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# Diversity and availability of edible caterpillar host plants in the Luki biosphere reserve landscape in the Democratic Republic of the Congo

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A B S T R A C T

Edible caterpillars are an important food and economic resource for rural African people. However, they are subject to a number of threats; in particular, their host plants are threatened. The Luki Biosphere Reserve landscape is a region of the Democratic Republic of Congo where the practice of eating caterpillars is a recent phenomenon; however, rural communities have reported their scarcity. This study assessed the diversity and availability of host plants of the edible caterpillars in the Luki Biosphere Reserve (LBR) landscape. Botanical inventories were conducted in eleven ha plots of each of the following habitats: forest, savannah under protection, fallow, and inhabited areas, covering an area of 44 ha. The coverage-based rarefaction and extrapolation method and the iNEXT online software were used to calculate the true diversity of edible caterpillar host plants. The diameter structure of the edible caterpillar host plant species was assessed by counting the number of individuals in each diameter class. The results revealed that in the Luki Biosphere Reserve landscape, edible caterpillars rely on 15 main plant host species (*Spondias mombin* L., *Petersianthus macrocarpus* (P.Beauv.) Liben, *Croton sylvaticus* Hochst. ex Krauss, *Hymenocardia acida* Tul., *Lannea welwitschii* (Hiern) Engl., *Macaranga spinosa* Müll.Arg., *Celtis mildbraedii* Engl., *Coelocaryon botryoïdes* Vermoesen, *Albizia gummifera* (J.F.Gmel.) C. A. Sm, *Bridelia atroviridis* Müll.Arg, *Ficus mucuso* Welw. ex Ficalho, *Funtumia elastica* (P.Preuss) Stapf, *Lannea welwitschii* (Hiern) Engl., *Milicia excelsa* (Welw.) C.C. Berg., and *Terminalia superba* Engl. & Diels). The habitats exhibited low species diversity of the edible caterpillar host plants. Moreover, several of these species are becoming scarce or are locally threatened with extinction. The trend in the diametric structure is similar to species evolving in a disturbed environment.The results of this study suggest potential habitat instability linked to human activities that could lead to biodiversity loss and, thus, a decline in edible caterpillars in the LBR landscape. A better understanding of the unfavourable conditions that influence the nutritional support for the edible caterpillars would help promote appropriate strategies that can be applied in local development plans for community lands at a landscape scale.

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## 1. Introduction

Forest ecosystems are of great importance to humanity. Besides their ecological and economic benefits, they provide products besides timber that secure livelihoods for 3.5–5.8 billion people worldwide (FAO, 2022). This helps increase the food security of populations living near forests (Badanaro et al., 2014; Lange and Nakurama, 2021). This is particularly true with regard to edible insects, a non-timber forest products (NTFPs), that represent a traditional food resource extensively harvested in forest ecosystems in the Democratic Republic of the Congo (DRC) (Bomolo et al., 2017; Ishara et al., 2022a; Nsevolo et al., 2022a), thus providing an alternative to meat products as sources of protein (Kusia et al., 2021; FAO, 2022; Nsevolo et al., 2022a).

The interest in consuming caterpillars has risen in a context where they are becoming scarce, prompting questions about the diversity and availability of their nutritional support. In the specific case of the landscape in the Luki Biosphere Reserve (LBR), edible caterpillars are collected from various species of host trees found in forests, savannahs under protection, fallow lands, and inhabited areas (Lonpi et al., 2023). Currently, limited (and up-to-date) data regarding the biodiversity and availability of edible caterpillar host plants across the landscape of LBR is available. Despite existing literature reporting that LBR is at risk of anthropogenic pressure due to commercial hunting, harvesting, and subsistence activities carried out by local populations (Cirezi et al., 2022; Opelele et al., 2021; Kwidja et al., 2023), the current state of plant biodiversity in general (and that of edible caterpillar host species in particular) remains largely under-documented.

