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REVIEW

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Lomami Buffer Zone (DRC): Forest composition, structure, and the sustainability of its use by local communities

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Abstract

The recently created Lomami National Park has an extensive Buffer Zone where local communities are allowed to use forest products sustainably. However, the management of this Buffer Zone is hampered by inadequate understanding of the floristic composition and the impacts of harvesting certain plant products. To fill in this data gap, we established and sampled 30 vegetation plots of 40 × 40 m, and investigated the population structure of 11 useful tree species preferred by local communities. We found that the Buffer Zone is mostly composed of mixed-species undisturbed old growth forest. It contains nine tree species of international conservation concern (listed in the IUCN Red list and/or apart from the Red list, *Gibourtia demeusei*, not been assessed by IUCN Red list, is listed in CITES Appendix II since January 2017; UNEP-WCMC, *Review of selected Dalbergia species and Guibourtia demeusei*, UNEP-WCMC, 2017). The floristic diversity of the Buffer Zone, which requires further investigation as some species remained unidentified. Most preferred tree species (including *Garcinia kola* and *Milicia excelsa*) are abundant and showed a reverse-J size distribution, indicating a relatively stable population structure. For these species, current levels of exploitation seem sustainable. Further research is needed for two nonabundant species of conservation concern (*Autranella congolensis* and *Michelsonia microphylla*). Although timber/firewood commercial harvesting is currently limited in the study area, the management plan of the Buffer Zone should consider these risks given increasing commercial hunting. Surveys and permanent plots provide essential information to guide the management of newly formed protected areas.

Abstract in French is available with online material.

KEYWORDS
extraction, floristic composition, forest structure, population structure, tropical forest

1 | INTRODUCTION

Tropical forests provide many benefits to humans, including material products (timber, water, food, medicine, raw materials, etc.), and services such as shelter, natural hazards prevention, carbon sequestration, and climate regulation (FAO, 2010). Nontimber forest products (NTFPs, food, medicine, and raw materials) are often of key importance to local communities, as they contribute to both food security and livelihoods (Sunderlin et al., 2005). There is an increasing interest in NTFPs, as it is argued that they can help promote biodiversity conservation and sustainable development (De Jong et al., 2000; Falconer, 1996).

However, NTFP harvesting can also have a negative impact on the survival, growth, and reproduction of the species targeted (Gaoue & Ticktin, 2007; Ticktin, 2004). The removal of wood, roots, whole plants, or bark (when ring debarking) usually leads to the death of an individual (Cunningham, 1993). The harvest of leaves, fruits, or seeds is often less destructive, although intensive harvesting of leaves can affect fruiting and intensive harvesting of fruits or seeds can affect plant regeneration (Gaoue & Ticktin, 2007). The vegetation type from which wild plants are collected, their abundance, and species' growth rates are other determinants of extraction sustainability: e.g., slow growing, old growth forest species that occur in low densities are particularly vulnerable to overharvesting (Peters, 1996). For many tropical tree species, the ecological impacts of NTFPs harvesting are unknown. This lack of knowledge hampers the identification of sustainable extraction levels (Ticktin, 2004). Sustainable harvesting of NTFP is essential not only for the conservation of the plant species targeted but also for the livelihoods of the peoples who depend on them (Ticktin, 2004).

Population structure assessments are considered cost-effective means for providing useful data on the impacts of plant harvesting and other disturbances, helping identify effective management strategies (Botha et al., 2002). Size class distribution (SCDs) slopes are often used as indicators of population trends. In general, negative SCD slopes indicate good recruitment, flat slopes indicate equal numbers of individuals in small and large size classes, and positive slopes indicate poor recruitment (Obiri et al., 2002). Flat or positive slopes may indicate several issues, such as: (i) a species needs a particular set of environmental conditions for reproduction (e.g., *Prunus africana*, Cuni-Sanchez et al., 2018), (ii) previously established cohorts have been removed (e.g., timber extraction, *Isoberlinia doka*, Jurisch et al., 2012), or (iii) there has been little recruitment for a number of years (e.g., due to intensive fruit harvesting, *Detarium senegalense*, Dangbo et al., 2019).

Apart from the plant part being harvested, and the harvesting techniques used, species' intrinsic characteristics are also of importance: e.g., if a species resprouts, it might be less affected by leaf harvesting (*Xymalos monospora*, Cuni-Sanchez et al., 2018). Similarly, if a species has clonal reproduction, the effects of intensive fruit harvesting might not be observed on the SCD (e.g., *Pentadesma butyracea*, Gaoue et al., 2017). Species' life history is also important: for very long-lived slow growing tropical trees, such as *Baillonella toxisperma*, which can reach 5 m diameter (Louppe, 2005), episodic recruitment might be enough for sustaining the population. Land use is also known to affect SCD and population structures, especially in savannah ecosystems, where fire and grazing play an important role in tree species' regeneration (Jurisch et al., 2012; Ouedrago et al., 2015). For many tropical tree species, size (e.g., diameter) and age might not be correlated in a straightforward manner, especially in small individuals exposed to limited light persisting beneath a closed canopy (see Hubau et al., 2019). Therefore, population dynamics from SCD must be inferred cautiously, preferably by using a large number of stems of different sizes (Young et al., 2017).

