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Short communication

University campuses as valuable resources for urban biodiversity research and conservation

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ABSTRACT

University campuses (including college campuses) are home to many ecologists and conservationists, resulting in a large number of studies on campus plant and animal taxa. However, a systematic review on the biodiversity of university campuses is still lacking. We conducted a comprehensive review covering the history, diversity and distribution patterns of living biodiversity on university campuses globally. We found over 300 university campuses that conducted biodiversity surveys, mostly on plants and birds, with China and India as research hotspots. These university campuses harboured high biodiversity, with an average of 199 plant species and 66 bird species on each campus, including many endemic and endangered species. Hence, university campuses provide a unique opportunity for urban biodiversity research, conservation and education, as well as connecting the public with nature through citizen science.

1. Introduction

Over half of the world's population live in cities and rapid urbanization is driving biodiversity decline (McKinney, 2002). To conserve biodiversity in urban ecosystems, it is critical to maintain urban green spaces (Cox and Gaston, 2018; Shaffer, 2018). Such a requirement has stimulated biodiversity research in public parks (Palliwoda et al., 2017), private gardens (Goddard et al., 2010) and university campuses (Liu et al., 2017; Wang et al., 2021) which can provide refugia for a diverse set of plant and animal species (Ives et al., 2016; Soanes and Lentini, 2019).

University campuses (including college campuses), can be important components of green spaces in urban environments (Colding, 2007; Vallejo et al., 2009), especially in developing countries where private green spaces are often lacking (Goddard et al., 2010). For example, university campuses cover over 620 km^2 of urban area in China (Zhang et al., 2018), and many are larger than 100 ha (Liu et al., 2017). Currently, there are more than 26,000 universities in the world (http://www.webometrics.info/en/node/54), each of which generally supports thousands of students. Unlike other urban green spaces (e.g. parks), university campuses are often home to naturalists (e.g. botanists, zoologists and conservationists), which provide a direct link to biodiversity research and education (Moerman and Estabrook, 2006). At the same time, students at universities can be educated with region-specific biodiversity to increase their appreciation of regional biodiversity and natural experiences (Zhang et al., 2014). As such, living biodiversity on campuses, such as plants (Güler, 2019; Liu et al., 2017), birds (Zhang et al., 2018) and insects (Guénard et al., 2015; Wheeler, 2008), have been recorded, protected and studied for educational and academic purposes by students and researchers for decades.

Biodiversity on university campuses has the potential to connect directly to the public. For example, biodiversity on university campuses influences perceived attractiveness of urban areas to students (Lindemann-Matthies and Brieger, 2016), promotes appreciation of the natural environment of local people (Colding and Barthel, 2017), and may lead the way to an ecologically responsible future (Uhl and Anderson, 2001).

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However, we lack a systematic review of global biodiversity patterns on university campuses, despite increasing availability of urban biodiversity data and a growing interest and demand for increasing biodiversity in urban areas. This paper aims to fill this important research gap by summarizing current studies on this topic.

2. Legacy of university campus biodiversity

The first modern universities were established centuries ago, and some of these included natural sites that persist to this day (Frascaroli et al., 2016). Additionally, counties with a university tended to have higher biodiversity than their neighbouring counties without universities (Moerman and Estabrook, 2006). Several reasons may explain this pattern. First, most ancient universities were built in rural or wilderness areas rather than in cities, and these regions were likely more species rich to begin with (Wheeler, 2008). Second, botanists and zoologists tend to introduce species into the universities where they work, for example by establishing botanical gardens, and thus actively increase total species richness in these regions (Pautasso and Parmentier, 2007). Third, biodiversity is more intensively surveyed in in regions with universities due to the large concentration of ecologists, botanists and zoologists in a single place. Following the establishment of modern universities, thousands of universities have been established across the world (Wheeler, 2008).

Botanical gardens are the frontiers for *ex situ* biodiversity conservation (Chen et al., 2009), conserving 30 % of all plant species diversity and over 41 % of known threatened species in the world (Mounce et al., 2017). Interestingly, the development of botanical gardens was originated from because of universities. The first botanical garden was founded in University of Pisa (1543) (Stearn, 1971) according to Wikipedia. Today, still over more than 400 botanical gardens belong to universities according to the Botanical Garden Conservation International database (BGCI, 2020). (https://www.bgci.org/). These botanical gardens associated with universities have high species diversity (Pautasso and Parmentier, 2007). For example, the University of Oxford contains 9378 cultivated taxa in its own botanical garden according to the BGCI website (BGCI, 2020).