To sustainably maintain the functions of forest ecosystems, it is helpful in not only characterizing the present biodiversity but also documenting the diversity and availability of host plants that serve as nutritional supports for edible caterpillars - a non-timber forest products (NTFPs) that significantly alleviate food insecurity among communities living near forest ecosystems in the DRC (Nsevolo et al., 2022a; Lonpi et al., 2023). Despite the scarcity of data at the local level in the LBR landscape, a recent nationwide study suggests a relative abundance of host plants of edible caterpillars in the DRC, with 22 species dominated by four families, including Fabaceae (34.4 %), Phyllanthaceae (10.6 %), Meliaceae (4.9 %) and Apocynaceae (4.1 %) (Nsevolo et al., 2022b).

Indeed, one of the characteristics of the vegetation in the LBR landscape is the physiological and floristic homogeneity of the plant communities (Lubini, 1997). The species of host plants of edible caterpillars there evolve under the same pedoclimatic conditions (Lubini, 1997). Furthermore, to combat vegetation loss and restore biodiversity in this landscape, anthropogenic savannahs are protected against bushfires, and beekeeping is practiced in fallow lands to enable the natural regeneration of plant species (Dejace, 2019; Djiofack et al., 2024). It would be logical to observe a stable species richness, the same edible caterpillar host plant species across habitats, and their abundance.

Moreover, studies have shown that restored habitats in tropical humid and equatorial forest zones have a higher floristic diversity (Bisiaux et al., 2009; Djiofack et al., 2024) than disturbed and unrestored ones, which exhibit an uneven distribution of individuals within species (Senouci, 2020). Similarly, an uneven distribution of individuals within a plant community indicates the scarcity of other species (Piba et al., 2019). Additionally, competition among species concerning their different temperaments is a factor to consider when assessing their rarity (Pascal, 2003). These data thus raise a legitimate question regarding the specific richness of habitats where edible caterpillars are collected in the LBR region, considering, among other factors, the vegetation characterization by Lubini (1997). This question is further reinforced when considering studies conducted in the Cataractes district (Kongo Central province, formerly Bas-Congo), a phytogeographic area close to the LBR landscape (Latham, 2008). Indeed, these works mention ten host plants of Lepidoptera of food interest, some of which might be found in LBR. Lubini (1997) describes the vegetation of LBR as mainly composed of species with a high recolonization capacity. Therefore, it is expected that the habitats where caterpillars are collected present suitable conditions for the growth of host species and that these species are available.

By combining data from a botanical inventory followed by calculation of the Shannon–Weaver diversity, Simpson evenness, and structural diameter, some of them commonly used to assess tree biodiversity (Stirling, 2007; Marcon, 2015; Averti et al., 2016; Ouattara et al., 2016; Kengne et al., 2018; Temgoua et al., 2019), this study aimed to provide an initial assessment of the diversity and availability of edible caterpillar host plants in the LBR landscape. To achieve this, this study formulates the following hypotheses:

From a floristic perspective, landscape and habitat in the LBR have sufficient overall species composition of caterpillar host species.

Fallow lands, forests, and savannahs under protection are more diverse than inhabited areas. The distribution of edible caterpillar host trees in these habitats are more even than those in human-inhabited areas.

The trend in diameter structure showed that edible caterpillar host trees in the Luki biosphere reserve landscape are rare, and locally threatened by extinction.

