution. As such we lack data on the potential risks, benefits, and interaction of utilizing multiple nature-based solutions concurrently. Research should build upon these findings, undertaking full life-cycle assessments of vegetation, nature-based solutions, and study the interaction of multiple interventions to fully capture how ecosystem service supply is impacted throughout the management lifespan of areas or green infrastructure.

For example, the use of floating ecosystems within urban blue space has become an increasingly attractive option for ecosystem service provision and greening grey water infrastructure where other planting options are not suitable (Li, Song, Li, Lu & Nishimura, 2010). There have been considerable investments in these floating ecosystems such as in the Wild Mile Chicago (wildmilechicago.org, (2021b) or the EU-funded Urban GreenUp programme (urbangreenup.eu, (2021a). However, the use of these technologies is still relatively novel and there has been little published research on their long-term functioning. Examples of experimental studies could focus on how these floating ecosystems enhance the aesthetic, environmental and biodiversity value of urban blue spaces. Understanding the longer-term community compositions and vegetation development of these systems would enable statutory organisations to better target their management regimes to meet environmental or biodiversity targets.

Policy goals for green infrastructure, nature-based solutions, and the value of biodiversity will only be developed if there is a clear economic case put forward for inclusion within urban areas. Our review found a lack of studies that provide clear and detailed economic analysis of the benefits or costs of ecosystem services provided by plants in urban areas. While some studies did attempt to quantify the values of services provisioned by plants (Sander & Haight 2012;

Silvennoinen, Taka, Yli-Pelkonen, Koivusalo, Ollikainen & Setala, 2017; Soto-Montes-de-Oca, Bark & Gonzalez-Arellano, 2020), many did not. For example, (Tsai, Floyd, Leung, McHale & Reich, 2016) examined relationships between urban vegetation cover and Body Mass Index, which could have further discussed relationships between public health and the economic impact of greenspace fragmentation. Of those studies which did discuss economic values many utilised i-Tree methods for the valuation of ecosystem services. For example, Hilde and Paterson (2014) used i-Tree valuation to assess the monetary benefits of trees in energy saving, sequestering carbon, and the management of air pollution in Texas.

Natural resource monitoring systems such as i-Tree are critical sources of information for decision-makers on natural resource management. They provide a powerful suite of different methods of assessing and valuing forest resources, understanding forest risk, and developing sustainable management plans to improve both environmental quality and human health. Natural Natural, 2013 recommended I-Trees tools as an appropriate valuation method for urban forests and trees, particularly so in financial terms to economically minded policymakers and statutory organisations. Ruam (2019a) observed that i-Tree Eco had helped some organisational actors to overcome the negative perception of tree management. However, enacting recommendations based on ITree, such as improved urban forest management, funding allocations or policies changes are still a barrier to achieving impact (Raum, Hand, Hall, Edwards, O'Brien, & Doick, 2019b).

It is evident that, to provide an economic case for the inclusion of a diverse range of vegetation and habitats, detailed examples of the potential benefits and costs of the inclusion of these systems are needed. These are not new concepts: the inclusion of nature-based solutions should have sound economic grounding, and without a cost-benefit analysis it is difficult to provide a strong evidence base for the financial benefits often attributed to nature-based solutions (Cousins, 2021; Pretty & Barton 2020). It is therefore surprising that this did not appear more prominently within the studies that we screened. The inclusion of grey literature may have enabled others to better quantify the economic benefits of vegetation in urban areas.

