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Restoration of Degraded Landscapes Along the Urban-Rural Gradient of Lubumbashi City (DR Congo) by *Acacia auriculiformis* Plantations: Spatial Dynamics and Impact on Plant Diversity

Yannick Useni Sikuzani [1,*], Héritier Khoji Muteya [1], Jonas Yona Mleci [1], Médard Mpanda Mukenza [2,3,*], François Malaisse [4] and Jan Bogaert [4]

[1] Unité Ecologie, Restauration Ecologique et Paysage, Faculté des Sciences Agronomiques, Université de Lubumbashi, Lubumbashi BP 1825, Democratic Republic of the Congo; hkhoji@doct.uliege.be (H.K.M.); jonasmleci@gmail.com (J.Y.M.)
[2] Ecole Régionale Post-Universitaire d'Aménagement et Gestion Intégrés des Forêts et Territoires Tropicaux (ERAIFT), Kinshasa, Democratic Republic of the Congo
[3] Département de Gestion des Ressources Naturelles Renouvelables, Faculté des Sciences Agronomiques, Université Technologique Katumba Mwanke, B.P. 74 (via Lubumbashi), Democratic Republic of the Congo
[4] Unité Biodiversité et Paysage, Gembloux Agro-Bio Tech, Université de Liège, 5030 Gembloux, Belgium; malaisse123@gmail.com (F.M.); j.bogaert@uliege.be (J.B.)
* Correspondence: sikuzaniu@unilu.ac.cd (Y.U.S.); m.mpanda@eraift-rdc.org (M.M.M.)

Abstract: With the liberalization of the mining sector, a considerable demographic explosion is witnessed in Lubumbashi city (southeastern of the D.R. Congo). The resulting spatial urban expansion is unplanned, reducing the vegetation cover abundance within and around the city. To address this situation, *Acacia auriculiformis*, an alien species, has been planted without planning and monitoring. We quantify the spatio-temporal pattern dynamics of *A. auriculiformis* along the urban-rural gradient from the digitisation of Google Earth images from 2006, 2014 and 2021, and evaluate tree diversity through floristic inventory. Results showed that the plantation of *A. auriculiformis*, belonging to park, street trees and green spaces-types, increased in patch number and acreage, mostly in urban zone. The values of the patch which were highest in 2006 decreased in 2021, especially in the urban zone. Thirty-nine trees species were founded on *A. auriculiformis* plantations, with *Albizia lebbeck*, *Albizia alba* and *Leucaena leucocephala* being the most common. However, results showed that 20 species out of 39 species found are exotic, half of which are invasive species. However, 19 trees species are indigenous, mainly found in peri-urban zones. Although most tree species were observed in urban zones, the average diameters were greater in the peri-urban zone. Overall, obtained results appear to suggest that the sustainability of *A. auriculiformis* within the urban and peri-urban zones of Lubumbashi city appears uncertain since a considerable number of attracted species are found to be alien invasive trees that pose a threat to biodiversity conservation. There is an urgent need for adoption of a master plan for sustainable integration and monitoring of trees plantations for limiting erosion of indigenous phytodiversity and the spread of alien invasive species populations in the adjacent rural area.

Keywords: urbanization; green infrastructure; urban forestry; biological invasion; ecological restoration

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1. Introduction

More than half of the world's population now lives in cities, and by 2050 it is expected to increase by about 3 billion people [1]. Accordingly, 90% of this growth will be concentrated in Africa and Asia, where urbanisation rates are expected to be around 56% and 64 % respectively. Landscape transformations due to urban development, which occurred in the northern hemisphere in the 20th century [2], currently dominate the landscape dynamics of southern countries [3–5], particularly due to rural-urban migration and the intrinsic demographic changes of the urban population itself [3]. This situation is particularly crucial on the African continent [6], where several generations of urban development master plans have proved to be completely inadequate for the extent of demographic growth and the economic fragility of the population [7]. In particular, the situation is worrying in sub-Saharan Africa, where the urban population is expected to grow fivefold from 200 million in 2000 to one billion in 2050, while the urbanised area is expected to increase twelvefold from ± 26 500 km^2 in 2000 to ± 325 500 km^2 in 2050 [3]. Increasing urban land cover is expected to have profound effects on local and global species diversity patterns [4]. Consequently, the future of vegetation is thus largely dependent on the management of the spatial pattern of cities [8], which are constantly expanding on peripheral rural areas [9]. In response, decision makers, planners, and scientists are focusing their efforts in and around cities to restore remnants of natural diversity. Indeed, as the restoration of the natural landscape in urban areas receiving considerable attention, urbanization is promoting the creation of novel ecosystems where alien plant species are being introduced [10] to provide, augment or restore specific ecosystem services [11]. Yet, cities are the sources of non-native species invasions into the natural habitats of the surrounding suburban and rural areas [12]. For example, in Singapore, nine invasive alien species (*Acacia auriculiformis, Cecropia pachystachya, Falcataria moluccana, Leucaena leucocephala, Manihot carthaginensis subp. glaziovii, Muntingia calabura, Piper aduncum, Pipturus argenteus,* and *Spathodea campanulata*) are dominant in all stages of plant succession on most of the abandoned where they developed a dense canopy forest dominated by invasive species [13]. The presence of alien species may negatively alter ecosystem functions, reduce the flows of ecosystem services, reduce native biodiversity, including into surrounding natural areas [14]. Ultimately, this has a negative impact on local economies and human well-being [15].