## 2. Materials and methods

### *2.1. Study area characteristics*

The LBR landscape is located in Kongo Central Province in the western DRC, within the geographical region of Mayombe. The designated LBR landscape includes the reserve and the surrounding area, extending approximately 20 km beyond it. This landscape is situated between latitudes 5°30′00″ and 5°10′00″ South and longitudes 12°50′00″ and 13°30′00″ East. The climate is humid tropical type (AW5, according to the Köppen classification) (Peel et al., 2007), with an average annual temperature of around 25 °°C and an annual precipitation of about 1201 mm (Angoboy et al., 2019). The region is marked by two seasons: a dry season of five months (mid-May to mid-October) and a rainy season of seven months (mid-October to mid-May).The vegetation of the LBR landscape is part of the southernmost tip of the Mayombe Guinean Forest, which extends across Gabon, the Republic of Congo, and Angola (Lubini, 1997). The landscape consists of dense evergreen humid forests transitioning towards semi-deciduous forests (White, 1986). Lubini (1997) studied the vegetation of the LBR, which is considered a remnant of the Mayombe Forest in the DRC after decades of intensive degradation. He noted that this vegetation comprised forest and non-forest flora characterised by numerous widely distributed species and multi-regional African species. The forest flora includes primary forests with four plant communities: *Gilletiodendron kisantuense* forest, *Gossweilerodendron balmiferum* forest, *Ganophyllum giganteum* and *Staudtia stipitata* forest, and *Corynanthe paniculata* and *Xylopia wilwerthii* forest. This forest flora also comprises secondary forests composed of *Terminalia superba* and *Xylopia aethiopica* forests. The species in secondary forests are from restored forests that are fast-growing, with a high recolonisation capacity, temporarily or permanently replacing the flora of primary forests. Non-forest flora included grassy savannahs of climatic origin and shrubby savannahs of anthropogenic origin. Shrubby savannahs, usually subjected to bushfires, evolved into a pioneering shrub group during reforestation when the fire regime ceased. There are also pre-forest fallow lands within the non-forest flora group, which are typical of human-inhabited areas (Lubini, 1997). These fallow lands consist of pioneer vegetation that recolonises bare soils (Lubini, 1997).

The stages of vegetation succession in the LBR described by Lubini (1997) include the following: (1) a pioneer stage composed of annual nitrophilous species that establish themselves after agricultural clearings. This is the stage of grassy fallow land, the duration of which depends on the levels of soil degradation and human activity. (2) The fallow land and forest regrowth stage appears after the first crop cycle following the disappearance of the grassy fallow land, allowing vegetation succession to proceed towards the stage of pre-forest fallow land. Meanwhile, the shrubby savannah, under protection for 5–10 years, turns into a forest regrowth. (3) The stage of young secondary forests is established when, in the fallow lands and forest regrowth areas, species of young secondary forests comprising *Musanga cecropioides* with *Croton sylvaticus* and various species of *Macaranga* and seedlings of *Terminalia superba* emerge. (4) The old secondary forest stage corresponds, on the one hand, to a forest of *Terminalia superba* and, on the other hand, to a forest of *Xylopia aethiopica* resulting from the reforestation of protected savannahs. (5) The forest replacement stage is marked by the presence of old secondary forest species, giving way to primary forest species.

### *2.2. Research design and sampling*

To study the diversity and availability of edible caterpillar host plants in the LBR landscape, sampling was conducted in four habitats: forests, savannahs under protection, fallow land, and inhabited areas. The study was conducted in 22 of the 57 villages in the RBL landscape. Villages were randomly selected without replacement. In addition, the choice of plots to be surveyed within each village was made first at random based on the geographical coordinate points selected for the study of the spatiotemporal dynamics of edible caterpillar-collecting ecosystems in the RBL landscape, which was being carried out at the same time as the present study. Thirty percent, representing 11 ha, of each of these geographical coordinates was retained for the present study. The choice of plots to be surveyed was then carefully considered, considering not only the willingness of the landowner to make them available for the surveys, but also the availability of local guides to accompany the team of botanists in the field. In areas where the land is under pressure, local communities are generally reluctant to the idea of quantification of their natural resources. However, because the aim of this study was to propose strategies for considering edible caterpillars in both the RBL management plan and the local development plans of the terroirs surrounding the RBL, it was judicious to assess the availability of edible caterpillar host species in these two environments using different