In July 2016, a new park was created in the Democratic Republic of the Congo (thereafter DRC): the Lomami National Park. This park, unlike its predecessors, was designed with a large Buffer Zone in which local communities were allowed to carry out certain extractive activities to satisfy their own needs (Mushagalusa, 2016). A management plan for the Buffer Zone was to be designed and implemented. But the design of this management plan was hampered by lack of data on floristic composition, timber, and NTFP harvesting and their impacts on the species targeted. The park provides habitat for threatened flagship species such as the forest elephant *Loxodonta africana cyclotis* (VU), the bonobo *Pan paniscus* (EN), the okapi *Okapia johnstoni* (EN), the Congo peafowl *Afropavo congensis* (VU), the recently discovered Dryas monkey *Cercopithecus dryas* (EN, only previously known from Salonga National Park), and the newly described Lesula monkey *Cercopithecus lomamiensis* (VU, endemic to this park) (ICCN, 2012) (EN: endangered, VU: vulnerable, according to the IUCN Red List, www.iucnredlist.org).

A recent ethnobotanical survey in Lomami area showed that six ethnic groups (including farmers and hunter-gatherers) used over 89 tree species for firewood, construction, medicine, and edible fruits,

Highlights

- Lomami Buffer Zone hosts abundant mixed-species undisturbed old growth forest.
- Nine tree species of international conservation concern are found in the Buffer Zone.
- Most preferred species are sustainably used: they are abundant and continuously recruiting.
- Further research is needed for *Autranella congolensis* and *Michelsonia microphylla*.

and some of these species were preferred for the same usage by most ethnic groups (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021). Species which are preferred by more people (e.g., more ethnic groups), and for more uses, are more likely to become overexploited. Also, four of the species mentioned were of conservation concern according to the IUCN Red List: *Autranella congolensis* (CR, critically endangered), *Garcinia kola* (VU), *Michelsonia microphylla* (VU), and *Milicia excelsa* (NT, near threatened) (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021).

To help inform the management plan of the Buffer Zone, the objectives of this study were to: (1) investigate forest composition and structure, (2) determine if timber and NTFP harvesting negatively affected the populations of local communities' preferred species; and (3) discuss the implications of the findings for forest management. Given the large number of useful tree species and taboos reported by this recent ethnobotanical survey (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021), and poor road infrastructure in the region which limits commercial extraction of forest products (Batumike et al., 2020), we hypothesized that (i) the Buffer Zone is mostly composed of mixed-species old growth forest (e.g., old fallows and secondary forests would be rare). We also hypothesized that (ii) type of usage would have an impact on species' population structures: e.g., harvesting for construction would be reflected with few individuals in large diameter classes, harvesting firewood (with machete) would be reflected with few individuals in small diameter classes, and fruit harvesting would also affect small individuals (due to lack of regeneration if most seeds are being collected). Therefore, type of usage would also contribute to determining if current subsistence use by local communities is sustainable.

2 | METHODS

2.1 | Study area

Lomami National Park (NP) has a core zone of about 9000 km^2 and a Buffer Zone of 22,000 km^2 (Bya'Ombe, 2016, see Figure 1). The core zone of the park is covered by savannah, swamp forests, and lowland tropical forests, some of the latter being monodominant stands of Limbali (*Gilbertiodendron dewevrei*). The climate is equatorial, with a mean annual rainfall of 1600 mm and mean monthly temperature of 23–26°C (ICCN, 2012). The dry season (June–July) lasts <2 months. Hunting, gold mining (through panning), or the collection of timber and NTFPs is not allowed in the park's core zone, but these activities (except mining) are allowed in the Buffer Zone. The main inhabitants of the region are farmers (mostly Kusu, Kuti, Ngengele, Silwamba, and Tetela) practicing small-scale slash-and-burn subsistence agriculture (cassava, maize, and rice), hunting and fishing, and Mbote (Pygmy) hunter-gatherers. All villages located near the park Buffer Zone have no access to electricity, running water, or mobile phone networks. There are few primary schools and health centers in the region (often >20 km apart). Roads are unpaved and most villages are only accessible by motorbike, some being inaccessible during most of the rainy season. At the moment there is no commercial harvesting of timber or firewood in the study area due to limited road infrastructure (Batumike et al., 2020). All ethnic groups (farmers and hunter-gatherers) mostly use tree species from the Buffer Zone for firewood, construction, medicine, and edible fruits (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021) as agroforestry is not practiced in the region. When clearing land for farming, farmers first burn a small patch of forest and then cut the standing dead trees with manual tools; they do not spare multipurpose trees providing NTFPs as these are perceived as abundant in the nearby forest (Figure 2).

2.2 | Data collection

Thirty vegetation plots of 40 × 40 m were established in the southern part of the Buffer Zone in October–November 2019 (Figure 1). Ten villages were used as access points and three plots were randomly sampled in closed canopy forest near each village. Closed canopy forests could potentially include old fallows, secondary forests, and primary forests, but not young fallows as these do not have a closed canopy. As we discuss below, all plots we sampled may be classified as old growth forests, as secondary and old fallows do not seem to be abundant in the Buffer Zone (probably due to low population density and small farm size when land clearing with fire and machete). Plots were located at least 200 m from each other.