Invasive species are under-studied in Sub-Saharan Africa compared to other parts of the world [10,16], with the spatial expansion of invasive alien plants and its impact on the phytodiversity, receiving little recent attention in the literature. The south-eastern part of the DRC which has some of the largest copper and cobalt deposits in the world [17,18], is no exception to this trend [19]. The exploitation of these deposits is prone to damage the land cover, and the natural ecosystems within and around Lubumbashi city are modified to fit the needs of the human populations like housing, energy, agriculture [20,21]. In this area, Lubumbashi city which was created ex nihilo in a formerly rural area within a miombo woodland, represents an interesting case study for the anthropisation of natural landscapes [22,23]. It has been strongly modified by mining activities through a strong industrialization of the landscape [24], but also because of a strong attractiveness of rural populations [25]. Rapid population growth has led to various anthropogenic effects, including deforestation [26], and a rapid and poorly planned spatial urban growth after the country's independence in 1960 [19,24]. Within 25 years (1984-2009), Lubumbashi city experienced a drastic rise of the spatial expansion rate from 100 ha to 500 ha [24].

Although the deforestation around the city was accelerated as of 1960 after the country's independence, it began as soon as the city was created in 1910 and has continued ever since following the demographic growth, commonly associated with increased consumption of charcoal and agricultural products [22]. As a result, a 70 % loss of forest was noted within a 25 km radius of Lubumbashi city between 1956 and 2009 [24]. Within the city, the set of admirable green spaces that were once carefully maintained, have been neglected and replaced by anthropogenic land cover/use [22], with numerous harmful effects on the environment. However, green spaces, which correspond to surfaces covered with vegetation [27], contribute to the purification of air and water, the treatment of waste and the regulation of the microclimate, etc. [28]. In addition, their presence also provides people with aesthetic pleasures, recreational opportunities, and physical and psychological well-being [29].

In the context of Lubumbashi city, the spread of invasive species is directly encouraged by human activity through the deliberate and accidental movement of plants. Particularly, invasive species are spread through the creation of green spaces planted with exotic trees fast-growing, like *Acacia auriculiformis*. *A. auriculiformis* is an alien invasive species of the Fabaceae family with creamy yellow fragrant flowers that tolerates many types of soil, including degraded lands. Introduced in Lubumbashi city in the early 2000, it is considered as beneficial nurse crops used as an ornamental plant, shade tree and as firewood [30]. Although the urban and peri-urban woody green spaces of Lubumbashi city are dominated by miombo woodland species, *A. auriculiformis* remained the most

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common species [31]. However, Ref. [32] findings revealed the reduction of species richness of indigenous plants as one of the major problems associated with the presence of dense stands of invasive alien trees and shrubs in the Fynbos Biome (South Africa), but this aspect is not understood under *A. auriculiformis* stands in Lubumbashi city. Yet, there is no study that has investigated the change in landscape pattern due to its expansion, and the impact on plant diversity since its introduction in Lubumbashi since. Likewise, a greater understanding of the spatial expansion and the ecological role of alien species might help to reduce controversy surrounding their purposeful use in restoration [33,34].

With the recent development of Google Earth images coupled to GIS and landscape ecology, the spatial expansion of plant communities can be mapped and quantified [35]. The expansion of plant communities which modify the ecological functioning of landscapes can be highlighted by an assessment of the properties of landscapes and the ecosystem services they provide [36,37], particularly through biodiversity analysis [38]. The present study characterizes the spatial evolution and the phytodiversity under *A. auriculiformis* plantations along the urban-rural gradient. We hypothesized that the positive anthropisation of the landscape through the creation of *A. auriculiformis* plantations could be accompanied by an increase in the patch number as well as area either in urban or peri-urban zones.

2. Materials and Methods

2.1. Study area: Urban zone and peri-urban zone of Lubumbashi city

Lubumbashi city (Figure 1) covers an area of nearly 747 km² (11°27'-11°47'S and 27°19'-27°40'E) at an altitude varying between 1200 and 1300 m. The climate is Cw type of the Köppen classification system [39], with a dry season (May to September), a rainy season (November to March) and two transition months (April and October).

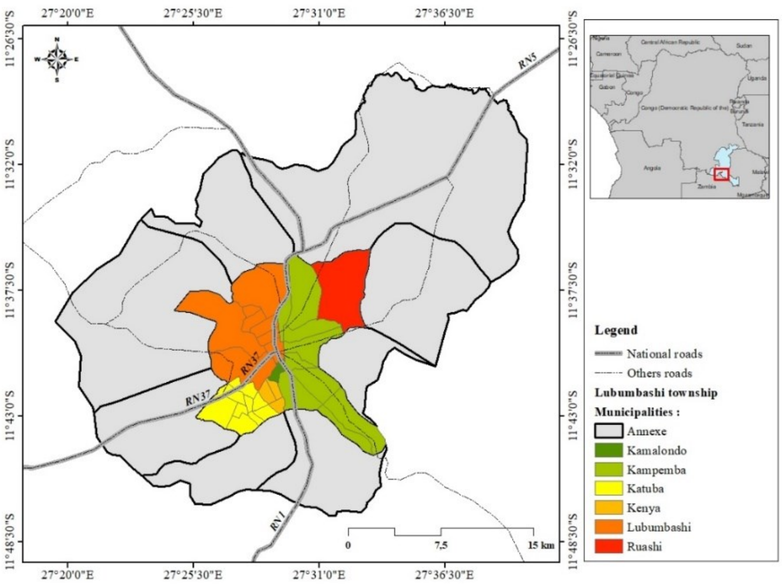

Figure 1. Geographical location of the study area (city of Lubumbashi), Upper Katanga province in the Democratic Republic of the Congo.

For the second half of the last century, the average annual temperature was around 20.1°C [39], though recent reports indicate ongoing warming [40]. In the dry season, winds from the Indian Ocean generally prevail, blowing in the east-south-east and east-north-east directions, which accelerates the spread of fumes from mining companies, and contributes to the pollution of the city [41]. The soils of the city are most ferralitic [39]. The natural wooded vegetation, currently in a fragmented state, is

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located several kilometers away from the city [24,26]. The population is around 2.5 million and is mainly engaged in agriculture, residential livestock, services, mining, and trade [42].

