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Source: Tropical Conservation Science, 11(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1940082918771325

Research Article

Tropical Conservation Science
Volume 11: 1–17
© The Author(s) 2018
DOI: 10.1177/1940082918771325
journals.sagepub.com/home/trc

Changes in the Spatial Pattern and Ecological Functionalities of Green Spaces in Lubumbashi (the Democratic Republic of Congo) in Relation With the Degree of Urbanization

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Abstract

An accurate description of spatial urban growth is a prerequisite step in order to implement appropriated policies to improve the ecosystem service performance of green spaces in a city. Such information is, however, absent in Lubumbashi, the second metropolis of the Democratic Republic of Congo, despite its high demographic growth rate and an unplanned spatial urban growth. This study was designed to characterize the spatial pattern of green spaces and the extent of changes driven by the urbanization along the urban–rural gradient using a combination of landscape metrics and floristic plots. Our results revealed that the number of patches was directly proportional to the degree of urbanization of the city, whereas the area of the green spaces and the index of the largest patch showed an inverse relationship with the urbanization degree. Urban green spaces were dominated by attached and roadside spaces that are more equipped and present a higher occurrence of cultivated plants. By contrast, peri-urban green spaces were characterized by buffer zones, fields, abandoned areas, and informal spaces, with an elevated proportion of invasive species and natural vegetation. Moreover, it was found that the number of exotic species increased with the degree of urbanization, reaching values considered a threat to the indigenous flora. The current results underline the need for urgent measures oriented both toward increasing the spatial connectivity between green spaces (e.g., by creating new green spaces planted with indigenous species) while reducing the spread of invasive species in the city.

Keywords

ecological functionality, green space, urban ecology, urban–rural gradient, spatial pattern

Introduction

With the current rate of population growth particularly in the developing countries of Africa, Asia, and Latin America (Cilliers, Cilliers, Lubbe, & Siebert, 2013), the world population is estimated to reach 9.6 billion inhabitants by 2050, with around 70% expected in urban areas (United Nations, 2014). According to United Nations Habitat (2014, p. 268), between 2010 and 2015, Africa has been urbanized at a higher annual rate (1.1%) than the world average rate of urbanization (0.9%), which is also reflected by the number of cities with more than 1

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Received 28 January 2018; Revised 6 March 2018; Accepted 21 March 2018

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million inhabitants that has drastically risen from one city in 1950 to 52 in 2014 and is expected to reach 68 in 2025. Such demographic explosion in urban areas causes a loss of green space cover due to fragmentation (Kong & Nakagoshi, 2005; McDonald et al., 2009; Millennium Ecosystem Assessment, 2005), as exemplified by the case of Abuja city (Nigeria) where a 7.1% annual loss of green space cover has been noted between 2000 and 2006 (Fanan, Dlama, & Oluseyi, 2011). Similarly, a loss of 380 indigenous species has been recorded in the city of Plzen (Czech Republic) over a period of 120 years (Chocholouskova & Pyšek, 2003).

In some African cities, the loss of indigenous species has been so high that the exotic species currently represent up to 80% of the flora (Bigirimana, Bogaert, De Cannière, Lejoly, & Parmentier, 2011; Rija, Said, Mwamende, Hassan, & Madoffe, 2014). Some of these species even become invasive, which can have consequences for biodiversity and ecosystem function, as well as for the economy of the countries involved (Doren, Volin, & Richards, 2009). Clearly, such urbanization-driven ecosystem simplification and biotic homogenization affects the ecological quality of green spaces, reducing their role as potential habitat for plants and animals, as well as recreational area for urban dwellers (Millennium Ecosystem Assessment, 2005).

In fact, the presence of green spaces regulates the microclimate, reduces noise, prevents water and air pollution, and contributes to the decontamination of municipal waste, thus, playing a major role in biodiversity preservation (Bolund & Hunhammar, 1999; Kong, Yin, James, Hutyra, & He, 2014). Therefore of it is prime importance to understand the spatial pattern and the quality of green spaces in urban areas, in order to design appropriate strategies for their sustainable management. While studies on the impact of urbanization on spatial pattern and ecological quality of green spaces are well documented in Europe, America and Asia (Gong, Chen, & Yua, 2013; Kong & Nakagoshi, 2005; La Rosa & Privitera, 2013), little is known for sub-Saharan African cities (Barau, Ludin, & Said, 2013; Bernholt, Kehlenbeck, Gebauer, & Buerkert, 2009; Bigirimana et al., 2011; Cilliers et al., 2013; Fanan et al., 2011; McConnachie, Shackleton, & McGregor, 2008; Osseni, Mouhamadou, Tohozin, & Sinsin, 2015), despite their favorable geographical location for green space establishment (Mensah, 2014); and Lubumbashi city in the southeastern part of the Democratic Republic of the Congo forms no exception to this hypothesis.

As the pattern and ecological quality of green spaces has been only scantily investigated in Lubumbashi city (Leblanc & Malaisse, 1978; Malaisse & Mutihac, 1976; Maréchal, Useni, Bogaert, Munyemba, & Mahy, 2018), a rapid and unplanned urbanization is generally observed. The continuous destruction of green spaces is evident in the city center where they are currently replaced by built-up, as well as in the new allotments in city periphery, where the discontinuous built-up establishment is accompanied by a systematic destruction of preexisting vegetation (Bruneau & Pain, 1990; Nkuku & Rémon, 2006; Useni, Cabala, et al., 2017), leading to a type of zone referred to as the peri-urban zone of the city (André, Mahy, Lejeune, & Bogaert, 2014).

This study was designed to fill these gaps by characterizing the green spaces along an urbanization gradient in Lubumbashi. Considering the fact that the traditional urban–rural opposition was completed taking into account the peri-urban zone (Bogaert, Bioloso, Vranken, & André, 2015; Trefon & Kabuyaya, 2015), it was crucial in the present to study green spaces in urbanized areas by considering separately urban and peri-urban green spaces. Therefore, the established theory of the urban–rural gradient (Kong & Nakagoshi, 2005; Li, Li, Zhu, Song, & Wu, 2013; McDonnell & Hahs, 2008; Niemelä et al., 2002; Qureshi, Breuste, & Lindley, 2010; Rija et al., 2014) was used in this study.

This study tests the following hypotheses: (a) green spaces in the urban zone are more fragmented and characterized by smaller areas than the peri-urban ones, (b) the proportions and types of green spaces are different between the urban zone and the peri-urban zone, and (c) compared to the peri-urban zone, green spaces in the urban zone are more equipped and characterized by higher proportions of anthropogenic vegetation while showing less vegetation strata and a higher proportion of exotic species.

Methods

Study Area

This study was carried out in Lubumbashi (Figure 1), the capital of the Upper Katanga Province, in the eastern part of the Democratic Republic of the Congo. Located between 11°27′ and 11°47′ S and between 27°19′ and 27°40′ E, the city is subdivided in seven municipalities, covering an area of about 747 km^2 (Nkuku & Rémon, 2006), mostly dominated by red and yellow lateritic soils (Leblanc & Malaisse, 1978). The climate is humid subtropical (Cw type of the Köppen classification system; Bultot, 1950), with one rainy season (November–March) and one dry season (May–September), separated by October and April as transitional months. From a phenological point of view, Malaisse (1974, p. 270) has distinguished five seasons: early rainy season (October–November), main rainy season (December–February), late rainy season (March–April), cold dry season (May–July), and warm dry season (August–September). The average annual rainfall is close to 1,200–1,300 mm, with an annual average temperature around 20°C and an