In each plot, tree diameter at 1.3 m along the stem from the ground (or above buttresses if present) of each tree ≥10 cm diameter was recorded following RAINFOR protocols (www.rainfor.org), and stems were identified to species in the field by a botanist (or a sample collected if unknown species by the botanist). Samples collected were taken to the Herbarium of Yangambi for identification. Nomenclature of plant families follows the Angiosperm Phylogeny Groups IV (APG IV, 2016) and species names are according to the 2016 African Plants Database (version 3.4.0). Species conservation status was checked against the IUCN Red List (www.iucnredlist.org). We obtained permission from park managers (ICCN, Kindu Office) to carry out this research in the park's Buffer Zone. As the Buffer Zone is also managed by local communities under customary law, we also asked for permission from local authorities at each village we sampled forest from.

2.3 | Data analysis

In order to investigate forest composition, we computed frequency of occurrence for each species and morphospecies recorded (% of plots sampled) and relative abundance at the plot level (% stems in the plot). For forest structure, we calculated stem density, density of large trees (≥70 cm diameter), basal area, and aboveground biomass (AGB). The Chave et al. (2014) equation, shown below, including tree

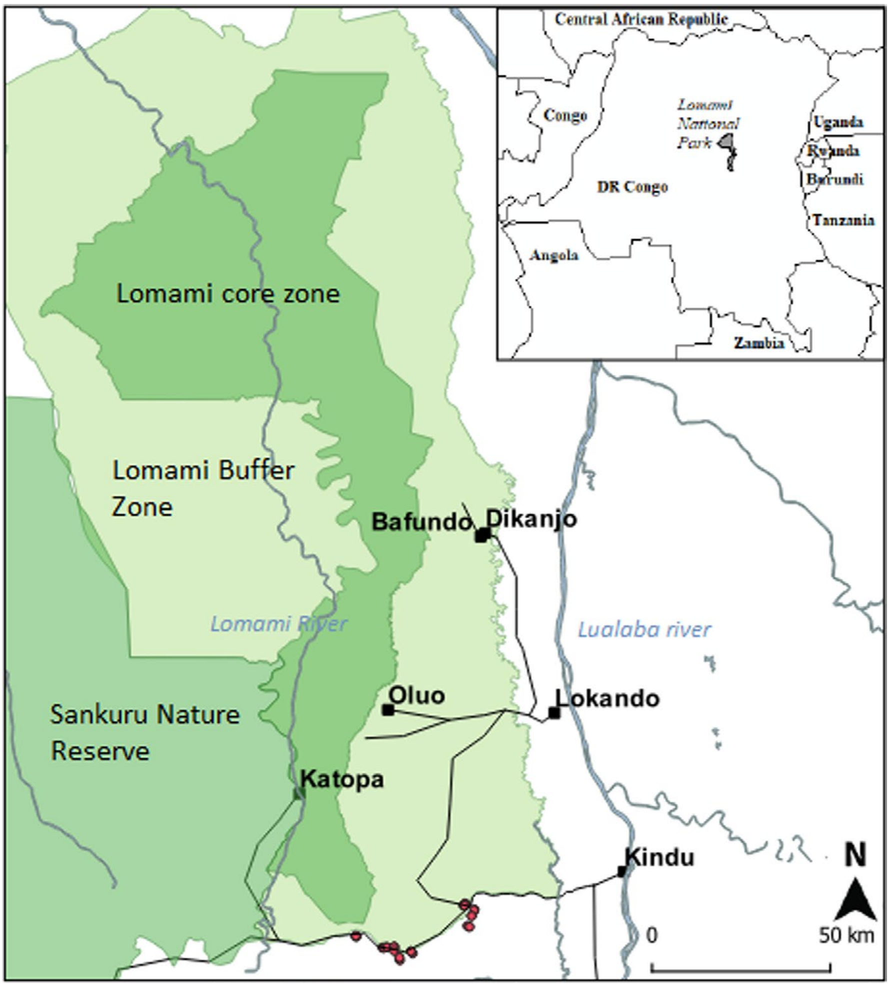

FIGURE 1 Study area, major towns, roads, rivers, and plots sampled (red dots). Some plots are located nearby and appear as one point in the map

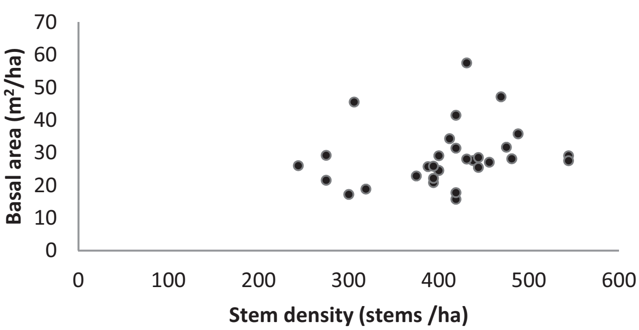

FIGURE 2 Stem density and basal area of the plots sampled in the Buffer Zone ($n = 30$ plots). Stem density and basal area are not significantly correlated: Pearson correlation $r = .219$, $p = .24$

diameter (D), wood mass density (WMD), and tree height (H), was used to estimate the AGB of each tree in the plot.

$$\mathrm{AGB} = 0.0673 \times \left(\mathrm{WMD} \times D^2 \times H\right)^{0.976}$$