Nature-based solutions

Our data demonstrate a wide range of different ecosystem services provisioned by nature-based solutions and vegetation in urban areas. This being the case, why is the adoption of nature-based solutions not commonplace? One answer may be the lack of good evidence globally for the effectiveness of nature-based solutions as per our analysis. The results of successful interventions that use nature-based solutions, including from the grey literature, are currently compiled, documented, and analysed in a selection tool developed by Oxford University (2020). From this kind of selection tool, solutions for common urban planning challenges can be created to aid in urban planners selecting appropriate nature-based solutions. However, our results suggest that there is likely a need to incorporate regionally specific species recommendations into these decision support tools to maximise biodiversity and service provisioning gains while minimising the risk of the use of non-native or damaging species. The weak evidence base may also contribute to a lack of engagement among some stakeholders Kabish (2015). found though a wide range of different ecosystem services were supplied, users had low awareness of the benefits of green spaces among different organisational actors, suggesting that training and engagement on the potential benefits of ecosystem services and nature-based solutions is essential. Santoro, Pluchinotta, Pagano, Pengal, Cokan, and Giordano (2019) state that effective management strategies are reliant on stakeholder's perceptions. Encouragingly, they found that stakeholders understood that the most suitable solution to reduce flood risk may not always be grey infrastructure projects. They highlight that engaging with multiple stakeholders is critical in successful risk management measures and that there is a critical need for supporting activities that help to address risk perceptions to encourage the implementation of nature-based solutions. Whilst the EU has set clear funding commitments for the research of nature-based solutions (Faivre et al., 2017), what is less clear are values of funding commitments for other global leaders such as America and China (Escobedo, Giannico, Jim, Sanesi & Lafortezza, 2019).

Conclusions

Given the predicted impacts of future urbanisation, climate change and population growth it is critical to understand the impact that these processes will have on urban areas, people, and ecosystems. Urban systems are complex and the roles and responses of plants within them are not well understood at either species or community level, particularly in urban blue space. This systematic review provides evidence that there are large gaps in our understanding of vegetation systems in developing nations, as most research is undertaken in wealthy western countries and China. There has been an emphasis on terrestrial ecosystems and a generic approach to "green" space via the use of remote sensing technologies, rather than a more nuanced ecological understanding of how networks of species interact across habitat types. Research should prioritise our understanding of both aquatic and terrestrial vegetation responses to urbanisation, particularly within an experimental and longer-term context. We noted few studies on urban blue space and aquatic plants, environments that have decreased within urban areas but may provide a multitude of regulation, cultural, and provisioning services. Work needs to focus on understanding ecosystem services at species or habitat level and develop best practices in management regimes for urban vegetation. This review also reveals important shortcomings in research that validates the economic justification for the application of natural vegetation and nature-based solutions.

Declaration of Competing Interest

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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Supplementary materials

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References

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018). Biodiversity and human health: Mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, *127*, 5–22.

Alberti, M. (2005). The effects of urban patterns on ecosystem function. *International Regional Science Review*, *28*, 168–192.

Amir, A. K. M., Katoh, Y., Katsurayama, H., Koganei, M., & Mizunuma, M. (2018). Effects of convection heat transfer on Sunagoke moss green roof: A laboratory study. *Energy and Buildings*, *158*, 1417–1428.

Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., et al. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B: Biological Sciences*, *281*, 20133330.

Avtar, R., Kumar, P., Oono, A., Saraswat, C., Dorji, S., & Hlaing, Z. (2017). Potential application of remote sensing in monitoring ecosystem services of forests, mangroves and urban areas. *Geocarto International*, *32*, 874–885.

Barragán, J. M., & de Andrés, M. (2015). Analysis and trends of the world's coastal cities and agglomerations. *Ocean & Coastal Management*, *114*, 11–20.

Basu, S., & Nagendra, H. (2020). The street as workspace: Assessing street vendors' rights to trees in Hyderabad, India. *Landscape and Urban Planning*, *199*, 7.

Bauduceau, N., Berry, P., Cecchi, C., Elmqvist, T., Fernandez, M., Hartig, T., Krull, W., Mayerhofer, E., Sandra, N., Noring, L. and Raskin-Delisle, K., 2015. Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: Final report of the horizon 2020 expert group on'Nature-based solutions and re-naturing Cities'.