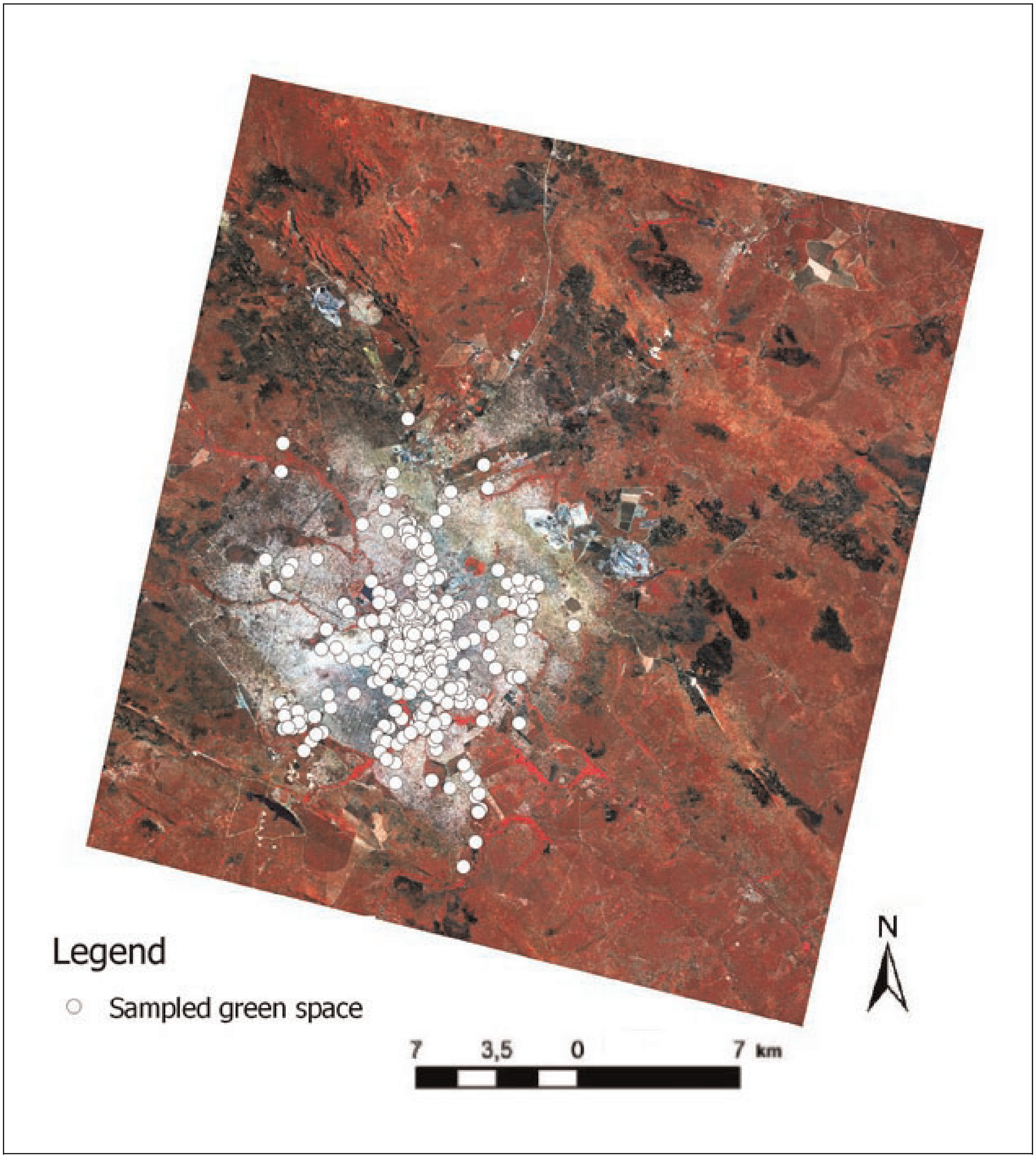

Figure 1. Map of the study area (Lubumbashi city, Upper Katanga province in DR Congo), where sampled green spaces are represented by black dots stuck onto the 2014 SPOT image.

annual mean relative humidity of 66% (Leblanc & Malaisse, 1978). At the beginning of the past century, the vegetation was dominated by the *miombo* woodland, which, due to diverse anthropogenic activities, is progressively replaced by a wooded savannah and then to a shrubby and ultimately to grassy savannah (Useni, Malaisse, et al., 2017).

Green Space Sampling and Data Collection

Prior to sampling, a decision tree (André et al., 2014) was used to separate the study area into two zones (urban and peri-urban zones) with respect to the proportion and density of built-up. Thereafter, a stratified random sampling of green spaces was applied starting from the main roads (Figure 1). Considering the spatial resolution of Google Earth images related to the location and year of image capture (Vranken et al., 2014), green spaces of 0.01 ha or less were not studied. Similarly, as suggested by Bigirimana et al. (2011) and Rija et al. (2014), domestic gardens (strongly influenced by socioeconomic factors) and rural green spaces (hardly influenced by the degree of urbanization) were not considered.

A GPS was used to record the geographical coordinates of the center of each green space, and correspondingly, green space polygons were digitized on Google Earth imagery and converted into vector format using the Quantum GIS 2.10.1 software. This software was further used to estimate the area of each polygon. As complementary data, the information regarding green spaces management was also collected, encompassing the level of green spaces accessibility for public, the presence of green spaces-related equipment (presence of seats, etc.), as well as the ownership status (Adinolfi, Suárez-Cáceres, & Cariñanos, 2014). Likewise, the presence of bare soil (>10%) as well as trees, shrubs, herbaceous, natural (spontaneous), seminatural (spontaneous and planted), and anthropogenic (planted) vegetation was verified. To determine species richness, plots of 1 m^2, 4 m^2, and 100 m^2 were used for herbaceous species, shrubs, and trees, respectively (Liang, Li, Li, & Valimaki, 2008). The number of plots was adapted to the green space area. As for plant species nomenclature, available floras (Lebrun & Stork, 1991–2015) and specialized literature (Bigirimana et al., 2011; Rija et al., 2014) were utilized; and the origin status of species was determined following Pyšek et al. (2004, p. 135). Briefly, exotic species were considered as species that are not indigenous to a specific geographic area (in Africa), while Afro-Asian species were considered as indigenous (Bigirimana et al., 2011). Invasive species, which reflect the degradation of ecosystem (Doren et al., 2009) and have a detrimental effect on the delivery of ecosystem services (McConnachie et al., 2008), were identified based on the global invasive species database (Lowe, Browne, Boudjelas, & De Poorter, 2000). In view of its place as an established invasive species in sub-Saharan Africa (Bromilov, 2010; Chukwuka, Ogunyemi, & Fawole, 2007; Ipou, Toure, Adou, Kouame, & Gue, 2011; Muoghalu & Chuba, 2005; Tiébré, Kassi, Kouadio, & N'guessan, 2012) and a dominant species in our study area (Malaisse, Schaijes, & D'Outreligne, 2016; Useni et al., 2018), *Tithonia diversifolia* (Hemsley) A. Gray was also integrated into the database of invasive species. In this study, the life forms were named following Raunkier's classification system (Raunkier, 1934) where species are separated in different types such as phanerophyta, chamaetophyta, hemicryptophyta, geophyta, therophyta, and hydrophyta. Finally, the characterized green spaces were categorized using existing typologies (Kong & Nakagoshi, 2005; La Rosa & Privitera, 2013; Mensah, 2014), which were applied using specific criteria (size and organization of green spaces, plant composition) within the concerned zones. Data were collected from February 16, 2015, to April 15, 2015, except for wetlands that were characterized at the start of the dry season between April 20, 2015, and May 25, 2015.

Data Analysis

A number of metrics including the number of patches, the total green space area, the mean green space area, the median green space area, the minimum green space, and the maximum green space area were used to evaluate the spatial pattern of green spaces in the two zones along the urban–rural gradient. The index of the largest patch, defined as the ratio of area of the largest green space to the total green space area, was also calculated. Overall, these landscape metrics quantify the degree of fragmentation of the studied patches (Bogaert & Mahamane, 2005). Moreover, the Fisher's exact test ($\alpha = .05$) was used first to assess differences in proportions between the two zones of the urban–rural gradient with respect to the parameters of green space management, the characteristics of vegetation, and the typology of green spaces and then to test the effects of urbanization degree on the proportion of exotic species. Data for life forms were summarized for each zone of the urban–rural gradient and analyzed using Pearson's chi-square tests. All statistical analyses were performed using R software (version 2.15.0).

Results

Spatial Pattern of Green Spaces

Table 1 and Figure 2 show that the urban zone presented significantly lower total area, mean area, maximum area, median area, and minimum area of the green spaces than the peri-urban zone; at converse, however, the number of green spaces was higher compared to the peri-urban zone. This observation was confirmed by the index of the largest patch (peri-urban zone: 14.9% vs. urban zone 8.1%). This is an indication of predominance of smaller green spaces in the urban area (except for the zoological garden and the golf field in the Western part of the city), which might in turn suggest either a tendency to green spaces fragmentation or a scarcity of spaces limiting the possibility to establish green spaces of bigger size. In general, green spaces in the urban area present acreages virtually threefold lesser than peri-urban green spaces.

Ecological Functionalities of Green Spaces Along Urbanization Gradient

Data in Table 2 show that more attached and roadside green spaces were observed in the urban zone compared

Table 1. Landscape Metrics Calculated for the Green Spaces of Lubumbashi City in 2015.

Zones	a_t	a_{min}	a_{max}	a_{med}	$\bar{a}$	D	PN
Urban	909.50	0.02	74.20	1.10	3.80	8.10	238
Peri-urban	2,567.70	0.03	381.70	3.10	22.90	14.90	112

Note. Area is given in hectare and the largest patch index is expressed in percentage. Urban and peri-urban zones were identified using a decision tree (André et al., 2014). All indices evidence a higher fragmentation degree of urban green spaces relative to the peri-urban green spaces. a_t = total green space area; $\bar{a}$ = average green space area; a_{min} = minimum green space area; a_{max} = maximum green space area; a_{med} = median green space area; D = index of the largest patch; PN = number of green spaces.