Using the best taxonomic match (species level, genus level, and family level in this order of preference if available), WMD of each stem was extracted from the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009) following Lewis et al. (2013). As tree height (H) was not sampled during the field campaign, we estimated it from tree diameter (D) through an allometric model of the Weibull form (Bailey, 1980; Feldpausch et al., 2012), as follows:

$$\mathrm{Height} = a \times \left(1 - \exp\left(-b \times D^c\right)\right)$$

To determine the parameters a, b, and c, we created a local height–diameter allometric equation for Lomami (as local height–diameter models are preferred, see Imani et al., 2017), using 100 tree height (H) and tree diameter (D) measurements made in two permanent plots established in the southern part of the parks' core zone (covering different species and stem diameters, unpublished data). These heights were measured using a handheld laser Nikon Forestry Pro. For Lomami, $a = 65.456$, $b = 0.05$, and $c = 0.559$.

With regard to preferred species used by people, we investigated species' density (ind/ha) and population structure, as population structure assessments are known to be cost-effective means of providing useful data on the impact of harvesting and other disturbances, contributing to the development of effective management strategies (Botha et al., 2002). Among the preferred tree species for food, medicine, firewood, and construction mentioned by local communities of six ethnic groups (see Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021), we selected the 11 species mentioned most often by most ethnic groups—excluding species found only in young fallows (*Synsepalum stipulatum*). To allow for visual comparisons of population structure, size class distributions (SCDs) were constructed and displayed graphically. Following Young et al. (2017), size class distribution histograms were classified as: (i) continuous recruitment (CR, reverse-J shape), (ii) episodic recruitment with a recent pulse of recruitment (ERR, different from reverse-J shape, but individuals with <20 cm dbh); and (iii) episodic recruitment with no recent pulse (ERNR, no individuals with <20 cm dbh). SCD slope was also used as indicators of population trends. A least squares linear regression was performed on the data of the SCD, with size class midpoint (ln transformed) as the independent variable and the average number of individuals per size class (ln (Ni +1)) as the dependent variable (Condit et al., 1998). In general, negative SCD slopes indicate good recruitment, flat slopes indicate equal numbers of individuals in small and large size classes, and positive slopes indicate poor recruitment (Obiri et al., 2002). IBM SPSS Statistics v25 was used for all statistical analyses.

3 | RESULTS

3.1 | Forest composition & structure

A total of 1951 trees (≥10 cm at 1.3-m-diameter breast height) were recorded across the 30 plots sampled. These belonged to 35 families, 96 genera, and 114 species. Ten individuals were identified to genus level and 74 individuals (3.7% of the total, corresponding to 42 morphospecies) could not be identified due to the poor quality of the samples collected.

Fifteen species occurred in half of the plots, representing up to 25% of the stems at the plot level (Table 1). The most frequently occurring species were as follows: *Strombosia pustulata*, *S. suaveolens*...

Seven species recorded are listed in the IUCN Red List: *A. congolensis* (CR), *Entandrophragma angolense* (VU), *G. kola* (VU), *M. excelsa* (NT), *Pterygota bequaertii* (VU), *Leplaea cedrata* (VU), and *Pradosia spinosa* (NT) (CR: critically endangered, VU: vulnerable, and NT: near threatened). *P. spinosa* has a small distribution and is threatened by habitat degradation while the other species have high value timber. Another species found in this park which is of conservation concern—but has not been assessed by the IUCN Red list yet—is *Guibourtia demeusei*, listed in CITES Appendix II on January 2017 (UNEP-WCMC, 2017). The frequency of occurrence of these red-listed species ranged from 3% to 20% of the plots, and from 1% to 26% of the stems (Table 1). The most frequent and abundant was *G. demeusei*, which is known to dominate seasonally flooded forests in parts of the Congo Basin (e.g., Ifo et al., 2018).

With regard to forest structure in the Buffer Zone, mean values for all plots (±standard deviation) were as follows: for stem density 406.6 ± 74 ind/ha, for basal area 28.8 ± 9.2 m^2/ha, for stem density of large stems (≥70 cm diameter) 12.2 ± 11.3 ind/ha, and for AGB 279.1 ± 114.1 Mg/ha. We found no significant correlation between stem density and basal area (Pearson correlation $r = .219$, $p = .24$).

TABLE 1 Frequency of occurrence (% of plots sampled) and maximum relative abundance at the plot level (% stems in the plot) for the most frequent species, and those of conservation concern

Species	Frequency occurrence (% plots)	Max abundance (% stems)
Most frequently occurring		
Strombosia pustulata	83.3	31.3
Santiria trimera	76.7	17.1
Baphia sp.	73.3	19.7
Strombosia scheffleri	66.7	30.4
Staudtia kamerunensis	63.3	6.2
Hymenocardia ulmoides	63.3	7.8
Voacanga bracteata	60.0	11.4
Funtumia africana	60.0	13.4
Uapaca sp.	56.7	15.3
Garcinia kola (VU)	56.7	11.2
Carapa procera	56.7	25.3
Pycnanthus marchalianus	53.3	4
Pentaclethra macrophylla	53.3	9.1
Ongokea gore	53.3	5.6
Eriocoelum microspermum	50.0	10.4
Species of conservation concern		
Milicia excelsa (NT)	20.0	4.4
Guibourtia demeusei[a]	16.7	26.5
Pterygota bequaertii (VU)	10.0	2.1
Leplaea cedrata (VU)	10.0	2.6
Autranella congolensis (CR)	10.0	2.8
Pradosia spinosa (NT)	3.3	1.4
Entandrophragma angolese (VU)	3.3	1.4

Abbreviations: CR, critically endangered; NT, near threatened; VU, vulnerable.