Bayón, Á., Godoy, O., Maurel, N., van Kleunen, M., & Vilà, M. (2021). Proportion of non-native plants in urban parks correlates with climate, socioeconomic factors and plant traits. *Urban Forestry & Urban Greening 127215.*

Beaury, E. M., Patrick, M., & Bradley, B. A. (2021). Invaders for sale: The ongoing spread of invasive species by the plant trade industry. *Frontiers in Ecology and the Environment.*

Biocca, M., Gallo, P., Di Loreto, G., Imperi, G., Pochi, D., & Fornaciari, L. (2019). Noise attenuation provided by hedges. *Journal of Agricultural Engineering*, *50*, 113–119.

Blakely, T. J., Harding, J. S., McIntosh, A. R., & Winterbourn, M. J. (2006). Barriers to the recovery of aquatic insect communities in urban streams. *Freshwater Biology*, *51*, 1634–1645.

Booth, D. B., Roy, A. H., Smith, B., & Capps, K. A. (2016). Global perspectives on the urban stream syndrome. *Freshwater Science*, *35*, 412–420.

Bouchard, N. R., Osmond, D. L., Winston, R. J., & Hunt, W. F. (2013). The capacity of roadside vegetated filter strips and swales to sequester carbon. *Ecological Engineering*, *54*, 227–232.

Branco, S., Videira, N., Branco, M., & Paiva, M. R. (2015). A review of invasive alien species impacts on eucalypt stands and citrus orchards ecosystem services: Towards an integrated management approach. *Journal of Environmental Management*, *149*, 17–26.

Carinanos, P., Casares-Porcel, M., de la Guardia, C. D., Aira, M. J., Belmonte, J., Boi, M., et al. (2017). Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health. *Environmental Research*, *155*, 219–227.

Carinanos, P., Delgado-Capel, M., Maradiaga-Marin, M. F., & Benitez, G. (2019a). Considerations on the allergy-risks related to the consumption of fruits from urban trees in Mediterranean cities. *Urban Forestry & Urban Greening*, 45.

Carinanos, P., Grilo, F., Pinho, P., Casares-Porcel, M., Branquinho, C., Acil, N., et al. (2019b). Estimation of the allergenic potential of urban trees and urban parks: Towards the healthy design of urban green spaces of the future. *International Journal of Environmental Research and Public Health*, *16*, 17.

Carle, M. V., Halpin, P. N., & Stow, C. A. (2005). Patterns of watershed urbanization and impacts on water quality 1. *JAWRA Journal of the American Water Resources Association*, *41*, 693–708.

Céréghino, R., Biggs, J., Oertli, B., & Declerck, S. (2007). The ecology of European ponds: Defining the characteristics of a neglected freshwater habitat. *Pond conservation in Europe* (pp. 1−6). Springer.

Chan, F. K. S., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y. T., et al. (2018). Sponge City" in China—A breakthrough of planning and flood risk management in the urban context. *Land Use Policy*, *76*, 772–778.

Chen, A. H., & Warren, J. (2011). Sustainable growth for China: When capital markets and green infrastructure combine. *Chinese Economy*, *44*, 86–103.

Chen, B., & Liang, L. (2020). Old-growth trees in homesteads on the Ryukyu archipelago, Japan: Uses, management, and conservation. *Small-Scale Forestry*, *19*, 39–56.

Cherqui, F., Belmeziti, A., Granger, D., Sourdril, A., & Le Gauffre, P. (2015). Assessing urban potential flooding risk and identifying effective risk-reduction measures. *Science of the Total Environment*, *514*, 418–425.

Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Rethinking sustainable development within the framework of poverty and urbanisation in developing countries. *Environmental Development*, *13*, 18–32.

Cousins, J. J. (2021). Justice in nature-based solutions: Research and pathways. *Ecological Economics*, *180*, 106874.

Czech, B., Krausman, P. R., & Devers, P. K. (2000). Economic associations among causes of species endangerment in the United States: Associations among causes of species endangerment in the United States reflect the integration of economic sectors, supporting the theory and evidence that economic growth proceeds at the competitive exclusion of nonhuman species in the aggregate. *Bioscience*, *50*, 593–601.