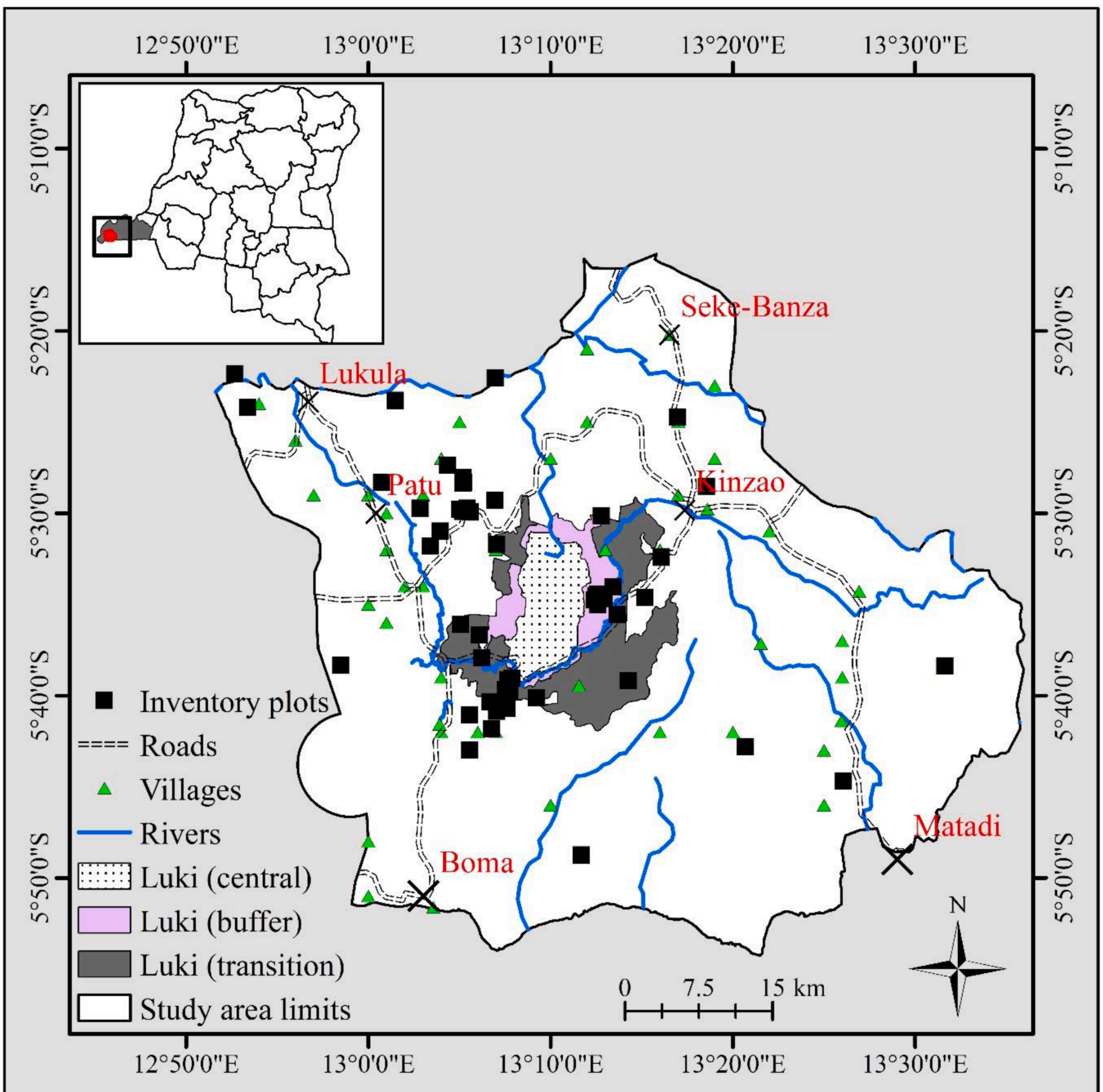


**Fig. 1.** Study area and inventory plots: grey, purple and white dotted lines correspond to the Luki biosphere reserve divided into three development zones. The white represents the surrounding area. The villages in which the surveys took place are marked with the green figure. The black dots represent inventory plots. The Luki biosphere reserve and surrounding area form the Luki biosphere reserve landscape.

management methods. Thus, when a geographic coordinate point was projected onto the land whose owner did not agree to the botanical inventory, a new point was immediately recruited to reach the total size of the predefined sample and cover the entire landscape. Therefore, the distances between the sampled units varied.

### 2.3. Data collection

The data were collected between January and March 2022. The botanical inventory method was used for the data collection (Djomo, 2015). This was conducted on square plots measuring 100 m × 100 m that were specifically set up for this purpose, with 11 repetitions for each habitat. After locating the plot, the direction of each layer was selected. The stakes were set, and a path was laid out to open the vegetation and reach the centre of the plot. In plots in the human inhabited areas, the centre was generally the village chief house from where the path started. Data were collected over a total area of 44 ha (Fig. 1). Within each plot, all trees were identified, and their names were recorded on a sheet indicating the plot number and identification of the relevant village.