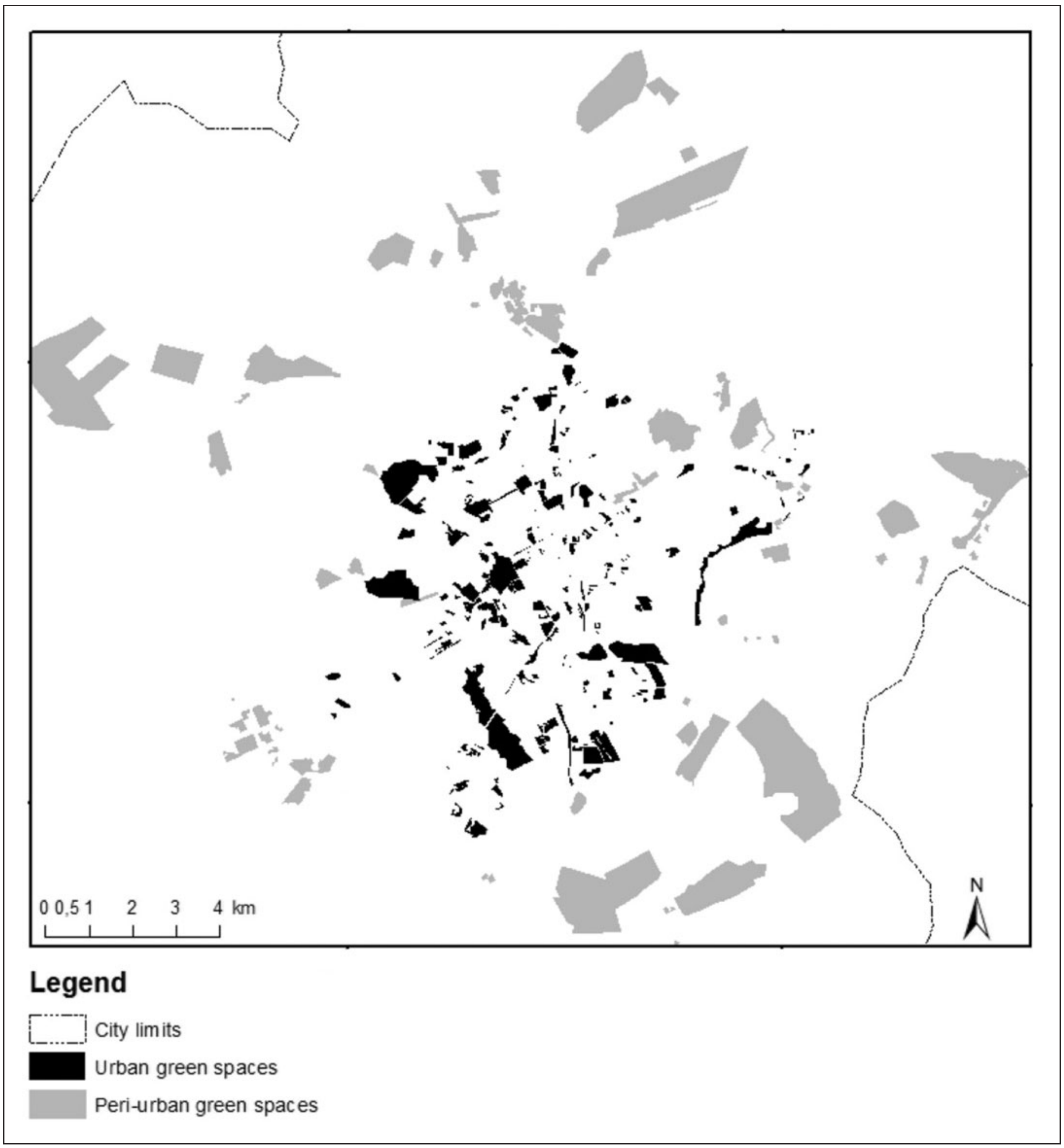

Figure 2. Spatial pattern of green spaces sampled along the urbanization gradient in Lubumbashi.

Table 2. Green Space Types of Lubumbashi City in 2015 Based on Existing Typologies (Kong & Nakagoshi, 2005; La Rosa & Privitera, 2013; Mensah, 2014).

Green spaces types	Urban zone		Peri-urban zone		Fisher's exact test
	$PN = 238$ (%)	$a_t = 909.5$ (%)	$PN = 112$ (%)	$a_t = 2,567.7$ (%)	
Park/Square[a]	2.9	1.5	0.0	0.0	*ns*
Garden[b]	1.3	5.0	1.8	1.2	*ns*
Nurserie[c]	1.3	0.7	0.0	0.0	*ns*
Green buffer[d]	2.1	0.1	5.4	4.4	**
Roadside green space[e]	12.7	2.5	6.3	2.4	**
Attached green space[f]	58.4	50.0	35.7	25.4	**
Friche/Informal green space[g]	7.1	12.5	22.3	43.7	***
Playground[h]	4.2	15.7	4.5	2.9	*ns*
Cemetery[i]	0.8	3.8	2.7	0.2	*ns*
Pasture[j]	0.4	2.3	0.9	2.6	*ns*
Wetland[k]	5.0	1.6	6.3	2.2	*ns*
Field[l]	3.8	12.5	14.1	15.0	***
Total	100.0	100.0	100.0	100.0	–

Note. Urban and peri-urban zones were identified using a decision tree (André et al., 2014). α_t = total area (ha); *PN* = number of green spaces.
[a]Green space open to the public, providing education, recreational enjoyment, with both natural and planted vegetation.
[b]Green space open to the public, protecting and preserving the flora, fauna, and providing scenic beauties, with a mosaic of remnant or naturalized habitat type.
[c]Green space for vegetation propagation and cultivation, supplying breeds, and sampling for urban greening.
[d]Linear corridors, protecting high-voltage transmission line, filtering wind, and cleaning pollutants, with planted vegetation.
[e]Linear corridors between the sidewalk and curb or island patch in the crossroad, buffering people from traffic, filtering noise and solar radiation, and so forth, with planted vegetation but limited plant diversity.
[f]Green space attached with industrial, commercial and utility land, and so forth, with planted vegetation but low diversity.
[g]Abandoned natural or seminatural lands within, around, and between developed patches, for the primarily purpose of spontaneous reforestation through undisturbed old-field succession. Green spaces available for public access and enjoyment, but with only low-key provision of facilities.
[h]Safe and highly accessible areas with recreational equipment and facilities for informal games and social encounters between families with children and senior citizens.
[i]Place where missing human beings, generally with spontaneous and cultivated vegetation.
[j]Meadow where cattle graze, with spontaneous and cultivated vegetation.
[k]Linear corridors along rivers, mostly with natural habitat type, and often high plant diversity.
[l]Large farmland areas for productive uses (mostly vegetable crops).
$^{**}p < .01$. $^{***}p < .001$. $ns = p > .05$.

to the peri-urban zone ($p < .05$). It was apparent that wastelands and informal green spaces, green buffers, and fields are more frequent in the peri-urban zone ($p < .05$). However, no significant differences could be found for the proportion of parks or squares, gardens, nurseries, playgrounds, cemeteries, pastures, and wetlands between both zones ($p > .05$; Table 2), which might be suggestive that the aforementioned types of green spaces were unaffected by the degree of urbanization.

Results showed a higher proportion of green spaces colonized by invasive species in the peri-urban zone, which was paradoxically accompanied by a higher proportion of natural vegetation ($p < .05$; Table 3). In line with a number of reports in the literature (Bromilov, 2010; Chukwuka et al., 2007; Ipou et al., 2011; Lowe et al., 2000; Muoghalu & Chuba, 2005; Tiébré et al., 2012), *Tithonia diversifolia*, *Imperata cylndrica*, *Leucaena leucocephala*, *Lantana camara*, and *Ricinus comunis* were also identified as alien invasive species in the study area. Moreover, following Fisher's exact test, significant differences regarding the equipment of the green spaces and the ownership status were noted between the two zones, with the urban zone presenting more equipped green spaces, most probably due to the lesser proportion of private green spaces in this zone ($p < .05$; Table 3). The degree of urbanization has no significant effect on the presence of different strata, the presence of bare soil, the presence of anthropogenic and seminatural vegetation, and on the accessibility of green spaces ($p > .05$).

A total of 108 species, including 71 exotic species (65.7%) belonging to 34 families were recorded within the study area, with 83 species found in the urban zone

Table 3. Vegetation Characteristics and Management Parameters of Green Spaces Located in the Urban and Peri-Urban Zones of Lubumbashi City in 2015.