[a]Refers to the species listed in CITES Appendix II.

The four plots which had pioneer or mango trees had values of stem density (444, 444, 419, and 469 ind/ha) and basal area (25.5, 28.5, 31.4, and 47.2 m^2/ha) similar to plots without, suggesting that these plots were disturbed by humans relatively long ago. It is also possible that elephants had dispersed mango trees and that pioneer species (*M. cecropioides* and *Macaranga* spp.) were colonizing a large canopy gap caused by natural factors (e.g., lightning). Overall, considering species' composition and forest structure, all plots sampled might be considered old growth forest (see Appendix for plot-level data).

3.2 | Population dynamics of preferred trees

Eight of eleven preferred species studied occurred in over 15% of the plots sampled, at variable densities (Table 2). These eight species (except one) showed a pattern of continuous recruitment, that is, a size–frequency distribution with a reverse-J shape (Figure 3). Four of these species displayed negative slopes which were significant (Table 2). *Garcinia kola* was only found in 10% of the plots, but it was locally abundant, and it showed a pattern of continuous recruitment (Table 2, Figure 3). Two species (*Alstonia boonei* and *A. congolensis*) were found in low numbers (<5 individuals) and we could not investigate their population structure.

Regarding the effects of type of usage on species' population structures, for firewood (*Symphonia globulifera*, *Xylopia aethioipica*, *G. dewevrei*, *Piptadeniastrum africanum*, and *Pycnanthus marchalianus*) and fruit (*G. kola*, *Chrysophyllum lacourtianum*, and *Annonidium mannii*) species, we expected few individuals in small diameter classes, but this was not what we observed (see Figure 3). For construction species (*M. excelsa*, *G. dewevrei*, *X. aethioipica*, and *A. mannii*), we expected few individuals in large classes, but this was only observed for the latter two species (Figure 3). Notably, "large diameter" should be contextualized: the maximum bole diameters of these species, which are 250, 200, 75, and 80 cm, respectively (see Table 2). This suggests that even *M. excelsa* and *G. dewevrei* could have shown even more individuals in the >80 cm class. However, we sampled few individuals (see Table 2).

4 | DISCUSSION

4.1 | Forest composition & structure

Lomami Buffer Zone is dominated by old growth undisturbed forest. Only 4 of the 30 plots sampled contained cultivated or pioneer species. Other protected areas in DRC have considerable amounts of disturbed or secondary forests: e.g., Salonga NP (secondary forests are dominated by *Oncoba welwitschii*, *P. bequaertii* and *Dialium pachyphyllum*, Makana et al., 2008), Ituri Forest (secondary forests are dominated by *M. cecropioides*, *Celtis* spp. and *Khaya anthoteca*, Makana & Thomas, 2006), or Yoko Forest Reserve (*M. cecropioides* can be found at 3 ind/ha, Vlemunckx et al., 2015).

Contrary to some parts of the core zone of the park, we did not find Limbali (*G. dewevrei*) monodominant stands. The old growth forests of the southern part of Lomami Buffer Zone are mixed-species forests, with abundant *Strombosia* spp., *S. trimera*, *S. kamerunensis*, and *Baphia* sp. The latter two species are also among the most abundant in Yangambi Biosphere Reserve (Kearsley et al., 2013, 2017) and Salonga NP (Makana et al., 2008). Remarkably, *Scorodophleus zenkeri*, *D. pachyphyllum*, *Petersianthus macrocarpus*, *Greenwayodendron sauveolens*, and *Anondium mannii*, among the most abundant species in other old growth forests in DRC (Katembo et al., 2020; Kearsley et al., 2013; Makana & Thomas, 2006; Makana et al., 2008), were not abundant in our study area. Apart from substrate and topography, endogenous processes may lead to multiple stable dominance states in mixed-species tropical forests (Katembo et al., 2020). Future work on soil composition and flooding patterns is needed to better understand the floristic composition of the Lomami Buffer Zone. Studying flooding patterns is important as 4 of the 30 plots we studied were dominated by *G. demeusei*, a species characteristic of semi-flooded forests, found elsewhere in, e.g., Salonga NP and the Republic of Congo (Ifo et al., 2018; Makana et al., 2008).

With regard to forest structure, stem density, basal area, and AGB for Lomami Buffer Zone were similar to those reported from other studies in DRC (Table 3). For example, AGB stocks were comparable to those sampled in the core zones of other protected areas in DRC (Table 3). Our findings confirmed the hypothesis that there is abundant mixed-species old growth forest in the Buffer Zone, rich in tree species of conservation concern (according to the IUCN Red List). Not only its remoteness, the lack of road infrastructure, the low population density but also the high cultural value local communities place on nature (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021) have helped to preserve these forests and the species within. More botanical research is needed, as numerous morphospecies remained unidentified. Marshall et al. (2016) estimated that the completeness of floristic species sampling was <10% for most of central DRC, including Lomami area.