A Garmin 64 s GPS was used to locate the study site and obtain waypoints for new plots. In addition, a penta decameter and liana wire were used to measure the dimensions of the plots to be surveyed and mark the plots under study, whereas a tape measure was used to measure the diameters at breast height of the caterpillar host trees. For the edible caterpillar host plants, only individuals with a diameter at breast height (dbh) ≥10 cm were inventoried. Their geographical coordinates were recorded and a mark was placed on them for future studies. A list from an ethnobotanical survey was used to identify the host plants of the caterpillars (Lonpi et al., 2023) (Appendix A). Only species with a citation frequency as reported by villagers greater than or equal to 1 % were included. In fact, in ethnobotanical surveys, some plants may have been identified as caterpillar trees; however, they are not necessarily food sources for the caterpillars. This explains why some species were mentioned only once and others two or three times (Lonpi et al., 2023).

### 2.4. Data analysis

#### 2.4.1. Analysis of the floristic composition and the diversity of edible caterpillar host plants in their habitat

Floristic composition, sometimes called specific composition, refers to the sum of all the species present in a certain area with a specific geographical composition. In this work, this is the sum of all woody plants inventoried at landscape level, with a breakdown of the number of woody plants hosting edible caterpillars by habitat (Marcon, 2015; Temgoua et al., 2019). Furthermore, species diversity is essential for assessing the myriad life forms of the biosphere within a specific ecological community. This measure considers three key ecological principles: species richness, abundance, and evenness (Stirling, 2007; Marcon, 2015). Species richness refers to the number of species present in a specific area, whereas species abundance refers to the number of individuals of each species within the same area. Species evenness, on the other hand, represents the distribution or uniformity of species resident in the designated area.

Species diversity is an essential concept for the assessment of ecosystem health. Indeed, a balance between species diversity and quantity can maintain ecosystem equilibrium. Generally, a more diverse ecosystem has higher productivity and greater capacity to withstand environmental pressures. In addition, ecosystems with greater species richness tend to have higher productivity, enhancing their sustainability and stability, and improving their ability to respond to a wide range of adversities.

Coverage-based rarefaction and extrapolation have been used to assess the diversity and availability of edible caterpillar host species in the RBL landscape (Chao and Jost, 2012). Coverage-based rarefaction and extrapolation is an analytical method that extrapolates standardised high-coverage samples rather than large samples. This makes it possible to construct a basic coverage sample curve incorporating both rarefaction and extrapolation and to compare samples of equal completeness rather than samples of equal size, thereby satisfying the replication principle (Chao and Jost, 2012). However, in this study, the results are presented only for rarefaction measurements and not for extrapolation. This is because the study assessed the availability of edible caterpillar host species within their habitats and in the landscape and not their predictions regarding the aim of the study.

In practice, the sample coverage must be estimated from the data (Chao et al., 2016). In this study, we used raw data from fieldwork. These data were entered into an Excel spreadsheet and organised in the form of a sample matrix, in which the columns correspond to the samples (inventoried plots) in each habitat, the rows represent the species, and each cell signifies the presence (1) or absence (0) of a particular species in a sample (Chao and Jost, 2012; Chao et al., 2016).

Using the prepared sampling data, spacing was calculated using the specialised online ecological analysis software, iNEXT, which was updated on 30 March 2024. The iNEXT calculates diversity estimates for rarefied and extrapolated samples based on a standardised level of sample completeness (measured by sample coverage) up to an appropriate coverage value (Chao et al., 2016). As a result, iNEXT uses diversity partitioned into alpha, gamma, and beta components using Hill numbers to analyse diversity. This diversity quantifies the number of equal abundances within a dataset with diversity components of order $q$ (Jost, 2006). When $q = 0$ (0 D, refers to species richness); when $q = 1$ (1 D refers to Shannon diversity, which also expresses the exponential of Shannon entropy). The measure $q = 2$ (2 D refers to Simpson's diversity) is expressed as the inverse of Simpson diversity (Jost, 2006; Chao et al., 2020). Zero D does not consider species abundance for diversity analysis and assigns a higher weight to rare species than 1 D (which considers abundance). In comparison, 2 D assigns a higher weight to the most abundant species (Jost, 2006). When the species abundance was completely balanced, the diversity profile is a horizontal line at the species richness level. Otherwise, the profile is theoretically a decreasing function of the order q. Consequently, the steepness of the slope reflected an imbalance in abundance. When species richness is fixed, the more uniform the distribution of abundances, the steeper the profile declines (Gotelli and Chao, 2013; Chao et al., 2020).