	Urban zone		Peri-urban zone		Fisher's exact test
	$PN = 238$ (%)	$a_t = 909.5$ (%)	$PN = 112$ (%)	$a_t = 2{,}567.7$ (%)	
Vegetation characteristics					
Presence of tree strata	29.8	24.8	32.1	40.6	*ns*
Presence de shrub strata	50.0	56.1	52.7	80.4	*ns*
Presence of herbaceous strata	92.0	98.5	94.6	98.6	*ns*
Presence of less than 10% of bare soil	68.1	69.0	71.4	92.7	*ns*
Presence of invasive species	43.3	49.9	70.5	62.4	***
Presence anthropogenic vegetation	54.3	42.3	40.1	15.7	*ns*
Presence of natural vegetation	12.1	14.5	23.2	49.0	**
Presence of seminatural vegetation	33.6	43.2	36.6	35.3	*ns*
Management parameters					
Presence of equipment	43.6	32.6	29.5	0.2	**
Free accessibility to citizens	90.3	92.9	95.5	98.3	*ns*
Presence of private green spaces	49.6	35.7	67.9	72.3	**

Note. Urban and peri-urban zones were identified using a decision tree (André et al., 2014). a_t = Total area (ha); *PN* = number of green spaces.
***$p < .001$. **$p < .01$. *ns* = $p > .05$.

Table 4. Life Forms of the Species in Urban and Peri-Urban Green Spaces of Lubumbashi City.

Life forms	Urban	Peri-urban	χ^2	*p*
Phanerophyta	37	31	0.5294	*ns*
Hemicryptophyta	17	15	0.1789	*ns*
Geophyta	7	8	0.1429	*ns*
Therophyta	23	24	1.2308	*ns*
Hydrophyta	1	1	–	–

Note. Life form proportions in urban and peri-urban green spaces of Lubumbashi city are not significantly different according to the chi-square test (df = 1; $\alpha = 0.05$). *ns* = $p > .05$. For details, see Appendix.

and 87 in the peri-urban. Among identified families, Poaceae and Fabaceae constitute the main group, although the most occurring species remained annual plants. Detailed information in relation botanical family of different species, their life forms, and their position in the urban rural gradient are provided in the Appendix. The urban zone was characterized by 61 exotic species (73.5%) against 52 (59.8%) for the peri-urban zone. The ecological analysis showed that the flora of Lubumbashi was dominated by phanerophyta (46 spp., 42.6% of total), while a lesser contribution was found for the therophyta (31 sp., 28.7% of total). Other life forms were hardly present (Table 4). Nonetheless, no significant differences in life forms were noted between the two zones of the urban–rural gradient (chi-square, Table 4).

Discussion

The accelerated spatial dynamics of Lubumbashi city as other African cities has negative effects on green spaces; the city is indeed experiencing an environmental crisis linked particularly to its uncontrolled urbanization. Hence in this study, urban and peri-urban green spaces were characterized separately, so as to clearly distinguish the associated effects of the urbanization degree on them. In this context, a decision tree (André et al., 2014) was utilized in view of its straightforward and time-effective approach, in addition to being based on morphological characteristics (André et al., 2014). These zones highlight new management methods of green spaces but above all typological choices of specific green spaces. We used typologies applied elsewhere (Kong & Nakagoshi, 2005; La Rosa & Privitera, 2013; Mensah, 2014) regrouping green spaces with respect to land cover, land use, and ownership, which are similar to categories of green spaces previously identified in Lubumbashi (Leblanc & Malaisse, 1978), although types such as nurseries, pastures, cemeteries, wetlands (Figure 3), and green buffers constitute additional features. Since they have been previously identified as an ideal compromise to characterize spatial pattern (Bogaert & Mahamane, 2005), metrics were utilized in this study to assess the spatial impact of urban growth on green spaces in Lubumbashi. However, considering that the shape of urbanized patches is entirely determined by the anthropogenic context (Cornelis & Hermy, 2004; Forman & Godron, 1986), the shape index of green spaces was not calculated in this study.

Figure 3. A wetland-like green space in the urban zone of Lubumbashi, with herbaceous species *Imperata cylindrica* and *Cyperus* spp in the foreground of the picture.

As the general trend in developing countries, unbuilt lands in urban and peri-urban zones are matter of less rigorous governance and management, mostly driven by various sociopolitical reasons (S. Shackleton, Chinyimba, Hebinck, Shackleton, & Kaoma, 2015). Results of our study demonstrated an increasing number of small green spaces with the degree of urbanization in Lubumbashi, which is exacerbated by the lack of a master plan for the management of the city, thus resulting in further destruction of preexisting green spaces, as they are systematically replaced by diverse types of built infrastructures. These findings are in line with observations in Abuja (Nigeria; Fanan et al., 2011), Greater Dhaka (Bangladesh; Byomkesh, Nakagoshi, & Dewan, 2012), and many European and U.S. cities (Fuller & Gaston, 2009; McDonald, Forman, & Kareiva, 2010) where a close relationship was evidenced between the pattern of urbanization and the intensity of green space removal and degradation. It is apparent from current results that the green spaces located in the urban zone of Lubumbashi tend to become more disconnected. And despite their lower number, it was shown that only a third of peri-urban green spaces are public, which can be explained not only by the sociopolitical context in the city characterized by land speculation (Groupe Huit, 2009) but also by the higher number of green spaces owned by private institutions like schools or churches (Nkuku & Rémon, 2006).

It is well known that the proportions of particular green space types are related to the degree of urbanization. Hence, like in Lubumbashi, the presence of roadside and attached green spaces in the urban zone is influenced by historical context and current political planning processes of the city (Nkuku & Rémon, 2006) and in older postcolonial municipalities, green spaces alongside public buildings, and streets lined with trees are frequently observed. As to wastelands and informal green spaces, their higher proportion in the peri-urban zone is explained by the expansion of discontinuous built-up (André et al., 2014) on ancient vegetated land. In Africa, the peri-urban zone with its higher proportion of fields is generally home to many economic activities sustaining the daily life of many households (André et al., 2014; Trefon & Kabuyaya, 2015). With this in mind, it is logical to assume that the rapid population growth that amplifies the competition for land could be a threat to those agricultural lands (Figure 4), and in general to all green space types, therefore causing the aforementioned environmental crisis.

In reaction to such an unfortunate perspective, local authorities and, in some cases, private institutions have devoted efforts to create new green spaces (Figure 5), frequently equipped, on the rare open spaces still existing in the city. For this reason, a close relationship between the presence of anthropogenic vegetation and the equipment of the green spaces was observed in the urban zone of Lubumbashi. Maréchal et al. (2018) confirmed this observation in Lubumbashi. The peri-urban zone showed an elevated proportion of green spaces colonized by invasive species. According to the intermediate disturbance hypothesis, the urban–rural interface shows a higher invasibility due to both urban edge effects and increased pressure of invasive species from the surrounding rural matrix (Catford et al., 2012; Doren et al., 2009; Radeloff et al., 2005). The peri-urban zone also showed a higher proportion of green spaces characterized by

Figure 4. *Brassica chinensis* on a field-like green space in the peri-urban zone of Lubumbashi city.

Figure 5. A garden-like green space, installed by the initiative of local authorities in the peri-urban zone of Lubumbashi city, dominated by populations of *Acacia auriculiformis*. This green space, adjacent to cassava field, is used for prayer and reading activities.

natural vegetation, normally typical of rural zones (Maréchal et al., 2018). Since peri-urban zones are assimilated to exogenous edge zones of urban patches (Bogaert et al., 2015), they present hybrid ecological conditions of both undisturbed (rural) and disturbed (urban) habitats (André et al., 2014; Niemelä et al., 2002; Radeloff et al., 2005; Rija et al., 2014).

The process of urbanization has highly transformed the landscape of Lubumbashi and has created heterogeneous urban vegetated lands with new environmental conditions, leading to an installation of exotic species at an appreciable degree (Figure 6). Similar situations have also been observed in other African cities, though in varied proportions (Bernholt et al., 2009; Bigirimana

Figure 6. A square in the urban zone of Lubumbashi city. In the foreground of the picture is the ligneous species *Delonix regia*, while *Cynodon dactylon,* an exotic species, constitutes the prevalent herbaceous species.

et al., 2011; Rija et al., 2014). The urbanization of a city has considerable impacts on the composition of urban flora (Godefroid, 2001; McKinney, 2008; Ricotta, Godefroid, & Rocchini, 2010; Tait, Daniels, & Hill, 2005). For the case of Lubumbashi, as revealed in the current study, it is worth mentioning that the species richness observed is approximately 4 times lower compared to values previously advanced by Leblanc and Malaisse (1978, pp. 70–90). This situation could be in relation with the removal of the original vegetation cover and its replacement by built-up, since 68% of species found earlier were located on wastelands and informal green spaces (Leblanc & Malaisse, 1978), currently occupied by built-up. This situation is particularly alarming in the peri-urban zones as these are dynamic zones that are characterized by rapid change as a result of an extension of the city and associated infrastructures (Chirisa, 2010; S. Shackleton et al., 2015).