There were few published biodiversity surveys from university campus before 1980 (Fig. 1). Only Miller and Curtis (1940) have recorded 148 bird species on the University of Washington campus in 1940, and researchers at the University of Florida campus has collected more than 1417 plant species since 1920s (https://www.floridamuseum.ufl.edu/herbarium/research/ufcampusflora.htm). Biodiversity surveys specifically aimed at university campuses only became common after World War II, such as the University of the South in 1948 (Evans et al., 2016), the Fergusson College in 1958 (Nerlekar et al., 2016a), Hokkaido University in 1991 (Namba et al., 2010), and Victoria University of Wellington of New Zealand in 1990 (Forsyth, 2016). In recent decades, hundreds of papers and books about biodiversity patterns inside university campuses have been published (Fig. 1), especially in Asian countries, e.g., China, India and Japan (Fig. 2). This may be because many Asian university campuses have clear boundaries (e.g., walls) and are studied as an independent unit. In contrast, university campuses in Europe and North America often have no clear physical boundaries or are spread out over individual buildings within an urban setting, and researchers in these countries have focused more on biodiversity patterns at the city level (Knapp et al., 2008) and those in private gardens (Goddard et al., 2010). Currently, many universities have websites showcasing the flora and fauna on their campuses (Table 1). Some universities have even developed mobile phone-based plant identification apps used for teaching based on campus inventory datasets (http://sydney.edu.au/news/sobs/1699.html?newsstoryid=14251).

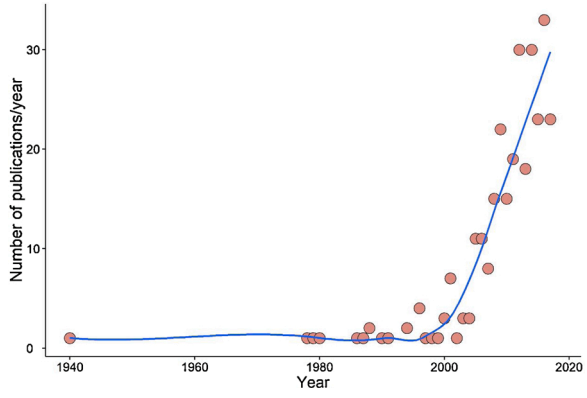

Fig. 1. Number of studies published in each year recording the biodiversity patterns on university campuses from 1940s to 2017. Data were compiled from publications with certain keywords searching.

University campuses are also hotspots for the discovery of new species, including small mites in bird feathers (Mironov and Chandler, 2017) and microorganisms (Liao et al., 2018), indicating that even highly urbanized areas can still contain undiscovered diversity. For example, a new large beetle species (Freitag, 2013) and a shrimp species (Wongkamhaeng et al., 2016) were found on highly urbanized university campuses. Interestingly, some of these new species are named after the campuses where they were found. For example, *Aphis mizzou* was named after the Mizzou campus of University of Missouri (Lagos et al., 2012), and *Hydraena ateneo* was named after the Ateneo de Manila University (Freitag, 2013). These studies have highlighted the value of university campuses for biodiversity research, education and conservation (Colding and Barthel, 2017; Güler, 2019).

3. Biodiversity in university campuses

To get a better overview of the biodiversity contained within university campuses, we did a literature search using the keywords "University campus/University/College campus/Campus flora/fauna" & "species diversity" or "biodiversity" or "Floristic inventory" or "fauna" or "diversity" or "checklist" or "plant/bird/snake/fungi/insect" in May 2018, using Google Scholar (https://scholar.google.com/), Web of Science (https://www.webofknowledge.com), and the China National Knowledge Infrastructure (https://www.cnki.net/) as well as Google. To maximize our database search, we also inquired with colleagues in related fields if they knew of any biodiversity studies in university campuses through personal communications. In total, we managed to compile a database of 320 biodiversity inventory studies on university campuses (Table S1).

3.1. Plants

Plants, and especially trees, are the most frequently studied taxa on campuses (Fig. 2) (e.g. Liu et al., 2017). University campuses maintain high plant species diversity relative to their small sizes, with an average of 199 plant species per campus (Fig. 3). For example, over 3000 vascular plant species were found on only 71 Chinese university campuses, accounting for nearly 10 % of total plant species richness of China (Liu et al., 2017). The New Botanical Garden of the University of Zürich holds 149 species of lichen-forming ascomycetes, which is about 10 % of all lichen species known from Switzerland (Aptroot and Honegger, 2006). Similarly, the university campus of Pune city in India, has up to half of the plant species in the city despite the small size of its campus (Kulkarni et al., 2001). However, species richness varies substantially among university campuses. For example, more than 1000 vascular plant species were found in the Northwest Agriculture & Forestry University in Shaanxi Province of China, while most other Chinese universities have less than 200 vascular plant species, with some of them are species poor (Liu et al., 2017). Current figures of campus plant diversity, however, maybe underestimated as a result of incomplete sampling. For