4.2 | Population dynamics of preferred trees

Most preferred trees species were found to be relatively abundant and showed a pattern of continuous recruitment. This pattern is typically associated with an ongoing establishment of young trees followed by gradual attrition as stems grow larger (Young et al., 2017). This suggests that the current levels of exploitation by local communities for food, medicine, construction, or firewood (depending on the species, Table 2) are not negatively affecting the regeneration of these species. Therefore, current levels of exploitation by local communities could continue. We highlight "current levels of exploitation," which means that construction only refers to building houses or bridges at the local level and firewood is only used for subsistence—as limited road infrastructure hampers timber/firewood trade.

TABLE 2 Preferred species uses, frequency of occurrence (% of plots sampled), relative density (ind/ha), number of adults sampled, size class distribution slopes, R^2 value and *p*-value of the slope regression (a regression of density on size class, to infer regeneration class), type of size class distribution histograms, maximum diameter the species can attain (D_{max}), and light requirements of the species

Species	Uses	Frequency	Stem density (ind/ha)	No adults	Slope	R^2	*p*-Value	Histogram	D_{max} (cm)	Light
Alstonia boonei De Wild.	Medicine, construction, taboo	3	6	1	na	na	na	na	150	1
Anonidium mannii (Oliv.) Engl. & Diels	Medicine, taboo	10	6–12	4	na	na	na	na	80	3
Autranella congolensis (De Wild.) A. Chev.	Seeds	10	12–43	14	−1.42	.89	.09	CoR	200	2
Chrysophyllum lacourtianum De Wild.	Medicine, firewood	17	6–37	12	**−1.34**	.89	**.001**	CoR	100	3
Garcinia kola Heckel	Fruits	23	6–18	11	−0.59	.67	.09	CoR	100	3
Gilbertiodendron dewevrei (De Wild.) J. Léonard	Medicine, construction, taboo	23	6–18	12	−0.04	.002	.91	CoR	200	3
Milicia excelsa (Welw.) C.C. Berg	Medicine, construction, firewood	27	6–12	10	**−1.1**	.735	**.006**	CoR	250	2
Piptadeniastrum africanum (Hook. f.) Brenan	Fruits, construction	30	6–12	14	−1.57	.912	.192	CoR	300	2
Pycnanthus marchalianus Ghesq.	Medicine, construction, firewood	40	6–62	24	**−1.35**	.748	**.006**	CoR	100	2
Symphonia globulifera L. f.	Medicine, firewood, taboo	47	6–37	23	0.11	.012	.79	ERR	150	3
Xylopia aethioipica (Dunal) A. Rich.	Medicine, firewood	53	6–18	23	**−1.57**	.819	**.002**	CoR	75	3

Notes: For light requirements: 1: pioneers light demanders, 2: nonpioneer light demanders, 3: shade bearers. Information about D_{max} and light requirements gathered from https://www.prota4u.org/. Note about uses: construction only refers to building houses or bridges at the local level and firewood is only used for subsistence as limited road infrastructure hampers timber/firewood trade. Significant *p*-values and related slopes are highlighted in bold.

Abbreviations: CoR, continuous recruitment; ERR, episodic recruitment with a recent pulse of recruitment; na, not available.