Darwall, W., Bremerich, V., De Wever, A., Dell, A. I., Freyhof, J., Gessner, M. O., et al. (2018). The alliance for freshwater life: A global call to unite efforts for freshwater biodiversity science and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *28*, 1015–1022.

De Vos, J. M., Joppa, L. N., Gittleman, J. L., Stephens, P. R., & Pimm, S. L. (2015). Estimating the normal background rate of species extinction. *Conservation Biology*, *29*, 452–462.

Delshammar, T., Östberg, J., & Öxell, C. (2015). Urban trees and ecosystem disservices - A pilot study using complaints records from three Swedish cities. *Arboriculture and Urban Forestry*, *41*, 187–193.

Depietri, Y., Welle, T., & Renaud, F. G. (2013). Social vulnerability assessment of the Cologne urban area (Germany) to heat waves: Links to ecosystem services. *International Journal of Disaster Risk Reduction*, *6*, 98–117.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., et al. (2018). Assessing nature's contributions to people. *Science*, *359*, 270–272 (New York, N.Y.).

Dickie, I. A., Bennett, B. M., Burrows, L. E., Nunez, M. A., Peltzer, D. A., Porte, A., et al. (2014). Conflicting values: Ecosystem services and invasive tree management. *Biological Invasions*, *16*, 705–719.

Ding, Y., Qian, S., Wu, X., Zhao, L., Lin, D., Zhang, J., et al. (2019). Homogenization of China's urban aquatic macrophyte communities: A meta-analytic study. *Ecological Indicators*, *106*, 105506.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., et al. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews*, *81*, 163–182.

Dulal, H. B. (2017). Making cities resilient to climate change: Identifying "win−win" interventions. *Local Environment*, *22*, 106–125.

Ehrlich, P. R., & Mooney, H. A. (1983). Extinction, substitution, and ecosystem services. *Bioscience*, *33*, 248–254.

Elmqvist, T., Colding, J., Barthel, S., Borgström, S., Duit, A., Lundberg, J., et al. (2004). The dynamics of social-ecological systems in urban landscapes: Stockholm and the National Urban Park, Sweden. *Annals of the New York Academy of Sciences*, 308–322.

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., et al. (2013). *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment*. Springer Nature.

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J. C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *116*, 5188–5193.

Escobedo, F. J., Giannico, V., Jim, C. Y., Sanesi, G., & Lafortezza, R. (2019). Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors. *Urban Forestry & Urban Greening*, *37*, 3–12.

Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environmental Pollution*, *159*, 2078–2087.

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-based solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental research*, *159*, 509–518.

Feld, C. K., da Silva, P. M., Sousa, J. P., de Bello, F., Bugter, R., Grandin, U., et al. (2009). Indicators of biodiversity and ecosystem services: A synthesis across ecosystems and spatial scales. *Oikos*, *118*, 1862–1871 (Copenhagen, Denmark).

Fernandez-Rodriguez, S., Cortes-Perez, J. P., Muriel, P. P., Tormo-Molina, R., & Maya-Manzano, J. M. (2018). Environmental impact assessment of Pinaceae airborne pollen and green infrastructure using BIM. *Automation in Construction*, *96*, 494–507.

Fischer, L. K., von der Lippe, M., Rillig, M. C., & Kowarik, I. (2013). Creating novel urban grasslands by reintroducing native species in wasteland vegetation. *Biological Conservation*, *159*, 119–126.

Foley, R., & Kistemann, T. (2015). Blue space geographies: Enabling health in place. *Health & Place*, *35*, 157–165.

Fusaro, L., Marando, F., Sebastiani, A., Capotorti, G., Blasi, C., Copiz, R., et al. (2017). Mapping and assessment of PM10 and O-3 removal by woody vegetation at urban and regional level. *Remote Sensing*, *9*, 17.