Thus, to compare multiple samples, we first constructed an integrated coverage-based sampling curve for each sample up to the maximum coverage value approximatively. We then selected the lowest among these maximum coverage as our 'based coverage'. Samples with higher coverage were then rarefied to the coverage of this sample. On each curve, we located a point with the same base coverage and estimated the species richness of all communities corresponding to that base point. Chao et al. (2016) recommended using bootstrap replications of 100 for scientific purposes, and to construct 95 % confidence intervals for expected rarefied and extrapolated species richness for any sample equal to the base coverage. This method suggests that for any fixed sample coverage less than or equal to the base coverage, if the confidence intervals do not overlap, significant differences at the 5 % level among species diversity are guaranteed (Chao and Jost, 2012).

#### 2.4.2. Assessment of trend in the diameter structure of edible caterpillar host trees

To determine the reasons for rarefaction indicating the unevenness of edible caterpillar host species in their habitats, the diameter structure was assessed. To this end, all individuals of caterpillar host tree species measured (dbh ≥ 10 cm) were distributed into diameter classes of 10 cm intervals (Favrichon et al., 1998). Eight diameter classes were defined. The limits of these classes were as follows: 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79 and > 80 cm. The diameter structure was assessed by counting the number of individuals within each diameter class. Temperament was also considered when interpreting the results (Pascal, 2003). Thus, the abundance of individuals of a given species in diameter classes <40 cm indicates good regeneration of that species (Opelele et al., 2022). However, for a species typical of forests, a low number of individuals of that species in diameter classes ≥40 cm implies that the absence or rarity of the species is not due to its temperament (there is good regeneration, but the species evolve in a disturbed environment) (Dzokou et al., 2022). In contrast, a low representation of individuals of a species in diameter classes <40 cm indicates poor regeneration (its absence or rarity is not due to temperament) (Essowazina et al., 2022; Opelele et al., 2022). The habitat characteristics of caterpillar host species in the LBR landscape, according to Lubini (1997) (Appendix B), were considered in this study to provide insights into their presence/absence and temperament.

## 3. Results

### 3.1. Floristic composition of edible caterpillar host species at the landscape and habitat scales

The floristic inventories enabled the identification of 3325 trees in 44 plots (44 ha) included in the study. Of these plants, 1224 belonged to 15 priority species on the ethnobotanical list of caterpillar trees in the LBR landscape, accounting for 36.81 % of the total inventoried trees. In terms of habitats, a total number of 365 caterpillar host trees were found in the forest, 272 in the savannah under protection, 299 in the fallow lands, and 288 in the inhabited area. Fourteen host species were identified in forests, 15 in savannahs under protection, 14 in fallow lands, and only six in inhabited areas (Table 1). Some species were found in all the habitats studied. *Hymenocardia acida* was not found in the forests and *Coelocaryon botryoïdes* was absent in fallow lands. In small numbers, edible caterpillar host species found in forests, savannahs under protection, and fallow lands were also found in the human inhabited areas.