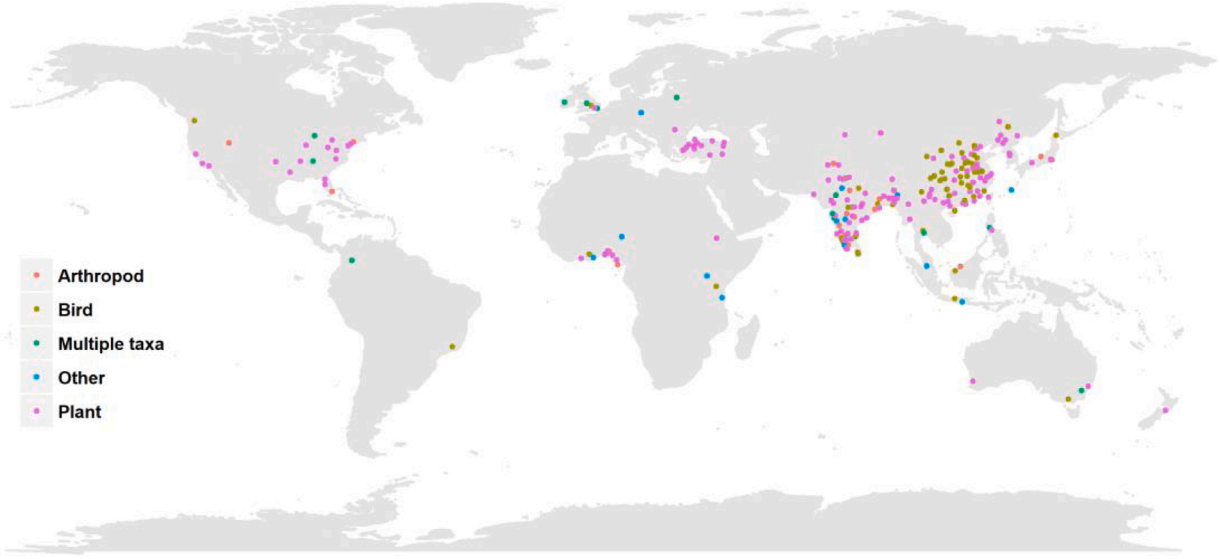

Fig. 2. Location of 320 studies related to biodiversity on university campuses included in our study for arthropods, birds, plants and other taxonomic groups.

Table 1
Universities with detailed information on multiple taxa found on campuses.

University	Species richness	Reference
Hong Kong Polytechnic University	22 birds, 10 butterflies and 1 mammal species	https://www.polyu.edu.hk/greencampus/fauna/
Peking University	210 birds, 11 mammals, 26 fish, 11 reptiles and 27 butterflies.	https://www.reading.ac.uk/news-and-events/releases/PR618137.aspx
University of Bennington	118 birds, 106 plants, 19 mammals and 20 fungi species	http://faculty.bennington.edu/-kwoods/biodiversity/
University of Sydney	294 plant species	http://campusflora.sydneybiology.org/
Georgia Southern University	135 birds, 19 mammals, 21 fish, 20 amphibians, 24 reptile species	https://www.inaturalist.org/projects/georgia-southern-biological-survey
Fergusson College campus	812 plants, 137 birds, 90 spiders, 93 butterflies, 5 amphibians, 26 reptiles, and 19 mammal species	(Nerlekar et al., 2016b, 2016a)
Universidad Militar Nueva Granada	205 plants, 80 birds, 1 frog, 1 snake and 10 mammal species	(Sánchez et al., 2015)
Vilnius University	76 birds, 7 fish, 6 amphibians, 1 reptile, and 30 mammal species	(Starodubaitė, 1999)

example, trees are generally better studied (Güler, 2019; Liu et al., 2017) than other life forms, such as herbaceous species and lianas, even though there are several studies that focus specifically on ferns (Ekanayake et al., 2001), bryophytes (Kou et al., 2012), lichens (Aptroot and Honegger, 2006) and ruderals on green roofs (Archibold and Wagner, 2007)