Garcia, X., Barcelo, D., Comas, J., Corominas, L., Hadjimichael, A., Page, T. J., et al. (2016). Placing ecosystem services at the heart of urban water systems management. *Science of the Total Environment*, *563*, 1078–1085.

Gardiner, M. M., Burkman, C. E., & Prajzner, S. P. (2013). The value of urban vacant land to support arthropod biodiversity and ecosystem services. *Environmental Entomology*, *42*, 1123–1136.

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, *33*, 115–133.

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235–245.
Gourdji, S. (2018). Review of plants to mitigate particulate matter, ozone as well as nitrogen dioxide air pollutants and applicable recommendations for green roofs in Montreal, Quebec. *Environmental Pollution*, *241*, 378–387.
Graca, M., Queiros, C., Farinha-Marques, P., & Cunha, M. (2018). Street trees as cultural elements in the city: Understanding how perception affects ecosystem services management in Porto, Portugal. *Urban Forestry & Urban Greening*, *30*, 194–205.
Greenway, M. (2017). Stormwater wetlands for the enhancement of environmental ecosystem services: Case studies for two retrofit wetlands in Brisbane, Australia. *Journal of Cleaner Production*, *163*, S91–S100.
Groffman, P. M., & Crawford, M. K. (2003). Denitrification potential in urban riparian zones. *Journal of Environmental Quality*, *32*, 1144–1149.
Grove, J. M., Locke, D. H., & O'Neil-Dunne, J. P. M. (2014). An ecology of prestige in New York City: Examining the relationships among population density, socio-economic status, group identity, and residential canopy cover. *Environmental Management*, *54*, 402–419.
Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment*, *584*, 1040–1055.
Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgstrom, S., Breuste, J., et al. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*, *43*, 413–433.
Haines-Young, R., & Potschin, M. (2012). Common international classification of ecosystem services (CICES, Version 4.1). *European Environment Agency*, *33*, 107.
Harrison, I. J., Green, P. A., Farrell, T. A., Juffe-Bignoli, D., Sáenz, L., & Vörösmarty, C. J. (2016). Protected areas and freshwater provisioning: A global assessment of freshwater provision, threats and management strategies to support human water security. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*, 103–120.
Hassall, C. (2014). The ecology and biodiversity of urban ponds. *Wiley Interdisciplinary Reviews Water*, *1*, 187–206.
Hilde, T., & Paterson, R. (2014). Integrating ecosystem services analysis into scenario planning practice: Accounting for street tree benefits with i-Tree valuation in Central Texas. *Journal of Environmental Management*, *146*, 524–534.
Hill, M. J., Biggs, J., Thornhill, I., Briers, R. A., Gledhill, D. G., White, J. C., et al. (2017). Urban ponds as an aquatic biodiversity resource in modified landscapes. *Global Change Biology*, *23*, 986–999.
Iversen, L. L., Girón, J. G., & Pan, Y. (2021). Towards linking freshwater plants and ecosystems via functional biogeography. *Aquatic Botany 103454*.
Jonsson, M., Bengtsson, J., Moen, J., Gamfeldt, L., & Snäll, T. (2020). Stand age and climate influence forest ecosystem service delivery and multifunctionality. *Environmental Research Letters*, *15* 0940a0948.