The life form of plants is an adaptive response to environment, in addition to providing an ecological classification that may be indicative of habitat conditions (Shaltout & El-Sheikh, 2002). Surprisingly, the higher presence of phanerophyta appears to be linked to the presence of roadside green spaces in the urban zone and remnant patches of *miombo* forest in the peri-urban zone. These two factors may explain the lower presence of phanerophyta in the city of Bujumbura (Bigirimana et al., 2011), although it is also surrounded by the *miombo* woodland and savannah vegetation. The dominance of phanerophyta observed in Lubumbashi, which also corroborates results previously obtained for the city of Kisangani in the Congo basin (Mutabana, 1982), appears to be critical in contributing to more resilient social–ecological systems, hence it should be taken into consideration in any urban planning initiative and in designing new housing developments (S. Shackleton et al., 2015). The presence of therophyta observed in almost all the studied zones might be due to disturbances in habitat conditions, favored by built-up expansion. Indeed, it is evident from the literature that the capacity to produce large quantities of seeds in therophyta, despite the reduced competitive capacity, would explain the maintenance of their populations in disturbed environments such as cultivated fields or fallows in urbanized areas (Wang et al., 2014).

Current findings demonstrated that both zones of the urban–rural gradient present a similar level of accessibility to the green spaces, which might be an indication of a free of charge access to the majority of green spaces. Likewise, it is thought that Lubumbashi green spaces are visited irrespective of the type of their vegetation or their management characteristics (Qureshi, Breuste, & Jim, 2013), which appears to be the opposite to the situation in cities like Santa Cruz (Bolivia), where a preference is noted for larger green spaces, with more amenities (Wendel, Zarger, & Mihelcic, 2012).

Implications for Conservation

A range of issues have been evidenced regarding land management in the city of Lubumbashi. The most flagrant cases concern the existence of less equipped and poorly structured quarters in the peri-urban zone, an uncontrolled extension of the city through creation of housing development endangering the existence of green spaces and associated infrastructures, and a lack of coordinated actions concerning the urban management in the city (Groupe Huit, 2009). As an evident demographic explosion is expected in the coming decades in the city, and considering the huge density of population observed in ancient colonial quarters, it appears logical to assume that such demographic explosion will most likely occur in the peri-urban zone where lands are being allotted at a worrying pace. Currently, in this peri-urban zone, the majority of lands are owned by privates, who are managing those lands and corresponding vegetal covers. In this context, an exacerbation of conflict between green space preservation and housing is expected in the future in the peri-urban zone, particularly fields. Conservation of fields could be critical to food security because their area diminishes every year to the benefits of infrastructure which has the priority over agricultural activities in the city, probably due to the ignorance of municipal offices.

Conversely, gardens around private businesses, factories, schools, and public office buildings could be important for species conservation and a range of ecosystem services in urban zone. Unfortunately, there is a strong trend to densification of the existing properties through the neighborhoods with the increase in population and the decrease in new allocations of parcels for building new houses and offices in urban zone. But in addition, when these attributions of new properties are done, they often public green spaces that previously supported a diversity of cultivated plants. Indeed, the species diversity of urban green spaces could also be forced to decrease.

Our study demonstrated that the urbanization in Lubumbashi city has brought about a tendency toward smaller and private green spaces, which could, in the long term, spoil green spaces-related benefits such as recreational opportunities, psychological well-being of citizens (Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006), and economic and ecological advantages (Bolund & Hunhammar, 1999; C. M. Shackleton & Blair, 2013). Such diverse benefits contribute to more resilient social–ecological systems and need to be a part of the future urban planning initiatives as well as in the design of new housing developments in Lubumbashi city. Indeed, it is now generally accepted that sustainability principles cannot be disregarded in urban planning in the perspective to create the conditions for comfortable and dignified living (C. M. Shackleton, Hebinck, Kaoma, Chishaleshale, & Chinyimba, 2014). Furthermore, an operational program of urbanism should be implemented so as to establish allotments capable of guarantying a minimum of green space to the annually occurring surplus of population in Lubumbashi city. Therefore, it is necessary for local populations to be aware of the importance of green spaces and their role in counteracting adverse effects associated with urbanization.

This study provides a better knowledge of the vegetation inside Lubumbashi city and its spatial organization, which is a first step toward monitoring the evolution of the vegetation in the current context of anarchic expansion of the city. Globally, obtained results highlighted the importance to preserve green spaces in the peri-urban zone of Lubumbashi city, where relatively high proportions of indigenous species and natural vegetation were recorded.

This study highlighted the compositional differences in green spaces between the planned (urban zone) and unplanned (peri-urban zone) neighborhoods in Lubumbashi city, which is probably associated with historical and current political planning processes in the city. Bearing this in mind, for future urbanization plan, a call is particularly made to local authorities and planners for the implementation of effective measures targeting to increase plant diversity within the city, for example, by restoring public urban green spaces using indigenous species identified in this study, with the aim to counteract exotic founded in high proportion in the studied area.

The urbanization process of Lubumbashi city resulted in the progressive elimination of natural vegetation like *miombo* woodland with its indigenous flora and its replacement by green space types dominated by exotic species. This is the well-known process of biological homogenization (McKinney, 2008). However, these recently created green spaces, and with high level of anthropization, cannot fulfill the ecological functions that were provided by the natural ones due to the difference in structure and species composition (Li et al., 2013). It is important to conserve and restore natural or seminatural green space in Lubumbashi city using indigenous species founded in our study.

Integrating indigenous species in roadside green spaces in the peri-urban zone could also increase the spatial connectivity of the green infrastructure, which is worth consideration in any plan of new housing developments in the peri-urban zone. The current study also revealed a notable occurrence of invasive species in the study area, especially in the peri-urban zone. But in the current context where the city of Lubumbashi does not have a master plan and monitoring program for invasive species, the invasion debt by new species and the extinction debt for all species are both high in the medium and long term. In this context, a regular inventory of the local flora is warranted in order to adopt efficient approaches to counteract the propagation of the large spectrum of exotic invasive species observed in the studied area. Likewise, flora monitoring could help to identify the species of socioeconomical interests. The current study listed species like the endemic *Bulbostylis pseudoperennis* (Goeth.) that exhibit potential in the restoration of degraded metal-rich habitats and the revegetation of metal bare soils in the katangan copperbelt area (Ilunga wa Ilunga et al., 2015). The same goes for *Leucaena leucocephala*, *Imperata cylindrica*, *Panicum maximum*, *Tithonia diversifolia*, and *Hyparrhenia* spp., which are essential for agropastoral activities; *Aloe vera* known for medicinal properties; while *Abelmoschus esculentus*, *Ipomoea batatas*, and *Citrus* spp. are of nutritional interest. In another respect, despite their potential ecological threats, biomass of *Tithonia diversifolia*, *Mimosa* spp., and *Eicchornia crassipes* (also listed in this study) could be oriented toward replenishment of soil fertility for agricultural production. It is hence evident with respect to how they are managed, be it invasive, exotic species can still prove useful for life in a given ecosystem.

Appendix

Table A1. Plant Species (Including Trees, Shrubs, and Herbs) Observed in Green Spaces in the UZ and PZ of Lubumbashi City Following Lebrun and Stork (1991–2015) Classification System.

			EX		IND	
Species	Family	Life forms	UZ	PZ	UZ	PZ
Abelmoschus esculentus (L.) Moench	Malvaceae	Th	x	x		
Acacia auriculiformis Benth.	Fabaceae	Ph	x			
Acacia mangium Willd.	Fabaceae	Ph	x			
Acacia polyacantha Willd.	Fabaceae	Ph	x	x		
Aframomum sanguineum (K.Schum.) K.Schum.	Zingiberaceae	Hc			x	
Aloe vera (L.) Burm.f.	Asphodelaceae	Hc				x
Amaranthus caudatus L.	Amaranthaceae	Th	x	x		
Amaranthus dubius Mart. ex Thell.	Amaranthaceae	Th	x	x		
Amaranthus hybridus L.	Amaranthaceae	Th	x	x		
Amaranthus spinosus L.	Amaranthaceae	Th	x	x		
Amaranthus tricolor L.	Amaranthaceae	Th	x	x		
Amaranthus viridis L.	Amaranthaceae	Th	x	x		
Arachis hypogaea L.	Fabaceae	Th	x	x		
Bambusa vulgaris Schrad.	Poaceae	Hc	x	x		
Bidens pilosa L.	Asteraceae	Th	x	x		
Bougainvillea glabra Choisy	Nyctaginaceae	Ph	x	x		
Bougainvillea spectabilis Willd.	Nyctaginaceae	Ph	x	x		
Brachystegia boehmii Taub.	Fabaceae	Ph			x	x
Brassica chinensis L.	Brassicaceae	Th	x	x		
Bulbostylis pseudoperennis Goetgh.	Poaceae	Hc			x	x
Canna indica L.	Cannaceae	Ge	x			
Carica papaya L.	Caricaceae	Ph	x	x		
Cassia occidentalis L.	Fabaceae	Ph	x	x		
Cassia siamea Lam.	Fabaceae	Ph	x	x		
Cassia katangensis (Ghesq.) Steyaert	Fabaceae	Ph				
Cassia mannii Oliv.	Fabaceae	Ph	x	x		
Centrosema pubescens Benth.	Fabaceae	Th		x		
Chloris gayana Kunth	Poaceae	Th			x	x
Citrus limon (L.) Burm.	Rutaceae	Ph	x	x		