2.2. Exploratory visits

Exploratory visits to the field sites were carried out from 01 to 19 June 2021 to locate the *A. auriculiformis* plantation, considered as spaces with a group of *A. auriculiformis* individuals planted either by the public authority or by private individuals. In each municipality of Lubumbashi city, we exchange with local authorities to present objectives of the study to the local authorities and seek their permission to undertake the study. The person in charge of administration or an influential member of the community was then instructed by the leaders to establish and deliver a list and addresses of all *A. auriculiformis* within their jurisdictions. The listed plantations have been visited based on local knowledge and located using a GPS Garmin 64st (±3 m precision). In addition, for each plantation visited, the position in the urban-rural gradient was given using the decision tree of [9], which is based on the morphological characteristics of urbanization (proportion, density, and continuity of the built-up). Accordingly, urban zone is characterized by densified and continuous built-up while the discontinuity of the otherwise less dense built-up characterizes the peri-urban zone.

2.3. Spatial analysis

Google Earth images from July 2006, July 2014 and July 2021 were used. These periods correspond to almost 5 years (2006), 13 years (2014) and 20 years (2021) after the introduction of A. auriculiformis in the region. The free program of Google Earth allows the vizualisation of the earth with a combination of satellite images and most aerial photographs (last ten years) with high resolution [43]. As a city of economic and interest in the country, Lubumbashi city is well covered by Google Earth images, hence consideration and precise land cover/use information is available, allowing certain processes to be monitored in the city. ArcGis software was used to produce the maps. Considering the spatial resolution of Google Earth images related to the location and year of image capture [44], *A. auriculiformis* trees located on residential plots and in rural zone (hardly influenced by the degree of urbanization), as well as plantations of less than 250m^2, were not considered. Correspondingly, polygons of *A. auriculiformis* plantations were digitized on Google Earth imagery and converted into vector format using ArcGis software. The spatial pattern of *A. auriculiformis* plantations along the urban-rural gradient was quantified by calculating three landscape indices, including total patch area (CA), Rate of change (RC) and patch number (PN), which are most relevant for informing on the human impact on landscape pattern [45].

2.4. Floristic data collection and analysis

To determine species richness, plots of 100m2 were established on each *Acacia auriculiformis* plantations and the number of plots was adapted to area of each plantation. A total of 27 plots, including 13 plots on the single peri-urban plantation and 14 plots in urban plantations (2-4 per plantation), were studied from July to August 2021. It will be noted for species richness determination, Ref. [46] suggest respectively plots of 1 m^2, 4 m^2, and 100 m^2 for herbaceous species, shrubs, and trees respectively. The This period of floristic inventory corresponds to the dry season in the Lubumbashi plain, which is why the herbaceous plants which develop favorably during the rainy season have not been studied. Indeed, many herbaceous plants in the Lubumbashi plain spend the unfavorable period, the dry season, in the state of regeneration organs (seeds, tubers, stumps, rhizomes) [47]. herbaceous flora has not been studied as it is more sensitive to disturbance (i.e., droughts) and even edaphic variation than the woody flora [48]. However, the trees age was estimated based on the stage of development (seedling and adult). Then, the average height and circumference at 1.30 m above the ground of adult *A. auriculiformis* individuals were estimated and measured respectively. The data collected made it possible to define (i) the species richness as the floristic list of plant species present in a site.

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About the identification of plant species, some species were identified using knowledge of plant systematics and others using available flora [49], and specialized literature [10,50] were utilized. The origin status of species was determined. Accordingly, exotic species were considered as species that are not indigenous to Africa; Afro-Asian species being considered as indigenous [10]. Among these exotic species, biological invasion status about each species was assembled from online databases and specialized literature (e.g., Ref. [51–55]). According to Ref. [56], alien invasive species is a non-native, naturalized species, showing a rapid expansion dynamic in its territory of introduction. The status of native miombo species was specifically determined based on checklists established by [57]. For each identified species, specific abundance and specific frequency were calculated. The specific abundance defined as the number of individual trees for each species while the specific frequency considered as the number of sites where the species was present [58]. Indeed, the relative frequency was calculated as the ratio between the frequency of the species and the total number of sites surveyed [59]. It should be noted that abundance and frequency were used to calculate diversity indices such as Simpson's index and Shannon's index using Paleontological Statistics software. Shannon's index is believed to emphasize the richness component of diversity, and Simpson's index, emphasizing the evenness component [60].

3. Results

3.1. Mapping and spatial pattern of Acacia auriculiformis plantations

It was revealed from the spatial pattern dynamics analysis, an increase of about 30% in *A. auriculiformis* plantation from 2006 (12 plantations) to 2021 (17 plantations). In terms of surface area, two tendencies were noted. A two-fold area increase (15.28 ha to 29.38 ha) of A. auriculiformis plantations was observed between 2006 and 2014; followed slight decrease of about 5% (29.38 ha to 27.89 ha) in the period from 2014 to 2021 (Table 1).

Analysis along the urban-rural gradient reveals an increase in the number of *A. auriculiformis* plantation patches from 11 (2006) to 14 (2014) and from 14 (2014) to 15 (2021) in urban areas. Meanwhile, the area occupied by *A. auriculiformis* plantations almost doubled from 13.68 ha in 2006 to 21.97 ha in 2021. In the peri-urban zone, the period 2006-2014 was characterised by an increase in the patch number, which tripled, while the class area increased fivefold. In the following period (2014-2021), the patch number of *A. auriculiformis* plantation decreased from 3 to 2. Over the same period, the class area was reduced by about 31% (Table 1 and Figure 2). Furthermore, the rate of change of land cover by *A. auriculiformis* plantations in both study areas remained positive over all periods, except between 2006 and 2014 when the peri-urban area recorded a negative rate of change. These results suggest that there has been overall (especially in the urban area) expansion or evolution of *A. auriculiformis* plantations in the study landscape (Table 1).