Kabisch, N. (2015). Ecosystem service implementation and governance challenges in urban green space planning-The case of Berlin, Germany. *Land Use Policy*, *42*, 557–567.
Kabisch, N., van den Bosch, M., & Lafortezza, R. (2017). The health benefits of nature-based solutions to urbanization challenges for children and the elderly - A systematic review. *Environmental Research*, *159*, 362–373.
Kettenring, K. M., & Adams, C. R. (2011). Lessons learned from invasive plant control experiments: A systematic review and meta-analysis. *Journal of Applied Ecology*, *48*, 970–979.
Khan, N., Jhariya, M. K., Yadav, D. K., & Banerjee, A. (2020). Structure, diversity and ecological function of shrub species in an urban setup of Sarguja, Chhattisgarh, India. *Environmental Science and Pollution Research*, *27*, 5418–5432.
Kiehl, K., Kirmer, A., Donath, T. W., Rasran, L., & Hölzel, N. (2010). Species introduction in restoration projects−Evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. *Basic and Applied Ecology*, *11*, 285–299.
Klein, R. W., Koeser, A. K., Hauer, R. J., Hansen, G., & Escobedo, F. J. (2019). Risk assessment and risk perception of trees: A review of literature relating to arboriculture and urban forestry. *Arboriculture & Urban Forestry*, *45*, 23–33.
Kowarik, I. (2018). Urban wilderness: Supply, demand, and access. *Urban Forestry & Urban Greening*, *29*, 336–347.
Lavorel, S. (2013). Plant functional effects on ecosystem services. *Journal of Ecology*, *101*, 4–8.
Lee, W. K., Tay, S. H. X., Ooi, S. K., & Friess, D. A. (2020). Potential short wave attenuation function of disturbed mangroves. *Estuarine, Coastal and Shelf Science.*
Leimu, R., & Koricheva, J. (2005). Does scientific collaboration increase the impact of ecological articles? *Bioscience*, *55*, 438–443.
Li, H., Ding, L., Ren, M., Li, C., & Wang, H. (2017). Sponge city construction in China: A survey of the challenges and opportunities. *Water*, *9*, 594.
Li, X. N., Song, H. L., Li, W., Lu, X. W., & Nishimura, O. (2010). An integrated ecological floating-bed employing plant, freshwater clam and biofilm carrier for purification of eutrophic water. *Ecological Engineering*, *36*, 382–390.
Lososová, Z., Chytrý, M., Tichý, L., Danihelka, J., Fajmon, K., Hájek, O., et al. (2012). Native and alien floras in urban habitats: A comparison across 32 cities of central Europe. *Global Ecology and Biogeography*, *21*, 545–555.
Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., et al. (2015). A review of urban ecosystem services: Six key challenges for future research. *Ecosystem Services*, *14*, 98–112.
MacFaden, S. W., O'Neil-Dunne, J. P. M., Royar, A. R., Lu, J. W. T., & Rundle, A. G. (2012). High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. *Journal of Applied Remote Sensing*, *6*, 063567.
Maes, J., & Jacobs, S. (2017). Nature-based solutions for Europe's sustainable development. *Conservation Letters*, *10*, 121–124.
Martin, L. J., Blossey, B., & Ellis, E. (2012). Mapping where ecologists work: Biases in the global distribution of terrestrial ecological observations. *Frontiers in Ecology and the Environment*, *10*, 195–201.
Mathey, J., Arndt, T., Banse, J., & Rink, D. (2018). Public perception of spontaneous vegetation on brownfields in urban areas-Results from surveys in Dresden and Leipzig (Germany). *Urban Forestry & Urban Greening*, *29*, 384–392.
McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, *22*, 276–282.

McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, *11*, 161–176.

Monaghan, P., Hu, S. C., Hansen, G., Ott, E., Nealis, C., & Morera, M. (2016). Balancing the ecological function of residential stormwater ponds with homeowner landscaping practices. *Environmental Management*, *58*, 843–856.

Mugiraneza, T., Ban, Y., & Haas, J. (2019). Urban land cover dynamics and their impact on ecosystem services in Kigali, Rwanda using multi-temporal Landsat data. *Remote Sensing Applications: Society and Environment*, *13*, 234–246.

Natural England. (2013). Green infrastructure—Valuation tools assessment. Natural England Commissioned Report NECR126.

Nejati, A., Rodiek, S., & Shepley, M. (2016). Using visual simulation to evaluate restorative qualities of access to nature in hospital staff break areas. *Landscape and Urban Planning*, *148*, 132–138.

Niinemets, Ü., & Peñuelas, J. (2008). Gardening and urban landscaping: Significant players in global change. *Trends in Plant Science*, *13*, 60–65.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, *134*, 103–112.

Perron, M. A. C., & Pick, F. R. (2020). Stormwater ponds as habitat for Odonata in urban areas: The importance of obligate wetland plant species. *Biodiversity and Conservation*, *29*, 913–931.

Piepenschneider, M., Buhle, L., Hensgen, F., & Wachendorf, M. (2016). Energy recovery from grass of urban roadside verges by anaerobic digestion and combustion after pre-processing. *Biomass & Bioenergy*, *85*, 278–287.

Powers, R. P., & Jetz, W. (2019). Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. *Nature Climate Change*, *9*, 323–329.

Pretty, J., & Barton, J. (2020). Nature-based interventions and mind−body interventions: Saving public health costs whilst increasing life satisfaction and happiness. *International Journal of Environmental Research and Public Health*, *17*, 7769.

Pyšek, P., Chocholousková, Z., Pyšek, A., Jarošík, V., Chytrý, M., & Tichý, L. (2004). Trends in species diversity and composition of urban vegetation over three decades. *Journal of Vegetation Science*, *15*, 781–788.

Qian, S., Qi, M., Huang, L., Zhao, L., Lin, D., & Yang, Y. (2016). Biotic homogenization of China's urban greening: A meta-analysis on woody species. *Urban Forestry & Urban Greening*, *18*, 25–33.

Rahel, F. J. (2002). Homogenization of freshwater faunas. *Annual Review of Ecology and Systematics*, *33*, 291–315.

Rai, P. K., & Singh, J. S. (2020). Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecological Indicators*, *111*, 20.

Raum, S., Hand, K. L., Hall, C., Edwards, D. M., O'Brien, L., & Doick, K. J. (2019b). Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-tree eco in great Britain. *Landscape and Urban Planning*, *190*, 103590.

Ren, Y., Qu, Z. L., Du, Y. Y., Xu, R. H., Ma, D. P., Yang, G. F., et al. (2017). Air quality and health effects of biogenic volatile organic compounds emissions from urban green spaces and the mitigation strategies. *Environmental Pollution*, *230*, 849–861.

Roman, L. A., Conway, T. M., Eisenman, T. S., Koeser, A. K., Barona, C. O., Locke, D. H., et al. (2021). Beyond 'trees are good': Disservices, management costs, and tradeoffs in urban forestry. *Ambio*, *50*, 615–630.

Sander, H. A., & Haight, R. G. (2012). Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing. *Journal of Environmental Management*, *113*, 194–205.

Santoro, S., Pluchinotta, I., Pagano, A., Pengal, P., Cokan, B., & Giordano, R. (2019). Assessing stakeholders' risk perception to promote nature based solutions as flood protection strategies: The case of the Glinščica river (Slovenia). *Science of the Total Environment*, *655*, 188–201.

Seamans, G. S. (2018). Grassroots citizen science in urban spontaneous vegetation. *Arboriculture and Urban Forestry*, *44*, 116–128.

Sgrigna, G., Baldacchini, C., Dreveck, S., Cheng, Z., & Calfapietra, C. (2020). Relationships between air particulate matter capture efficiency and leaf traits in twelve tree species from an Italian urban-industrial environment. *Science of the Total Environment*, 718.

Shoffner, D., & Royall, D. (2008). Hydraulic habitat composition and diversity in rural and urban stream reaches of the North Carolina Piedmont (USA). *River Research and Applications*, *24*, 1082–1103.

Silvennoinen, S., Taka, M., Yli-Pelkonen, V., Koivusalo, H., Ollikainen, M., & Setala, H. (2017). Monetary value of urban green space as an ecosystem service provider: A case study of urban runoff management in Finland. *Ecosystem Services*, *28*, 17–27.

Singh, A. K., Singh, H., & Singh, J. S. (2018). Plant diversity in cities: Call for assessment and conservation. *Current Science*, *115*, 428–435.