(continued)

Table A1. Continued

Species	Family	Life forms	EX		IND	
			UZ	PZ	UZ	PZ
Citrus maxima (Burm.) Merr.	Rutaceae	Ph	x	x		
Citrus reticulata Blanco	Rutaceae	Ph	x	x		
Citrus sinensis (L.) Osbeck	Rutaceae	Ph	x	x		
Crepidorhopalon tenuis (S.Moore) Eb.Fisch.	Scrophulariaceae	Th			x	
Cucurbita pepo L.	Cucubirtaceae	Hc	x	x		
Cupressus atlantica Gaussen	Cupressaceae	Ph	x			
Cupressus bakeri Jeps. ssp. *matthewsii* C.B. Wolf	Cupressaceae	Ph	x			
Cupressus macrocarpa Hartw.	Cupressaceae	Ph	x			
Cynodon dactylon (L.) Pers.	Poaceae	Hc	x	x		
Cyperus papyrus L.	Cyperaceae	Hy			x	x
Daucus carota L.	Apiaceae	Ge	x	x		
Delonix regia (Hook.) Raf.	Fabaceae	Ph			x	x
Dioscorea bulbifera L.	Dioscoreaceae	Ph			x	
Echinochloa colona (L.) Link	Poaceae	Th			x	x
Elaeis guineensis Jacq.	Arecaceae	Ph			x	x
Eleusine indica (L.) Gaertn.	Poaceae	Hc	x	x		
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Ph	x			
Euphorbia enopla Boiss.	Euphorbiaceae	Ph				x
Euphorbia hirta L.	Euphorbiaceae	Hc			x	x
Euphorbia tirucalli L.	Euphorbiaceae	Ph			x	x
Hymenocallis acutifolia (Herb. ex Sims) Sweet	Amaryllidaceae	Ge	x	x		
Hyparrhenia rufa (Nees) Stapf	Poaceae	Hc			x	x
Imperata cylindrica (L.) Raeusch.	Poaceae	Th			x	x
Ipomoea batatas (L.) Poir.	Convolvulaceae	Ge	x	x		
Julbernardia globiflora (Benth.) Troupin	Fabaceae	Ph			x	
Julbernardia paniculata (Benth.) Troupin	Fabaceae	Ph			x	
Lantana camara L.	Verbenaceae	Ph	x			
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Ph	x	x		
Loudetia simplex (Nees) C.E.Hubb.	Poaceae	Hc			x	
Mangifera indica L.	Anacardiaceae	Ph	x	x		
Manihot glaziovii Müll.Arg.	Euphorbiaceae	Ph	x	x		
Manihot esculenta Crantz	Euphorbiaceae	Ph	x	x		
Microchloa altera (Rendle) Stapf	Poaceae	Hc			x	x
Mimosa invisa Colla	Fabaceae	Ph		x		
Mimosa pigra L.	Fabaceae	Ph		x		
Mimosa pubescens Vent.	Fabaceae	Ph		x		
Mimosa pudica L.	Fabaceae	Th		x		
Monotes katangensis (De Wild.) De Wild.	Dipterocarpaceae	Ph			x	
Musa acuminata Colla	Musaceae	Hc	x	x		
Musa balbisiana Colla	Musaceae	Hc	x	x		
Panicum maximum Jacq.	Poaceae	Th			x	x
Papaver somniferum L.	Papaveraceae	Hc	x	x		
Paspalum notatum Flüggé	Poaceae	Ge	x	x		
Passiflora edulis Sims	Passifloraceae	Ph	x			
Persea americana Mill.	Lauraceae	Ph	x	x		

(continued)

Table A1. Continued

Species	Family	Life forms	EX		IND	
			UZ	PZ	UZ	PZ
Phoenix dactylifera L.	Arecaceae	Ph	x			
Phragmites australis (Cav.) Trin. ex Steud.	Poaceae	Ph				x
Phyllostachys aurea Rivière & C. Rivière	Poaceae	Ph	x			
Pinus pinea L.	Pinaceae	Ph	x	x		
Psidium guajava L.	Myrtaceae	Ph	x	x		
Pterocarpus angolensis DC.	Fabaceae	Ph				x
Ricinus communis L.	Euphorbiaceae	Ph	x			
Rumex abyssinicus Jacq.	Polygonaceae	Ge			x	
Rumex acetosella L.	Polygonaceae	Ge			x	
Rumex alpinus L.	Polygonaceae	Ge		x		
Rumex cordatus Poir.	Polygonaceae	Ge		x		
Rumex densiflorus Osterh.	Polygonaceae	Ge		x		
Rumexs anguineus L.	Polygonaceae	Ge		x		
Saccharum officinarum L.	Poaceae	Hc		x		
Sansevieria trifasciata Prain	Liliaceae	Hc				x
Setaria appendiculata (Hack.) Stapf	Poaceae	Th	x	x		
Setaria elementii (Domin) R.D. Webster	Poaceae	Th	x	x		
Setaria geminata (Forssk.) Veldkamp	Poaceae	Th	x	x		
Setaria incrassata (Hochst.) Hack.	Poaceae	Th			x	x
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	Th	x	x		
Setaria sphacelata (Schumach.) Stapf & C.E.Hubb. ex Moss	Poaceae	Th			x	x
Setaria verticillata (L.) P. Beauv.	Poaceae	Th	x	x		
Sorghum abyssinicum (Fresen.) Kuntze	Poaceae	Th			x	
Sorghum angustum S.T.Blake	Poaceae	Th			x	
Sorghum bicolor (L.) Moench	Poaceae	Th			x	
Sorghum laxiflorum F.M.Bailey	Poaceae	Th			x	
Sorghum saccharatum (L.) Moench	Poaceae	Th			x	
Sorghum vulgare Pers.	Poaceae	Th			x	
Sporobolus pyramidalis P.Beauv.	Poaceae	Hc				x
Stylosanthes guianensis (Aubl.) Sw.	Fabaceae	Hc	x			
Terminalia catappa L.	Combretaceae	Ph	x	x		
Tithonia diversifolia (Hemsl.) A.Gray	Asteraceae	Hc	x	x		
Typha latifolia L.	Typhaceae	Ph	x			
Zea mays L.	Poaceae	Th	x	x		

Note. Origin of species: exotic and indigenous. Life forms: phanerophyta, hemicrytophyta, geophyta, therophyta, and hydrophyta. EX = exotic; IND = indigenous. Ph = phanerophyta; Hc = hemicryptophyta; Ge = geophyta; Th = therophyta; Hy = hydrophyta PZ = peri-urban zone; UZ = urban zone.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Y. U. S. received financial support from the ARES-CCD (Belgium) PRD CCPGU for the research, authorship, and/or publication of this article. R.S.K. is supported by a scholarship of ULiège (PACODEL).

References

Adinolfi, C., Suárez-Cáceres, G. P., & Cariñanos, G. P. (2014). Relations between visitor's behavior and characteristics of