The results show also that the *A. auriculiformis* plantations belong to three green space types: parks, street trees and attached green spaces. Parks and street trees showed a simultaneous increase in the patch number and in the class area. By cons, in the case of parks, the number of patches doubled from 1 in 2006 to 2 in 2021, while the area increased 39-fold from 0.14 ha 5.41 ha in the same period. As for street trees, the number of patches and the class area have respectively doubled and tripled. Indeed, the number of patches almost doubled from 3 in 2006 to 5 in 2021, while the class area increased by about three-fold from 1.21 ha to 3.62 ha in the same period. Conversely, although the patches number of attached *Acacia* and the class area were respectively increased by 20% and 40% from 2006 to 2014, a slight decrease (18%) in class area was recorded from 2014 to 2021 (Table 1).

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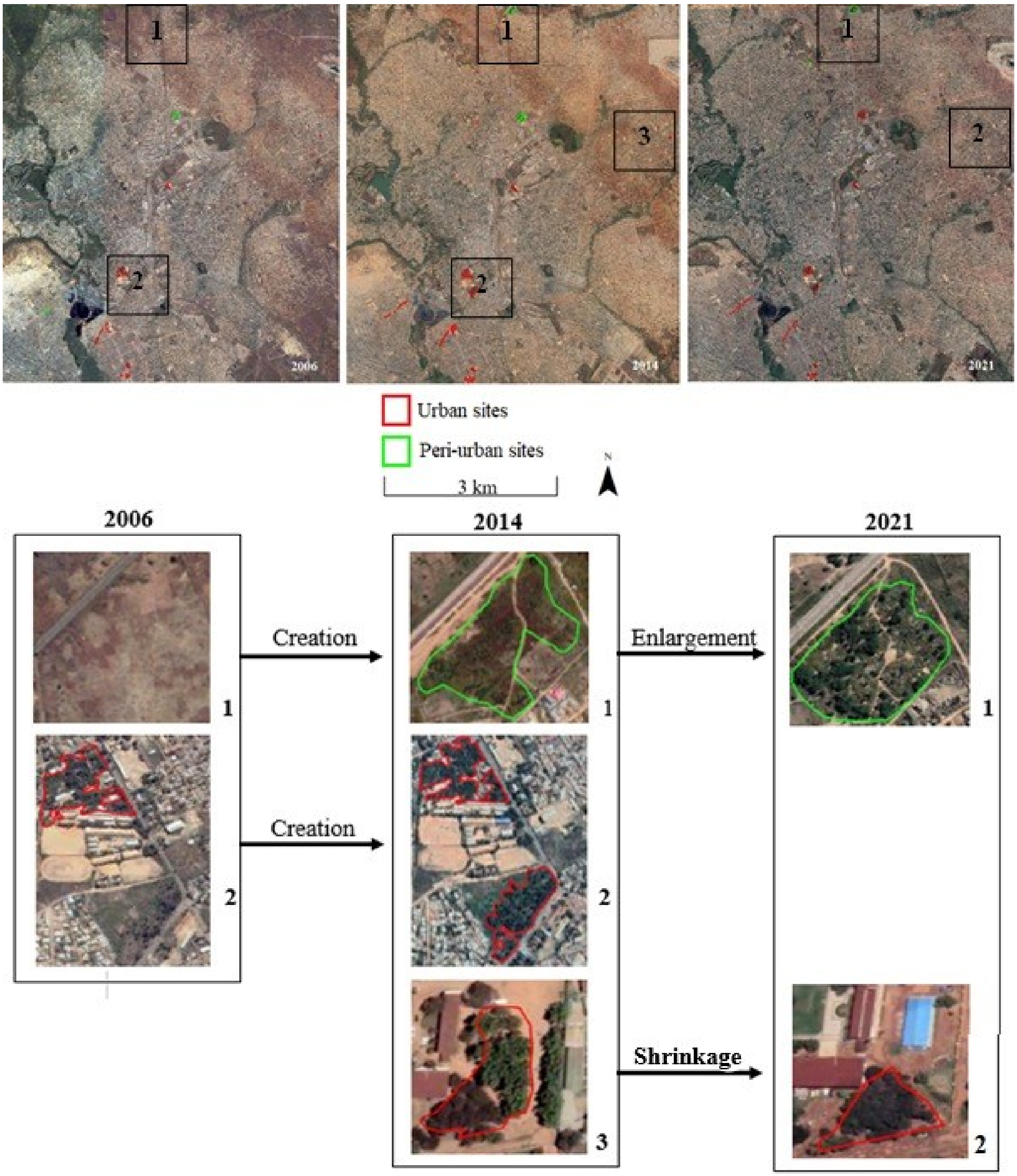

Figure 2. Maps of the evolutionary trends of the area and number of patches of *A. auriculiformis* plantations in the urban and peri-urban zones of the city of Lubumbashi from the digitisation of Google Earth images of 2006, 2014 and 2021.

Table 1. Types of green space covered by *Acacia* plantations in the urban and peri-urban zones of the city of Lubumbashi from the digitization of Google Earth images of 2006, 2014 and 2021. PN: patch number; CA: class area (ha); PZ: peri-urban zone; UZ: urban zone and RC: Rate of change (%).