Sjoman, H., Hirons, A. D., & Bassuk, N. L. (2015). Urban forest resilience through tree selection-variation in drought tolerance in Acer. *Urban Forestry & Urban Greening*, *14*, 858–865.

Soto-Montes-de-Oca, G., Bark, R., & Gonzalez-Arellano, S. (2020). Incorporating the insurance value of peri-urban ecosystem services into natural hazard policies and insurance products: Insights from Mexico. *Ecological Economics*, *169*, 11.

Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2017). Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. *Landscape and Urban Planning*, *158*, 105–118.

Tang, S., Wang, L. C., & Wu, X. G. (2019). Valuation of wetland ecosystem services in rapidly urbanizing region: A case study of the nanjing jiangbei new area, China. *Applied Ecology and Environmental Research*, *17*, 10909–10927.

Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R., & Legendre, F. (2017). Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports*, *7*, 1–14.

Tsai, W. L., Floyd, M. F., Leung, Y. F., McHale, M. R., & Reich, B. J. (2016). Urban vegetative cover fragmentation in the US associations with physical activity and BMI. *American Journal of Preventive Medicine*, *50*, 509–517.

Tsai, W. L., Leung, Y. F., McHale, M. R., Floyd, M. F., & Reich, B. J. (2019). Relationships between urban green land cover and human health at different spatial resolutions. *Urban Ecosystems*, *22*, 315–324.

Urban GreenUP (2021a).
Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote sensing of Environment*, *8*(2), 127–150.
Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., & Gellynck, X. (2011). The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landscape and Urban Planning*, *103*, 198–206.
von Döhren, P., & Haase, D. (2015). Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators*, *52*, 490–497.
Waltham, N. J., Burrows, D., Wegscheidl, C., Buelow, C., Ronan, M., Connolly, N., et al. (2019). Lost floodplain wetland environments and efforts to restore connectivity, habitat, and water quality settings on the great barrier reef. *Frontiers in Marine Science*, *6*, 14.
Weber, F., Kowarik, I., & Saumel, I. (2014). A walk on the wild side: Perceptions of roadside vegetation beyond trees. *Urban Forestry & Urban Greening*, *13*, 205–212.
West, A. (2015). Core concept: Ecosystem services. *Proceedings of the National Academy of Sciences*, *112*, 7337–7338.
Wild Mile Chicago (2021b). abstrackr.cebm.brown.edu. (2020). Abstrackr.
Williams, N. S. G., Hahs, A. K., & Vesk, P. A. (2015). Urbanisation, plant traits and the composition of urban floras. *Perspectives in Plant Ecology Evolution and Systematics*, *17*, 78–86.
Wittig, R., & Becker, U. (2010). The spontaneous flora around street trees in cities—A striking example for the worldwide homogenization of the flora of urban habitats. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *205*, 704–709.
Ziter, C. (2016). The biodiversity−ecosystem service relationship in urban areas: A quantitative review. *Oikos*, *125*, 761–768 (Copenhagen, Denmark).
Zub, L. N., Prokopuk, M. S., & Pogorelova, Y. V. (2019). Species composition of higher aquatic plants of urban water bodies as the index of environment quality. *Hydrobiological Journal*, 55.

Further Reading

Nature-based Solutions Initiative (2020). University of Oxford, naturebasedsolutionsinitiative.org. Accessed 12/12/2021.
Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., et al. (2001). Terrestrial Ecoregions of the World: A new map of life on earth A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *Bioscience*, *51*, 933–938.
Raum, S., Hand, K. L., Hall, C., Edwards, D. M., O'Brien, L., & Doick, K. J. (2019a). Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-Tree eco in great Britain. *Landscape and Urban Planning*, 190.
Wallace, B. C., Small, K., Brodley, C. E., Lau, J., & Trikalinos, T. A. (2012). *January). Deploying an interactive machine learning system in an evidence-based practice center: abstrackr.Proceedings of the 2nd*. ACM SIGHIT international health informatics symposium.