3.2. Birds

University campuses are a major refuge for birds in cities. On average, each campus contains 66 species of birds (Fig. 3), many of which are endangered species. For example, just 38 Chinese university campuses contained 29 % (393 species) of all Chinese bird species, including two endangered and four vulnerable species (Zhang et al., 2018). There were 145 bird species recorded for the Sabaragamuwa University campus of Sri Lanka, including a globally vulnerable species and 4 near-threatened species (Surasinghe and Alwis, 2010). About 80 species were found in and around the University of the Philippines campus, many of which were endemic to the Philippines (Vallejo et al., 2009). Some birds are good adaptors to urbanization. For example, on the Punjab University campus of Pakistan, garbage-eating bird species were relatively abundant (Sidra et al., 2013). On Hokkaido University campus, populations of species adapted to human landscapes have increased based on a 15-year bird census (Namba et al., 2010). However, in some university campuses bird diversity has declined due to habitat degradation. For example, the Pondicherry University campus of India recorded 77 bird species in 1977, but only 59 species in 1998, and 48 species in 2003 (Subramanean and Davidar, 2004).

3.3. Arthropods

A wide range of arthropods have been studied within university campuses, including ants (Guénard et al., 2015), spiders (Adarsh et al., 2015), beetles (Banerjee, 2014), and butterflies (Antony et al., 2016). For example, ant species richness in North Carolina State University in Wake County (USA) was extremely high with 89 species, including 10 exotic species, which represents 79 % of the species known from this county (Guénard et al., 2015). The study suggested that university campuses play a more important role in conservation than generally appreciated because they also preserve little know, or even disliked species. Indeed, of the arthropods, butterflies are the most studied group as they attract human interest and represent high diversity (Table S1). For example, 105 and 86 butterfly species were found in Kerala University (Antony et al., 2016) and Mysore University of India (Sarjan et al., 2014), respectively.

3.4. Mammals, herpetofauna and other species

Most university campuses contained only a few mammal species (Table S1). For example, 19 mammal species were found at Fergusson College campus of India (Table 1), with most of these species being bats and rodents. However, University of California Santa Cruz had nearly 50 mammal species, including the puma, because it has a 166-ha nature reserve within the campus (https://news.ucsc.edu/2015/09/wildlife-on-campus.html). University campuses also support a large number of fungi (Opande et al., 2017; Maseno University, Kenya) and fishes (Olds et al., 2016; University of Notre Dame campus, USA). Several studies have investigated reptiles, amphibians and other species on university campuses. For example, there were 36 snake species in the Chittagong University campus of Bangladesh, many of which are venomous (Ahsan et al., 2015). Six amphibian species and 20 reptile species were found in Hechi University of China (Jiang et al., 2011).

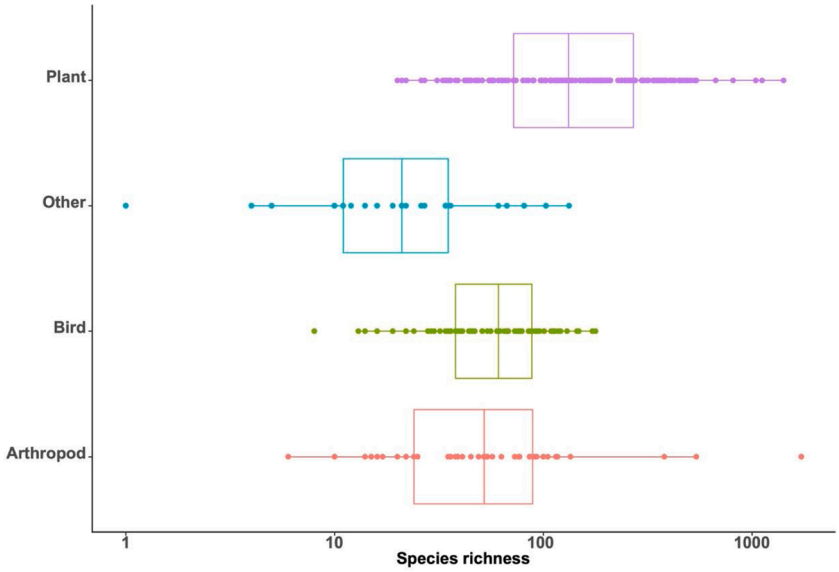

Fig. 3. Number of species inventoried from 320 university campuses in this study. Other species includes mammals, microorganisms, reptiles, fishes and amphibians.