	Attached green space		Park		Street trees	
	PN	CA (ha)	PN	CA (ha)	PN	CA (ha)
			2006			
PZ	1	1.60	0	0.00	0	0.00
UZ	7	12.33	1	0.14	3	1.21
			2014			

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PZ	2	4.18	1	4.36	0	0.00
UZ	8	18.36	1	0.33	5	2.15
			2021			
PZ	1	0.65	1	5.27	0	0.00
UZ	9	18.21	1	0.14	5	3.62
		2006-2014			**2014-2021**	
RC in PZ		433.75			-30.68	
RC in UZ		52.33			113	

3.2. Flora richness and diversity under the plantation of A. auriculiformis along the urban-rural gradient of Lubumbashi city

The data on floristic spectra revealed a total of 39 species in the plantation of *A. auriculiformis*, with 29 species in urban zone and 10 in peri-urban zone. And slighty higher diversity index values were recorded in urban zone as compared to the peri-urban zone (Table 2). Moreover, Table 3 shows that the proportions of adult trees are higher than those of seedlings in the *A. auriculiformis* plantations in both urban (94.2% against 5.8%) and peri-urban plantations (89.3 % against 10.7%). However, no significant variation ($p>0.05$) were found regarding height and tree diameter in the studied zones of the urban-rural gradient (Table 4).

Table 2. Diversity of trees and shrub in *A. auriculiformis* plantations in urban and peri-urban zones of Lubumbashi city. PZ: peri-urban zone; UZ: urban zone.

Indices	UZ	PZ
Species richness (n=39)	29	20
Genera (n=29)	20	16
Family (15)	11	9
Simpson_1-D	0.76	0.68
Shannon_H	2.34	1.63

Table 3. Proportions of age (adult and seedling) of *A. auriculiformis* trees in plantations of urban and peri-urban areas. PZ: peri-urban zone; UZ: urban zone.

	Proportion of adult (%)	Proportion of seedling (%)
UZ (n=207)	94.2	5.8
PU (n=150)	89.3	10.7

Table 4. Average height and average diameter of *A. auriculiformis* trees in urban and peri-urban plantations in Lubumbashi. PZ: peri-urban zone; UZ: urban zone. ns=p>.05.

	Average height (m)	Average diameter (cm)
UZ (n=104)	10.87±4.09	28.02±14.8
PZ (n=61)	11.03±10.6	30.4±15.7
T	0.11	0.96
p-value	ns	ns

Table 5 shows that 39 species were inventoried in all *A. auriculiformis* plantations in Lubumbashi. *A. auriculiformis* plantations in urban zone revealed 29 species while the plantations of peri-urban zone revealed only 20 species. Naturally, *A. auriculiformis* was the most abundant species in the plantations of urban and peri-urban zones with a proportion of 46.6% and 45.5% respectively while the other species have less than 5%, except L. leucocephala which has 30.6% in the peri-urban zone. Moreover, the relative frequency was 100% for *A. auriculiformis* in all plantations. It is followed by *A. lebbeck*, *A. alba* and *L. leucocephala* with 50% in the plantations of urban zone while the remaining

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species represented 25%. In the *A. auriculiformis* plantations of peri-urban zone, species showed a relative frequency of 50%. Results also showed that 20 species out of 39 species found are exotic (51.3%) and only 19 species are indigenous (48.7%). It should be noted that 18 of the 19 indigenous species inventoried are characteristic of the miombo woodland (94.7%), except *E. guineensis*. Furthermore, our results show that 10 of the 20 exotic species recorded have been reported in the literature as invasive species, namely *Acacia melanoxylon, Acacia heterophylla, Acacia auriculiformis, Acacia mangium, Melia azedarach, Leucaena leucocephala, Callistemon viminalis, Eucalyptus camaldulensis,* and *Eucalyptus globulus*

These species are principally located in peri-urban zone. All species inventoried belong to 15 families including *Anacardiaceae, Apocynaceae, Arecaceae, Ebenaceae, Fabaceae, Kirkiaceae, Lamiaceae, Lauraceae, Meliaceae, Mimosaceae, Moraceae, Myrtaceae, Phyllanthaceae, Pinaceae* and *Rhamnaceae*. In the *A. auriculiformis* plantations of urban zone and peri-urban zone, the Fabaceae family predominated with respectively 37.9% and 50% of species followed by Mimosaceae family.

Table 5. Relative abundance (RA), and relative frequency (RF), species status of origin of species under *Acacia auriculiformis* plantations in urban zone (UZ) and peri-urban zone (PZ) of Lubumbashi city. Ex: exotic species; In: indigenous species. Species preceded by * are characteristic of the miombo woodland. RA is calculated as the ratio of the total number of individuals of a given species to the total number of individuals of all species in the plantations RF is the ratio of the total number of observations of the species to the total number of investigated plantations. + Invasive species according to [32,51–55].