green spaces in the city of Granada, south-eastern Spain. *Urban Forestry and Urban Greening*, *13*, 534–542. doi:10.1016/j.ufug.2014.03.007
André, M., Mahy, G., Lejeune, P., & Bogaert, J. (2014). Vers une synthèse de la conception et d'une définition des zones dans le gradient urbain-rural [Toward a synthesis of the concept and a definition of the zones in the urban-rural gradient]. *Biotechnologie, Agronomie, Société et Environnement*, *18*(1), 61–74.
Barau, A. S., Ludin, A. N. M., & Said, I. (2013). Socio-ecological systems and biodiversity conservation in African city: Insights from Kano Emir's Palace gardens. *Urban Ecosystems*, *16*(4), 783–800. doi:10.1007/s11252-012-0276-x
Bernholt, H., Kehlenbeck, K., Gebauer, J., & Buerkert, A. (2009). Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. *Agroforestry Systems*, *77*, 159–179. doi:10.1007/s10457-009-9236-8
Bigirimana, J., Bogaert, J., De Cannière, C., Lejoly, J., & Parmentier, I. (2011). Alien plant species dominate the vegetation in a city of sub-Saharan Africa. *Landscape and Urban Planning*, *100*, 251–267. doi:10.1016/j.landurbplan.2010.12.012
Bogaert, J., Biloso, A., Vranken, I., & André, M. (2015). Peri-urban dynamics: Landscape ecology perspectives. In: J. Bogaert, & J-M. Halleux (Eds.). Territoires périurbains: Développement*, enjeux et perspectives dans les pays du sud [Peri-urban areas: development, challenges and prospects in the South]* (pp. 63–73). Gembloux, Belgique: Les Presses Agronomiques de Gembloux.
Bogaert, J., & Mahamane, A. (2005). Ecologie du paysage: Cibler la configuration et l'échelle spatiale. *Annales des Sciences Agronomiques du Bénin [Landscape ecology : focus on spatial pattern and scale]*, *7*, 39–68.
Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*, 293–301. doi:10.1016/S0921-8009(99)00013-0
Bromilov, C. (2010). *Problem plants and alien weeds of South Africa* (3rd ed.). Pretoria, Republic of South Africa: Briza Publications.
Bruneau, J. C., & Pain, M. (1990). *Atlas de Lubumbashi Atlas de Lubumbashi*. Nanterre, France: Centre d'Etude Géographique sur l'Afrique Noire.
Bultot, F. (1950). *Carte des régions climatiques du Congo Belge établie d'après les critères de Köppen* [Climatic maps of the Belgian Congo regions established according to the criteria of Köppen]. Bruxelles, Belgique: Bureau climatique, Institut National pour l'Etude Agronomique au Congo-Belge.
Byomkesh, T., Nakagoshi, N., & Dewan, A. M. (2012). Urbanization and green space dynamics in Greater Dhaka, Bangladesh. *Landscape Ecology Engineering*, *8*, 45–58. doi:10.1007/s11355-010-0147-7
Catford, J. A., Daehler, C. C., Murphy, H. T., Sheppard, A. W., Hardesty, B. D., Westcott, D. A., . . . Hulme, P. E. (2012). The intermediate disturbance hypothesis and plant invasions: Implications for species richness and management. Perspectives in Plant Ecology*, Evolution and Systematics*, *14*, 231–241. doi:10.1016/j.ppees.2011.12.002
Chirisa, I. (2010). Peri-urban dynamics and regional planning in Africa: Implications for building healthy cities. *Journal of African Studies and Development*, *2*(2), 15–26.
Chocholouskova, Z., & Pyšek, P. (2003). Changes in composition and structure of urban flora over 120 years: A case study of the city of Plzen. *Flora*, *198*, 366–376. doi:10.1078/0367-2530-00109
Chukwuka, K. S., Ogunyemi, S., & Fawole, I. (2007). Ecological distribution of *Tithonia diversifolia* (Hemsley) A. Gray, a new exotic weed in Nigeria. *Journal of Biological Science*, *7*(5), 709–719.
Cilliers, S. S., Cilliers, J., Lubbe, R., & Siebert, S. (2013). Ecosystem services of urban green spaces in African countries – perspectives and challenges. *Urban Ecosystems*, *16*, 681–702. doi:10.1007/s11252-012-0254-3
Cornelis, J., & Hermy, M. (2004). Biodiversity relationships in urban and suburban parks in Flanders. *Landscape and Urban Planning*, *69*, 385–401. doi:10.1016/j.landurbplan.2003.10.038
Doren, F. R., Volin, J. C., & Richards, J. H. (2009). Invasive exotic plant as indicators for ecosystem restoration: An example from the Everglades restoration program. *Ecological Indicators*, *95*, 529–536. doi:10.1016/j.ecolind.2008.08.006
Fanan, U., Dlama, K. I., & Oluseyi, I. O. (2011). Urban expansion and vegetal cover loss in and around Nigeria's federal capital city. *Journal of Ecology and the Natural Environment*, *3*(1), 1–10.
Forman, R. T. T., & Godron, M. (1986). *Landscape ecology*. New York, NY: John Wiley & Sons.
Fuller, R. A., & Gaston, K. J. (2009). The scaling up of green space coverage in European cities. *Biology Letters*, *5*, 352–355. doi:10.1098/rsbl.2009.0010
Godefroid, S. (2001). Temporal analysis of the Brussels flora as indicator for changing environmental quality. *Landscape and Urban Planning*, *52*, 203–224. doi:10.1016/S0169-2046(00)00117-1
Gong, C. F., Chen, J., & Yua, S. (2013). Biotic homogenization and differentiation of the flora in artificial and near-natural habitats across urban green spaces. *Landscape and Urban Planning*, *120*, 158–169. doi:10.1016/j.landurbplan.2013.08.006
Groupe Huit. (2009). *Elaboration du plan urbain de référence de Lubumbashi* [Development of the urban reference plan of Lubumbashi] (Rapport final Groupe Huit). Lubumbashi, Democratic Republic of the Congo: Beau, Ministère des Infrastructures et Travaux Publics.
Ilunga wa Ilunga, E., Mahy, G., Piqueray, J., Séleck, M., Shutcha, M. N., Meerts, P., & Faucon, M.-P. (2015). Plant functional traits as a promising tool for the ecological restoration of degraded tropical metal-rich habitats and revegetation of metal-rich bare soils: A case study in copper vegetation of Katanga. *Ecological Engineering*, *82*, 214–221. doi:10.1016/j.ecoleng.2015.04.084
Ipou, I. J., Toure, A., Adou, A. M. D., Kouame, K. F., & Gue, A. (2011). A new invasive species of the agrosystems in the south of Côte d'Ivoire: *Tithonia diversifolia* (Hemsl.) A. Gray (Asteraceae). *African Journal of Food Science and Technology*, *1*(6), 146–150.
Kong, F., & Nakagoshi, K. (2005). Changes of urban green spaces and their driving forces: A case study of Jinan city, China. *Journal of International Development and Cooperation*, *11*(2), 97–109.
Kong, F., Yin, H., James, P., Hutyra, L. R., & He, H. S. (2014). Effect of spatial pattern of green spaces on urban cooling in a large metropolitan area of eastern China. *Landscape and Urban Planning*, *128*, 35–47. doi:10.1016/j.landurbplan.2014.04.018
La Rosa, D., & Privitera, R. (2013). Characterization of non-urbanized areas for land-use planning of agricultural and

green infrastructure in urban context. *Landscape and Urban Planning*, *109*, 94–106. doi:10.1016/j.landurbplan.2012.05.012

Leblanc, M., & Malaisse, F. (1978). *Lubumbashi, un écosystème urbain tropical* [Lubumbashi, a tropical urban ecosystem]. République du Zaïre: Centre International de Sémiologie, Université Nationale du Zaïre, Lubumbashi.

Lebrun, J.-P., & Stork, A. L. (1991–2015). *Enumération des plantes à fleurs d'Afrique tropicale et Tropical African Flowering Plants: Ecology and Distribution* (Vol. 1–7). Conservatoire et Jardin botaniques de la Ville de Genève.

Li, J., Li, C., Zhu, F., Song, C., & Wu, J. (2013). Spatiotemporal pattern of urbanization in Shangai, China, between 1989 and 2005. *Landscape Ecology*, *28*, 1545–1565. doi:10.1007/s10980-013-9901-1

Liang, Y.-Q., Li, J.-W., Li, J., & Valimaki, S. K. (2008). Impact of urbanization on plant diversity: A case study in built-up area of Beijing. *Forestry Studies in China*, *10*(3), 179–188. doi:10.1007/s11632-008-0036-4

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the world's worst invasive alien species: A selection from the global invasive species database*. Auckland, New Zealand: Invasive Species Specialist Group.

Maas, J., Verheij, R. A., Groenewegen, P. P., de Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology and Community Health*, *60*, 587–592.

Malaisse, F. (1974). Phenology of the Zambezian woodland area with emphasis on the miombo ecosystem. In: H. Lieth (ed.) *Phenology and seasonality modelling* (Vol 8, pp. 269–286). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-51863-8_23

Malaisse, F., & Mutihac, G. (1976). Contribution à l'étude de l'écosystème urbain lushois : Les enceintes de parcelles [Contribution to the study of the urban ecosystem of Lubumbashi: Enclosures of parcel]. *Centre International de Sémiologie*, *1*, 3–14.

Malaisse, F., Schaijes, M., & D'Outreligne, C. (2016). *The copper-cobalt flora of Upper-Katanga and Copperbelt: Field guide*. Gembloux, Belgium: Les Presses Agronomiques de Gembloux.

Maréchal, J., Useni, S. Y., Bogaert, J., Munyemba, K. F., & Mahy, G. (2018). *La perception par des experts locaux des espaces verts et de leurs services écosystémiques dans une ville tropicale en expansion: Le cas de Lubumbashi* [Local expert perception about green spaces and their ecosystem services in a tropical city in expansion: The case of Lubumbashi (DR Congo)]. In: G. Mahy, G. Colinet, & J. Bogaert (Eds.). *Anthropisation des paysages katangais [Anthropization of katangan landscapes]* (pp. 57–67). Gembloux, Belgique: Les Presses Agronomiques de Gembloux.