4. Biodiversity dynamics

Although university campuses form an important component in urban biodiversity conservation, university campuses can also show biodiversity declines over time. For example, Victoria University of Wellington in New Zealand lost 146 plant species from 1990 to 2015 (Forsyth, 2016), and Fergusson College campus has experienced a net loss of 120 species of plants? from 1958 to 2014 (Nerlekar et al., 2016a). Habitat destruction is one of the main drivers of biodiversity loss on campuses, as indicated by birds in the Pondicherry University campus (Subramanean and Davidar, 2004). Moreover, there is a tendency of biological homogenization in urban environments (Knapp et al., 2012). For example, populations of Large-billed Crow (*Corvus macrorhynchos*) and Mallard (*Anas platyrhynchos),* which are urban adaptors, have increased while there was a drastic decline of the more specialised Eurasian Tree Sparrows (*Passer montanus*) through a 15-year bird census (Namba et al., 2010). At last, exotic species account for a large proportion of the species found in university campus, due to introduction of ornamental species, scientific collections, and economic reasons such as maintenance costs of plants (van Kleunen et al., 2018). Some of these exotic species are invasive species and may result in substantial loss of native species (Guénard et al., 2015). As a result, biodiversity on university campuses, such as tree species on Chinese university campuses, exhibited significant biotic homogenization (Wang et al., 2021).

5. Connect people with biodiversity in university campuses

Students represent the potential next-generation conservationists (though a tiny proportion in many cases), and their conservation willingness is strongly influenced by their experiences with nature (Zhang et al., 2014). As such, biodiversity on university campuses should be used as a valuable education resource for students (Colding and Barthel, 2017). Fortunately, biodiversity on university campuses has been used as an efficient tool to improve students' biodiversity knowledge through outdoor teaching. For example, native woodlands on the campus of the Musashi Institute of Technology of Japan have been protected and used for biodiversity education (Kobori and Primack, 2003). Biodiversity found on university campuses can also be used for restoration purposes in surrounding areas (Huang et al., 2009) as well as for biodiversity educational courses (Struwe et al., 2014). Learning from these materials has been shown to promote students' willingness to study biodiversity (Colding and Barthel, 2017). This is important because regional biodiversity knowledge can have a significant influence on their attitudes towards paying for biodiversity conservation (Martín-López et al., 2007).

Current conservation efforts mostly focus on natural ecosystems and often have tried to avoid areas that are substantially influenced by humans (Wheeler, 2008). However, opportunities to establish nature reserve in urban areas, although still rare (Goddard et al., 2010), are a serious possibility. For example, conservationists at Peking University are planning to turn their historical university campus into a small nature reserve to conserve urban biodiversity and connect people to the biosphere as well as for environmental education (Chen, 2019). Moreover, biodiversity data from university campuses is accumulating rapidly (Liu et al., 2017; Zhang et al., 2018), largely due to the popularity of citizen science in recent decades. This has facilitated research on the linkage between biodiversity and human well-being in urban areas (Colding and Barthel, 2017).

It is important that campus biodiversity is tightly connected to the public because conservation success depends on public support (Miller and Hobbs, 2002). First, many university campuses are considered as recreational sites and attract thousands of visitors every year (Colding and Barthel, 2017). A considerable proportion of visitor activities in these green spaces are related to local plant species (Palliwoda et al., 2017), for example flower watching in Spring. Hence, biodiversity on university campuses provides a valuable opportunity for public education. In addition, many plants are identified and tagged in Chinese universities (Liu et al., 2017), which is an efficient way to increase plant knowledge among visitors. Second, projects based on citizen science are burgeoning in biodiversity research and can be expanded to university campuses (Silvertown, 2009). For example, researchers can use the same tree species in different universities to compare leaf phenological changes in response to global warming through a citizen science-based approach. In turn, citizen science has stimulated the public's interest in biodiversity data collection. For this reason, botanists and ecologists from China have founded the Chinese University iPlant Association in 2017, including 40 universities that have contributed reliable data for species identification, for public education and for citizen science (http://site.nsii.org.cn/campusflora.html).

6. Conclusions

Our study shows that since 1940 at least 300 universities have conducted campus biodiversity surveys. University campuses are important

urban green spaces for biodiversity research and education as well as leisure as they are tightly connected to the daily life of people who live and work there. Therefore, biodiversity on university campuses provides a unique chance to connect people with nature. To increase human well-being and conserve nature for the long term, we propose that university campuses with high biodiversity should be protected and used as a valuable resource for biodiversity education, research and conservation. In addition, biodiversity conservation should be considered in the landscape design of university campuses. Specifically, we suggest: (a) biodiversity on university campuses would need to be investigated and monitored for more biodiversity-friendly designs; (b) allow parts of the campus to "go wild" and manage certain areas with minimal landscaping to maximize species diversity; (c) more campus biodiversity-based science popularization should be promoted.

Author contributions

JL, YZ and JZ led the conceptualization of the project; JL, GF and XS collected data; JL and FS led the writing and all authors contributed critically to the drafts and gave final approval for publication.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2021.127255.

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