Family	Species	RA UZ (n=223)	RA PZ (n=134)	RF UZ (n=4)	RF PZ (n=2)	Origin status
Anacardiaceae	*Mangifera indica* L.	3.1	1.5	25.0	50.0	Ex
Apocynaceae	**Diplorhynchus condylocarpon* (Muell. Arg.) Pichon	0.0	0.7	0.0	50.0	In
Arecaceae	*Elaeis guineensis* Jacq.	1.3	0.0	25.0	0.0	In
Ebenaceae	**Diospyros discolor* Willd.	0.0	0.7	0.0	50.0	In
Fabaceae	+*Acacia auriculiformis* A. Cunn. ex Benth.	46.6	45.5	100.0	100.0	Ex
Fabaceae	+*Acacia heterophylla* Willd.	4.5	0.0	25.0	0.0	Ex
Fabaceae	+*Acacia mangium* Willd.	2.7	3.0	25.0	50.0	Ex
Fabaceae	+*Acacia melanoxylon* R.Br.	2.2	0.0	25.0	0.0	Ex
Fabaceae	**Baphia bequaertii* De Wild.	0.0	0.7	0.0	50.0	In
Fabaceae	*Bauhinia variegata* L.	1.3	0.0	25.0	0.0	Ex
Fabaceae	**Brachystegia boehmii* Taub.	3.1	0.7	25.0	50.0	In
Fabaceae	**Brachystegia longifolia* Benth.	0.0	0.7	0.0	50.0	In
Fabaceae	**Brachystegia spiciformis* Benth.	1.3	0.7	25.0	50.0	In
Fabaceae	*Ceratonia siliqua* L.	2.7	0.0	25.0	0.0	Ex
Fabaceae	*Delonix regia* (Bojer) Rafin	1.3	0.0	25.0	0.0	Ex
Fabaceae	**Erythrophleum africanum* (Welw. ex Benth.) Harms	0.0	0.7	0.0	50.0	In
Fabaceae	**Isoberlinia angolensis* (Benth.) Hoyle & Brenan	0.0	0.7	0.0	50.0	In
Fabaceae	**Julbernardia paniculata* (Benth.) Troupin.	1.8	0.0	25.0	0.0	In
Fabaceae	**Pterocarpus angolensis* D.C	0.0	0.7	0.0	50.0	In
Fabaceae	*Senna siamea* Lam.	0.4	0.0	25.0	0.0	Ex
Fabaceae	*Tipuana tipu* (Benth.) Kuntze	0.0	0.7	0.0	50.0	Ex
Kirkiaceae	**Kirkia acuminata* Oliv.	0.9	0.0	25.0	0.0	In
Lamiaceae	**Vitex madiensis* Oliv.	0.0	0.7	0.0	50.0	In
Lauraceae	*Persea americana* Mill.	0.9	0.7	25.0	50.0	Ex

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Meliaceae	+*Melia azedarach* L.	0.0	0.7	0.0	50.0	Ex
Mimosaceae	**Albizia adianthifolia* (Schum.) W. F. Wight	1.3	6.7	25.0	50.0	In
Mimosaceae	*Albizia brevifolia* Schinz.	0.4	0.0	25.0	0.0	Ex
Mimosaceae	+*Albizia lebbeck* (L.) Benth.	2.7	30.6	50.0	0.0	Ex
Mimosaceae	+*Leucaena leucocephala* (Lam.) De Wit.	7.2	2.2	50.0	50.0	Ex
Moraceae	**Ficus benjamina* L.	0.4	0.0	25.0	0.0	In
Moraceae	**Ficus sp*	0.9	0.0	25.0	0.0	In
Moraceae	**Ficus sycomorus* L.	1.3	0.7	25.0	50.0	In
Myrtaceae	+*Callistemon viminalis* (Sol. ex Gaertn.) G.Don	0.9	0.0	25.0	0.0	Ex
Myrtaceae	+*Eucalyptus camaldulensis* Dehnh.	2.2	0.0	25.0	0.0	Ex
Myrtaceae	+*Eucalyptus globulus* Labill.	0.9	0.0	25.0	0.0	Ex
Phyllanthaceae	**Pseudolachnostylis maprouneifolia* Pax.	3.1	0.0	25.0	0.0	In
Pinaceae	*Abies alba* Mill.	2.2	0.0	50.0	0.0	Ex
Pinaceae	*Pinus pinea* L.	0.4	0.0	25.0	0.0	Ex
Rhamnaceae	**Ziziphus mucronata* Willd.	1.3	0.0	25.0	0.0	In

4. Discussion

4.1. Spatial pattern dynamics of A. auriculiformis and impact on phytodiversity

In Lubumbashi city, a thorough diagnosis of governance management has revealed an unclear role attribution among different services in Lubumbashi city (municipality, province, state / division of housing, urban planning, land registry, roads / technical concessionaires), resulting in competence conflicts [61]. Moreover, a systematic lack of public budgeting has been noted, particularly for equipment costs, maintenance costs, especially regarding public green spaces. On the overall scale of the city, unplanned urbanisation is accompanied by a dramatic regression of green spaces, through the densification of buildings and peri-urbanisation, where new housing estates are created [19]. Ref. [22] reported that the built-up area tripled from 94.14 km2 to 291.31 km2 between 1989 and 2014 in the city of Lubumbashi, while green areas lost their space from 575.27 km² to 484.64 km² during the same period, with the most concerned being the cover of public green spaces. Further, Ref. [61] concluded that there is virtually no provision for green spaces in most neighborhoods, with green spaces systematically destroyed to make way for constructions, notably fuel stations, mostly for those located at the cross-roads. This situation is exacerbated by the policy of land speculation, which means that even vacant, untended green spaces have a high monetary value when they are divided up and sold as plots. In fact, the populations in search of space to erect buildings care little about the sustainability of green spaces [22], probably due to the lack of knowledge of the various functions performed by them. To get around this bleak situation, in certain sectors of life, the population has begun to organize what the 'bankrupt' state cannot do, through solidarity networks and neighborhood, professional and even religious associations. It is in this context that *A. auriculiformis* plantations have been created to compensate for the loss of green spaces. As these plantations are often located in private concessions, they enjoy security of tenure and are thus protected from urbanisation pressure. Ref. [62] reported that formal green spaces are usually well protected. On the other hand, public green spaces, especially parks, mostly belonging to the state, are easily converted into other land cover/uses because they are not legally secured [63].