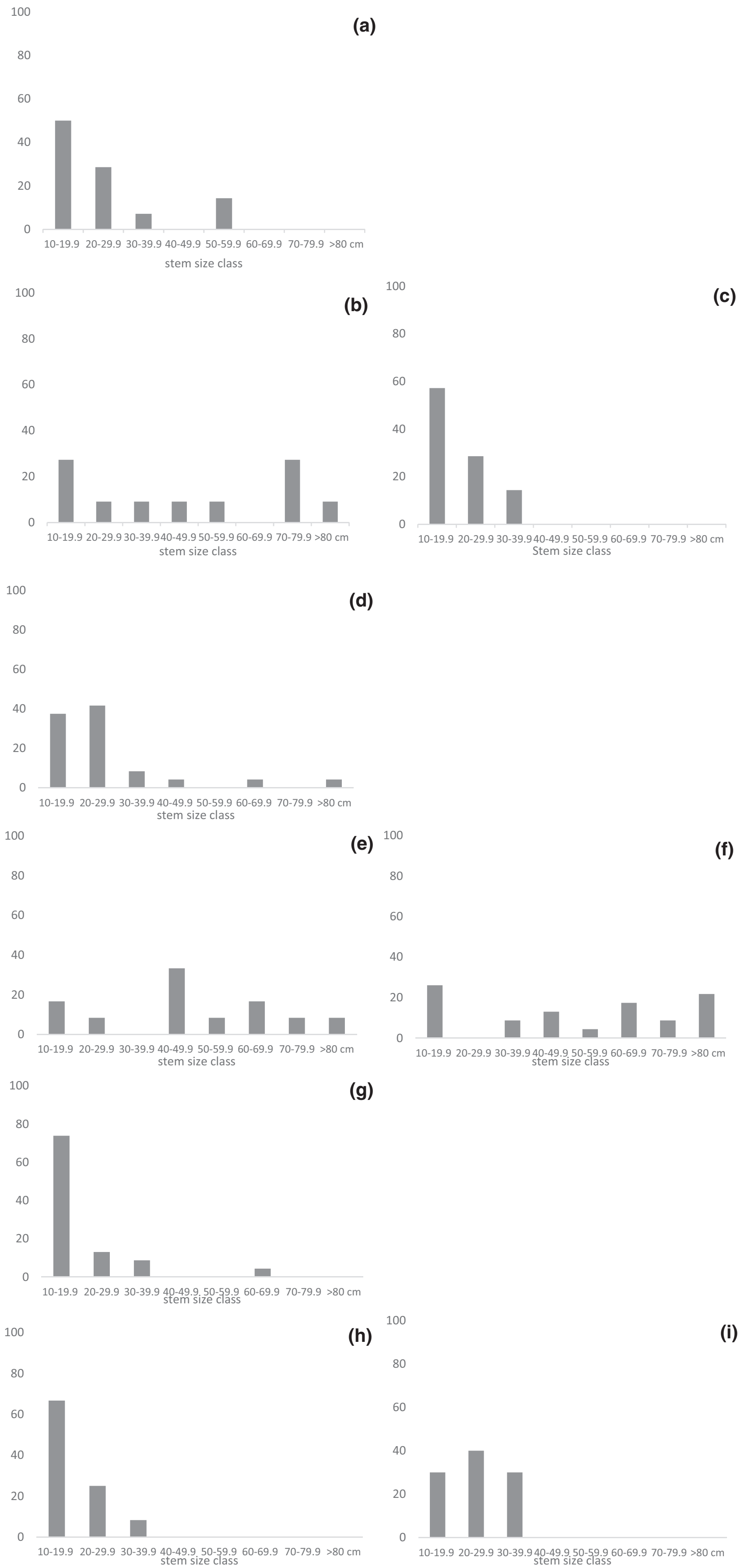

FIGURE 3 Size class distribution in Lomami Buffer Zone of the preferred useful species by local communities. Further details about uses and number of individuals sampled are provided in Table 2. (a) *Anonidium mannii*, (b) *Chrysophyllum lacourtianum*, (c) *Garcinia kola*, (d) *Gilertiodendron dewevrei*, (e) *Milicia excelsa*, (f) *Piptadeniastrum africanum* (g) *Pycnanthus marchalianus*, (h) *Symphonia globulifera*, and (i) *Xylopia aethioipica*

Current levels of exploitation include trading medicinal products of *G. kola* and *M. excelsa* to be sold in Kindu market. We observed that the currently employed harvesting methods of these products were sustainable: *G. kola* seeds were harvested from the floor and *M. excelsa* bark was harvested in small amounts (no ring debarking).

The situation for uncommon species (*A. boonei* and *A. congolensis*) is different. We found so few individuals that we could not investigate their population structure. For *A. boonei*, the low abundance we observed is most likely linked to the inability of this species' to regenerate under closed canopy forest (as seedlings require light, Palla, 2005). This species is widespread in tropical Africa (from Senegal to Ethiopia) and can be found in young fallows, secondary forests, and old growth forests. However, some populations are of conservation concern due to overexploitation of the bark, which is known to recover poorly (Palla, 2005). In Lomami, local populations also use the bark for medicine, and it is traded in Kindu town (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021). We recommend more research on this species: it could be abundant in young fallows, in which case conservation action in the Buffer Zone would not be needed.

For *A. congolensis*, which is only found in old growth forests, low abundance is a common feature of the species (Lemmens, 2007). Fruits take 10–14 months to ripen. Seedlings grow very slowly (1 cm per month) and are classified as nonpioneer light demanders, preferring small gaps in the forest canopy (Lemmens, 2007). Given that in Lomami area this species is only used for medicine (the bark), and that it is considered a taboo species, it is unlikely that it is its medicinal use which is driving the low abundance. However, more research is recommended. Future studies could map individuals in the park Core and Buffer Zones and investigate bark regeneration. Another species which requires further investigation is *M. microphylla* (VU) used only in the central part of the park (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021). We were unable to find any individuals in the plots we sampled.

In the plots we studied, we found four species of conservation concern (according to IUCN Red List or CITES) which are not being used by local communities (as reported by Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021): *P. spinosa*, *L. cedrata*, *P. bequaertii*, and *G. demeusei*. The first three species are sparse, and we could not compute their population structure. For *G. demeusei*, which was locally abundant, the population histogram indicated episodic recruitment with a recent pulse of recruitment (figure not included). *G. demeusei* seeds are dispersed by water (Meunier et al., 2015). Little is known about this species' seedling establishment and survival, which could be episodic (related to particularly dry or wet years). In the Republic of Congo, an absence of this species in small diameter classes was noted for *G. demeusei*-dominated forests (Ifo et al., 2018). Episodic recruitment is likely to be the norm for this species, therefore, no management intervention is needed for this species in the Buffer Zone for now.

Overall, we were unable to observe distinct SCD patterns across species studied, most likely because (i) species had multiple usages, each usage targeting different diameter classes, (ii) the importance of medicinal use could have ensured sustainable harvesting of other products and diameter classes, and/or (iii) we sampled few individuals to be able to see subtle changes due to different usages. Notably, species' life history should also be considered in the analysis of SCDs. All species studied are either long-lived nonpioneer light demanders or shade bearers (Table 2). And most can reach large sizes (Table 2). Episodic recruitment could be enough for sustaining these species' populations.