McConnachie, M. M., Shackleton, C. M., & McGregor, G. K. (2008). The extent of public green space and alien plant species in 10 small towns of the sub-tropical Thicket Biome, South Africa. *Urban Forestry and Urban Greening*, *7*(1), 1–13. doi:10.1016/j.ufug.2007.12.003

McDonald, R. I., Forman, R. T. T., & Kareiva, P. (2010). Open space loss inequality in United States' cities, 1990-2000. *PLoS One*, *5*(3), e9509 doi:10.1371/journal.pone.0009509

McDonald, R. I., Forman, R. T. T., Kareiva, P., Neugarten, R., Salzer, D., & Fisher, J. (2009). Urban effects, distance and protected areas in urbanizing world. *Landscape and Urban Planning*, *93*, 63–75. doi:10.1016/j.landurbplan.2009.06.002

McDonnell, M. J., & Hahs, A. K. (2008). The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: Current status and future directions. *Landscape Ecology*, *23*(10), 1143–1155. doi:10.1007/s10980-008-9253-4

McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, *11*, 161–176. doi:10.1007/s11252-007-0045-4

Mensah, C. A. (2014). Urban green spaces in Africa: Nature and challenges. *International Journal of Ecosystems*, *4*(1), 1–11. doi:10.5923/j.ije.20140401.01

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

Muoghalu, J. I., & Chuba, D. K. (2005). Seed germination and reproductive strategies of *Tithonia diversifolia* (Hemsl.) Gray and *Tithonia rotundifolia* (P.M) Blak. *Applied Ecology and Environmental Research*, *3*, 39–46.

Mutabana, N. (1982). *Phytocénoses de l'écosystème urbain de Kisangani* [Plant assemblages of the city of Kisangani] (Doctoral dissertation). University of Kisangani, Democratic Republic of Congo.

Niemelä, J., Kotze, D. J., Venn, S., Penev, L., Stoyanov, I., Spence, J., Hartley, D., & de Oca, M. (2002). Carabid beetle assemblages (Coleoptera, Carabidae) across urban–rural gradients: An international comparison. *Landscape Ecology*, *17*, 387–401. doi:10.1023/A:1021270121630

Nkuku, K. C., & Rémon, M. (2006). *Stratégies de survie à Lubumbashi (R-D Congo). Enquête sur 14000 ménages urbains* [Survival stratégies in Lubumbashi. Survey on 14000 urban households]. Paris, France: Archive congolaise, l'Harmattan.

Osseni, A. A., Mouhamadou, I. T., Tohozin, B. A. C., & Sinsin, B. (2015). SIG et gestion des espaces verts dans la ville de Porto-Novo au Bénin [GIS and Green Spaces' Management in PortoNovo Town in Benin]. *Tropicultura*, *33*(2), 146–156.

Pyšek, P., Richardson, D. M., Rejmanek, M., Webster, G. L., Williamson, M., & Kirschner, J. (2004). Alien plants in checklists and floras: Towards better communication between taxonomists and ecologists. *Taxon*, *53*, 131–143.

Qureshi, S., Breuste, J. H., & Jim, C. Y. (2013). Differential community and the perception of urban green spaces and their contents in the megacity of Karachi, Pakistan. *Urban Ecosystems*, *16*(4), 853–870. doi:10.1007/s11252-012-0285-9

Qureshi, S., Breuste, J. H., & Lindley, S. J. (2010). Green space functionality along an urban gradient in Karachi, Pakistan: A socio-ecological study. *Human Ecology*, *38*(2), 283–294. doi:10.1007/s10745-010-9303-9

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland-urban interface in the United States. *Ecological Applications*, *15*(3), 799–805. doi:10.1890/04-1413

Raunkier, C. (1934). *The life forms of plants and statistical plant geography*. Oxford, England: Clarendon Press.

Ricotta, C., Godefroid, S., & Rocchini, D. (2010). Patterns of native and exotic species richness in the urban flora of Brussels: Rejecting the 'rich get richer' model. *Biological Invasions*, *12*(1), 233–240. doi:10.1007/s10530-009-9445-0

Rija, A. A., Said, A., Mwamende, K. A., Hassan, S. H., & Madoffe, S. S. (2014). Urban sprawl and species movement may decimate natural plant diversity in an Afro-tropical city. *Biodiversity Conservation*, *23*, 963–978. doi:10.1007/s10531-014-0646-1

Shackleton, C. M., & Blair, A. (2013). The abundance of urban public green space influences residents' perceptions, uses and willingness to get involved in two small towns in South Africa. *Landscape and Urban Planning*, *113*, 104–112. doi:10.1016/j.landurbplan.2013.01.011

Shackleton, C. M., Hebinck, P., Kaoma, H., Chishaleshale, M., Chinyimba, A., Shackleton, S. E., . . . Gumbo, D. (2014). Low-cost housing developments in South Africa miss the opportunity for household level urban greening. *Land Use Policy*, *36*, 500–509. doi:10.1016/j.landusepol.2013.01.002

Shackleton, S., Chinyimba, A., Hebinck, P., Shackleton, C. M., & Kaoma, H. (2015). Multiple benefits and values of trees in urban landscapes in two towns in northern South Africa. *Landscape and Urban Planning*, *136*, 76–86. doi:10.1016/j.landurbplan.2014.12.004

Shaltout, K. H., & El-Sheikh, M. A. (2002). Vegetation of the urban habitats in the Nile Delta region, Egypt. *Urban Ecosystems*, *6*, 205–221. doi:10.1023/A:1026105612771

Tait, C. J., Daniels, C. B., & Hill, R. S. (2005). Changes in species assemblages within the Adelaide metropolitan area, Australia, 1836-2002. *Ecological Applications*, *15*(1), 346–359. doi:10.1890/04-0920

Tiébré, M.-S., Kassi, N. J., Kouadio, Y. J-C., & N'guessan, K. E. (2012). Etude de la biologie reproductive de *Tithonia diversifolia* (Hemsl.) Gray (Asteraceae): Espèce non indigène invasive en Côte d'Ivoire [Study of reproductive biology of *Tithonia diversifolia* (Hemsl.) Gray (Asteraceae): Invasive non-native specie in Ivory Coast]. *Journal of Asian Scientific Research*, *2*(4), 200–211.

Trefon, T., & Kabuyaya, N. (2015). Les espaces périurbains en Afrique centrale [Peri-urban spaces in central Africa]. In: J. Bogaert, & J-M. Halleux (Eds.). *Territoires périurbains: Développement, enjeux et perspectives dans les pays du sud* (pp. 33–42). Gembloux, Belgique: Les Presses Agronomiques de Gembloux.

United Nations. (2014). *World urbanization prospects: The 2014 revision*. New York, NY: United Nations.

United Nations Habitat. (2014). *The state of African cities 2014. Re-imagining sustainable urban transition*. Nairobi, Kenya: United Nations Human Settlements Program.

Useni, S. Y., André, M., Mahy, G., Cabala, K. S., Malaisse, F., Munyemba, K. F., & Bogaert, J. (2018). Interprétation paysagère du processus d'urbanisation à Lubumbashi (RD Congo): Dynamique de la structure spatiale et suivi des indicateurs écologiques entre 2002 et 2008 [Landscape interpretation of the urbanization process in Lubumbashi (DR Congo): Land cover dynamics and monitoring of ecological indicators between 2002 and 2008]. In: G. Mahy, G. Colinet, & J. Bogaert (Eds.). *Anthropisation des paysages katangais [Anthropization of katangan landscapes]*. Gembloux, Belgique: Les Presses Agronomiques de Gembloux.

Useni, S. Y., Cabala, K. S., Nkuku, K. C., Amisi, M. Y., Malaisse, F., Bogaert, J., & Munyemba, K. F. (2017). Vingt-cinq ans de monitoring de la dynamique spatiale des espaces verts en réponse à l'urbanisation dans les communes de la ville de Lubumbashi (Haut-Katanga, RD Congo) [Twenty-five years of monitoring of green space pattern dynamics in response to urbanization in the municipalities of Lubumbashi City (Upper Katanga, D.R. Congo)]. *Tropicultura*, *35*(4), 300–311.

Useni, S. Y., Malaisse, F., Cabala, K. S., Munyemba, K. F., & Bogaert, J. (2017). Le rayon de déforestation autour de la ville de Lubumbashi (Haut-Katanga, RD Congo): Synthèse [The deforestation radius around Lubumbashi city (Upper Katanga, DR Congo): Synthesis]. *Tropicultura*, *35*(3), 215–221.

Vranken, I., Marielle, A., Mujinya, B. B., Munyemba, K. F., Baert, G., Van Ranst, E., Visser, M., & Bogaert, J. (2014). Termite mound identification through aerial photographic interpretation in Lubumbashi, Democratic Republic of the Congo: Methodology evaluation. *Tropical Conservation Science*, *7*(4), 733–746. doi:10.1177/194008291400700411

Wang, G.-M., Zuo, J.-C., Li, X.-R., Liu, Y.-H., Yu, J.-B., Shao, H.-B., & Li, Y.-Z. (2014). Low plant diversity and floristic homogenization in fast-urbanizing towns in Shandong Peninsular, China: Effects of urban greening at regional scale for ecological engineering. *Ecological Engineering*, *64*, 179–185. doi:10.1016/j.ecoleng.2013.12.054

Wendel, H. E., Zarger, R. K., & Mihelcic, J. R. (2012). Accessibility and usability: Green spaces preferences, perceptions, and barriers in a rapidly urbanizing city in Latin America. *Landscape and Urban Planning*, *107*, 272–282. doi:10.1016/j.landurbplan.2012.06.003.