Visual analysis of change maps in the study areas showed an expansion of *A. auriculiformis* plantations, most noticeable in the urban area between 2006 and 2021, probably due to the human preferences for ornamental purposes. Indeed, the urban flora constitutes a subset of the species pool after passing through several filters including strong influences of human preferences [64]. Due to its rapid growth, *A. auriculiformis* is used to establish plantations, as reported by Ref. [65] that in the absence of human disturbance, it takes nearly 40 years for native miombo species to reach the adult stage. Nevertheless, as compared to the peri-urban zone, the number of *A. auriculiformis* patches in urban zone is reported to be higher. Due to limited budgets, the public services attention is mostly drown in urban zone to increase their visibility [66], which increased the number of parks and street trees planted with *A. auriculiformis*.

On the other hand, most of the public service buildings around which *A. auriculiformis* plantations are located occurred in urban zones [63]. The almost absence of public infrastructure in peri-urban areas has already been reported in Central Africa [66]. The increase in the patch number of *A. auriculiformis* plantations is accompanied by an increase in their area. This is not only due to the growth of the tree crown over time, but also to the densification of the plantation as the consequence of the development of new individuals from seeds. Refs. [67,68] hypothesized that specific seed and seedling viability depends on the distance to the parent plant or the density of young individuals. This mortality, due to pathogens and predators, modifies the initial distribution of seeds and leads to maximum recruitment at an intermediate distance from the parent plant [69]. It should be noted, however, that land security also contributes to the easy expansion of *A. auriculiformis* individuals. In this context, the land insecurity could be a threat to the ecological restoration project within the city, particularly in the peri-urban which are dynamic zones that are characterized by rapid change because of an extension of the city and associated infrastructures [70].

Although the regression of green space coverage was already revealed in Lubumbashi city [22], our results showed an increase in the acreage of introduced patches of green space planted with *A. auriculiformis*, which is in accordance with the theory of patch origin [71]. Although progress is being made, it still appears that this landscape restoration with *A. auriculiformis* will not succeed to compensate for the loss of natural patches. This is in line with the findings of Ref. [72], since exotic and potentially invasive species are used for this purpose, resulting in the ecosystems damage. Moreover, there is no longer sufficient space to implement large-scale reforestation programmes in urban zone and peri-urban zone of Lubumbashi city [61]. There are more plant species accompanying *A. auriculiformis* in the urban zone than in the peri-urban zone, particularly exotic species, leading to high plant diversity. 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 [19]. However, older plantations in the urban zone would explain this, as the sites planted with *A. auriculiformis* have been recently developed in the peri-urban zone. This corroborates results of Ref. [73] that revealed much higher species richness for the ground flora in the 28-yr-old forest comparatively to a 1-yr-old field in the southern Appalachian watershed. In addition, the environmental conditions specific to the urban area (high temperatures, low water availability) constitute a filter that would have eliminated species not adapted to these conditions [74]. Indeed, urbanization mostly exclude species (native and non-native) with limited dispersal capacity and select species capable to long-distance dispersal [64]. Since most of the native tree felling left the stumps, it appears that the presence of some miombo woodland species under *A. auriculiformis* plantations could be explained by stump regeneration, especially in peri-urban zone. Indeed, a few years later they would have regenerated from the stumps. Several authors have shown that the stumps of miombo woodland species regenerate when there is no disturbance [75,76].

A. auriculiformis has a high N2-fixing potential, given its excellent nodulation observed in many soils [77]. The species is known for its high litter content, which can be used for soil fertility enhancement, and its prunings have also been used in alley cropping as a biofertiliser [78]. On the other hand, it is known to be invasive [79], leaving the possibility for other species, more often invasives, to establish. This was confirmed by our results which indicate that half of the identified alien species are invasive and echoed the hypothesis of ecological facilitation [80]. The results of the present study show an expansion of *A. auriculiformis* plantations in Lubumbashi. This is good news on the one hand, given the capacity of this species to improve edaphic and carbon storage factors.

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The ability of *A. auriculiformis* fallows to improve soil fertility has been demonstrated in the Bateke Plateau (D.R. Congo), notably through significant increases in organic carbon content, total nitrogen content, cation exchange capacity and sum of base cations, OM content and soil pH under *A. auriculiformis* plantations [81]. Similarly, Ref. [82] showed higher phosphorus levels under *A. auriculiformis* than in natural forests; and Ref. [83] showed a high carbon stock in A. auriculiformis plantations in forests in southern Benin. All these are important indications in the current context of the pronounced regression of the miombo woodland in the Lubumbashi lowlands [19].

However, the expansion of *A. auriculiformis* plantations could determine a progressive loss of floristic identity if the management of these plantations is not assured, since this species is classified as potentially invasive [84]. Already, Ref. [85] reported a dominance of more than 85% of the soil cover by *A. auriculiformis* at the expense of other species in the classified forests of Ouèdo in Benin. The results of the floristic inventories carried out in this study show that native species are established in *A. auriculiformis* plantations. However, the ecological impacts of *A. auriculiformis* plantations are still unclear in the Lubumbashi region and in DR Congo. A report on the potential risks of *A. auriculiformis* plantations in the Bateke plateau was prepared by [79]. Based on preliminary findings, the most important potential risks associated with non-native *Acacia* plantations were invasion of the species, depletion of groundwater reserves and reduced soil productivity.

The difference in plant diversity under *A. auriculiformis* plantations also results from the fact that urban landscapes have different species composition of introduced species in accordance with landscape-divergence hypothesis. In fact, fragments within the same landscape tend to converge in species composition, whereas those in different landscapes diverge in composition [86]. Accordingly, that the highest plant diversity noted in urban zone could be due to local-level landscaping aesthetics and socioeconomic characteristics, acting as dominant bottom-up anthropogenic forces [87]. The propagation of similar plants or landscape elements in the neighborhoods is indeed,due to actions of residents that copy, adapt, exchange plants and suggest ideas, the phenomenon referred as "neighbor mimicry effect" [88].