TABLE 3 Values of stem density, basal area, and aboveground biomass (AGB) reported in this study with regard to other studies available from protected areas in the Democratic Republic of the Congo

	Stem density (ind/ha)	Basal area (m^2/ha)	AGB (Mg/ha)
Lomami Buffer Zone (this study)	406.6	28.8	279.1
Salonga National Park (Makana et al., 2008)	347	25.5	—
Ituri Forest (Makana & Thomas, 2006)	447.8	31.9	—
Yangambi Biosphere Reserve (Kearsley et al., 2013)	467	31.5	321
Forests of eastern Kisangani (Katembo et al., 2020)	427	22.6	447.8
Maringa-Lopori-Wamba Landscape (Bauters et al., 2019)	450	28	370

4.3 | Caveats and future research

Our study has helped shed light in the floristic data gap for Lomami Buffer Zone, with suggestions for management. However, our study has some limitations. Firstly, we only sampled the southern part of the Buffer Zone due to insecurity in the central and northern part during the time our fieldwork took place. Although the southern part is the most accessible from Kindu, and therefore most likely to be more exploited than other parts of the Buffer Zone, further research is recommended in the central and northern parts, where floristic composition is likely to be different. For example, *Julbernardia seretii* which forms monodominant stands (Katembo et al., 2020) was not found in our study area, but this species was cited among the preferred trees for firewood by some communities living in the central part of Buffer Zone (Batumike, Imani, Bisimwa, Fidele, et al., 2021; Batumike, Imani, Bisimwa, Mambo, et al., 2021). Secondly, we did not sample trees 10 cm diameter (juveniles and subadults) due to difficulties in seedling and sapling identification in the field. Although juvenile traps, related to fire and browsing by livestock (see Ouedrago et al., 2015), are unlikely to be major issues in this wet rainforest, future work should consider assessing these size classes, particularly for sparse trees. It is possible that fruit harvesting is impacting adult recruitment of some species (e.g., *G. kola*) in ways that are not yet apparent. Third, we only investigated number of uses, and not level of usage (e.g., 50% fruits harvested and 50% of the stem debarked). Quantifying the level of utilization could help better understand the impacts of each type of usage and the combined effects of different usages (e.g., how debarking affects tree fruiting, and therefore, seeds available for regeneration). Fourth, we inferred population dynamics from SCDs, an approach which has limitations, particularly in a rainforest context. It has been shown that SCD at a given point in time does not necessarily predict future population changes in the rainforest (Condit et al., 1998; Feeley et al., 2007) because of the large interspecific variations in life history strategies. It has also been shown that SCD is less predictive of subsequent population change for larger slow growing long-lived rainforest trees (Feeley et al., 2007), and several of the species we studied are such type of species (Table 2). Also, our SCDs were based on diameter sizes, not tree age, and we assumed that trees above 10 cm were reproducing adults. Future work should focus on estimating size/age of first fruiting for each species and how tree size affects seed production (e.g., Londres et al., 2017).

5 | CONCLUSIONS

Results show that the Lomami Buffer Zone has abundant undisturbed mixed-species old growth forests, rich in tree species of conservation concern internationally (according to IUCN Red List or CITES). Our findings also show that most tree species used by local communities are relatively abundant and they are continuously recruiting, which suggests that current levels of exploitation are sustainable. However, for three "unabundant" species (*A. congolensis* CR, *E. angolense* (VU), and *M. microphylla* VU), more research is needed before determining if current levels of exploitation are sustainable. Although our study is only a snapshot of current population structure of the studied species, it is a baseline which can be used to monitor changes over time related to, e.g., larger volumes being harvested, or climatic changes.

At the moment, commercial timber and firewood exploitation in the study area is limited. However, if road infrastructure improves, both activities could increase, with potential negative effects on the species' populations targeted for such activities, and for the livelihoods of the communities that depend on them for other uses (e.g., medicine). While local communities already use customary laws to regulate the extraction of certain natural resources within sustainable levels, foreigners (including Congolese from other ethnic groups outside the study region) might extract some resources in large volumes for commercial profit (as already shown for bush meat, see Batumike et al., 2020). We recommend that the management plan of the Buffer Zone clearly prohibits the harvesting of timber or firewood from any species of conservation concern internationally, and that it states that in the case of commercial timber or firewood harvesting of other species, a system of quotas should be first discussed and agreed upon at the village level for local communities only, as it has been suggested for hunting (Batumike et al., 2020). This park was created with a large Buffer Zone in which local communities could carry out certain extractive activities to satisfy their own needs, so any present or future extraction should not hamper the needs of these same communities.

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AUTHOR CONTRIBUTIONS

Conceived and designed the study: RB, GI, and AC-S. Performed the fieldwork: RB and JK. Identified plant samples: JK. Analyzed the data: RB and AC-S. Wrote the paper: RB and AC-S with input from all co-authors. Revised paper: RB and AC-S.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Dryad Digital Repository: https://doi.org/10.5061/dryad.0cfxpnw3s (Batumike, Imani, Bisimwa, Mambo, et al., 2021).

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