Albizia lebeck is one of the most abundant species accompanying *A. auriculiformis*. The choice of this species the vegetation of disturbed areas is due to its adaptability, rapid growth as well as its high capacity to produce seeds to generate other trees [89,90]. However, these characteristics can increase the invasiveness of the species. Furthermore, some introduced species in cities have high invasiveness [14], due to their prolific seed production, widely dispersed seeds, nitrogen-rich and warm habitats preference, making them able to establish and thrive along edges [91]. However, *A. auriculiformis* trees are larger in size and stem diameter in the peri-urban zone due to the lower plant diversity which limits interspecific competition [92].

4.2. Implications for (peri-)urban landscape ecological restoration

It has been reported that more exotic species abundant under *A. auriculiformis* plantations and like L. leucocephala are invasive. It can be noted that there is an ecological facilitation potentially invasive *A. auriculiformis* and other invasive species like *L. leucocephala*. Also, urbanized areas are subject to a lot of disturbance, which is a factor that facilitates the introduction and establishment of alien species [74]. Disturbances, whether natural or anthropogenic, have an impact on population and community structures [93]. They play an important role in maintaining biodiversity because they are a source of heterogeneity [94], in that they create or release ecological niches [95]. Our results highlight the abundance of species belonging to the Fabaceae family, which have the ability to capture atmospheric nitrogen, thus increasing resource availability. The latter aspect favours the establishment of new plant species on a site [56]. It has long been established that ecological restoration assessment is based on the original state as a reference [96], while naturally, the reference state has never been reached as demonstrated by number of case studies [97], explaining why most researchers use the concept of rehabilitation rather than restoration which implies a return to the initial ecosystem, both in terms of structure and ecological functionality [98]. The recovering of the initial state of ecosystems is hampered by many factors, including the effect of alien invasive plants, which negatively influences their resilience and therefore makes impossible the limit ecological restoration [97]. Even the biodiversity restoration approach does not match with the rehabilitation of ecosystem [99], simply because the introduction of exotic species reduces the local plant diversity, although exotic species have some advantages such as combatting erosion [97]. This was also emphasized by [100], working on exotic species of the genera *Eucalyptus, Pinus* and *Callitris* at the edge of the Bururi reserve and reported that these exotic species strongly contributed to the protection of the soil against erosion, but they unfortunately cause the disappearance of almost all local species in the reforested areas, implying that the choice of species during the rehabilitation of a degraded ecosystem should be meticulous because their assemblage considerably influences the functioning of the rehabilitated ecosystem [99].

On the other hand, invasive alien species are better adapted to colonize the diversity of fragmented habitats in (peri-) urban areas than native species that do not adapt to anthropogenic disturbances [101], with the risk of further degrading ecosystems. It should be noted that urban flora is a subset of the species pool after passing through 4 filters, namely habitat transformation, habitat fragmentation, urban environmental conditions, and human preferences [64]. Under the action of the above-mentioned filters, some species benefit from urban conditions while others, native species in our case, are negatively affected and gradually disappear depending on the intensity of these filters. Another problem is the rapid expansion of invasive species, favored by the lightness of their seeds, which are massively produced [56]. However, the peri-urban area of Lubumbashi where *A. auriculiformis* plantations are present constitutes an edge between the urban and rural areas [102]. It is therefore possible that the species escapes from the peri-urban area and colonizes the adjacent rural area, where the vegetation still retains a certain level of naturalness [23]. This is not without socio-environmental problems. In rural areas, invasive species also harm livelihoods and increase vulnerability through encroaching on land and reducing mobility or access. They can also decrease the supply of natural resources used by households and reduce agricultural production (livestock and/or crops), thus result in losses of income and increased vulnerability. Furthermore, some invasive species were seen to have negative implications for human health and safety and reduce the cultural value of landscapes [103]. Despite its various advantages (creation of green space plots, ornamentation and shade, production of firewood etc.), the sustainability of *A. auriculiformis* plantation in Lubumbashi city is uncertain, as it causes several environmental damages. Apart from its major contribution to the loss of floristic identity by promoting the introduction of other invasive species, *A. auriculiformis* increases the level of soil acidity, as demonstrated the Batéké plateau in Kinshasa [104]. Consequently, the ecological restoration process should avoid exotic species, some of which are potentially invasive and may further degrade ecosystems. This process will favour native species like *Brachystegia spiciformis, Combretum collinum* and *Pterocarpus tinctorius* which are the most productive potential candidates for restoration, based [105].

5. Conclusion

The present study is a contribution to the understanding of the impact of the ecological restoration project based on *A. auriculiformis* plantations through a spatial analysis and floristic inventory, along the urban-rural gradient of Lubumbashi city. Results reveal that regardless of the type of plantation or the zone of the urban-rural gradient, *A. auriculiformis* patch number increased, with its acreage doubling in 15 years, as result of restoration of degraded landscape during urbanization process. *A. auriculiformis* plantations were dominated by Fabaceae and exotic species with a higher number in urban zone compared to peri-urban zone. 19 native species, among which 18 trees species characteristic of the miombo woodland were identified. The plantations were more diversified in urban zone than the peri-urban. Due to rapid growth and expansion, our results showed that mature *Acacia* trees dominate the plantations. Overall, it is apparent that the *A. auriculiformis* project has reached its aim, allowing extension of green areas in some cases, while attracting both exotic species and native species to the miombo woodland. However, the sustainability of this activity appears uncertain since a considerable number of attracted species are found to be invasive alien trees that pose a threat to biodiversity conservation. The approach adopted in this study could be the starting point for the formulation of policies and technical tools regarding ecological restoration process in the city of Lubumbashi.

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