### 3.2. Richness, diversity, and evenness of edible caterpillar host species in collection habitats

Three specific diversities were calculated based on the plots arranged in the different habitats: richness, Shannon's diversity, and Simpson's evenness. The estimation of edible caterpillar host species richness ($q = 0$) standardized by sampling coverage and obeying the principle of replication, reveals that for the 11 sample units inventoried in each habitat, fallow plots had a high richness, with approximately 155 individuals. The fallow lands were followed by the forest plots containing 150 individuals. The savannah under protection plots recorded 100 individuals, and those in inhabited areas approximately 100 individuals (Fig. 2a). For the same sample units, the coverage ratio was 0.75 for fallow land. On the other hand, the same coverage ratio was achieved in inhabited areas under five sample units. While for the forest and savannah under protection plots, the ratio of 0.75 was achieved around seven sample units (Fig. 2b). Furthermore, for the sampling coverage ratio of approximately 0.76, the fallow land has a richness of approximately 155 individuals. Forest plots had 122 individuals, while the same ratio for savannah under protection plots, and human inhabited areas showed 90 and 73 individuals respectively (Fig. 2c). These results suggest, for the $q = 0$ richness measurement that fallow lands plots had a high richness. Fallow lands are followed by forest and savannah under protection plots. Plots in inhabited areas tend to have a scarcity of edible caterpillar host species.

With regard to the estimation of species diversity ($q = 1$) with sample coverage and obeying the principle of replication, for the 11 sample units taken in each habitat, fallow lands showed the greatest diversity, with approximately 135 individuals. The fallow lands were followed by forest plots containing approximately 125 individuals. Savannahs under protection and inhabited areas had the same number of individuals at 80 (Fig. 3a). Furthermore, in relation to the sampling coverage ratios, it can be observed that for the 11 sampling units, the ratio is around 0.95 for inhabited areas, 0.90 for forests, 0.80 for savannahs under protection, and 0.75 for fallows (Fig. 3b). This could mean that a large cover or surface area is required to obtain a high diversity of edible caterpillar host species in inhabited areas, unlike forests, savannahs under protection, and fallows, which require much smaller surface areas. Thus, the baseline coverage taken for savannah under protection plots showed that, for a ratio of approximately 0.80, fallow plots recorded 130 individuals, forest plots approximately 110 individuals, savannah under protection plots approximately 70 individuals, and inhabited areas approximately 50 individuals (Fig. 3c). This suggests a high diversity and abundance of edible caterpillar host species in fallow lands, forests, and savannahs under protection compared to the values in inhabited areas.

In addition, the estimation of Simpson's evenness ($q = 2$), standardised by coverage and obeying the replication principle, revealed the absence of a horizontal line for all habitats. Regarding the relationship between the number of sample units and diversity, coverage curves were concave for all sample units (Fig. 4a). The same observation was made for the function representing the sample units and the sample coverage ratio (Fig. 4b). The tangents of various concave curves would lie above the various curves, representing increasing functions. However, the curves representing sample coverage ratios and diversity exhibited convex shapes (Fig. 4c). All curves show a decreasing profile (Fig. 4c). The decreasing profile for plots in human inhabited areas was much

**Table 1**
Specific composition of edible caterpillar host species in habitats and the landscape of the Luki biosphere reserve.

| | Forest | Savannah under protection | Fallow land | Inhabited areas | Landscape |
|---|---|---|---|---|---|
| Species | Frequency | Frequency | Frequency | Frequency | Frequency |
| *Albizia gummifera* | 47 | 6 | 30 | 2 | 85 |
| *Bridelia atroviridis* | 4 | 1 | 2 | 0 | 7 |
| *Celtis mildbraedii* | 9 | 7 | 38 | 0 | 54 |
| *Coelocaryon botryoïdes* | 1 | 2 | 0 | 0 | 3 |
| *Croton sylvaticus* | 50 | 16 | 68 | 0 | 134 |
| *Ficus mucuso* | 12 | 6 | 6 | 0 | 24 |
| *Funtumia elastica* | 10 | 12 | 16 | 0 | 38 |
| *Hymenocardia acida* | 0 | 12 | 1 | 0 | 13 |
| *Lannea welwitschii* | 29 | 33 | 12 | 10 | 84 |
| *Macaranga spinosa* | 19 | 32 | 7 | 0 | 58 |
| *Milicia excelsa* | 7 | 3 | 11 | 3 | 24 |
| *Petersianthus macrocarpus* | 13 | 3 | 4 | 0 | 20 |
| *Ricinodendron heudelotii* | 102 | 121 | 75 | 1 | 299 |
| *Spondias mombin* | 40 | 6 | 15 | 263 | 324 |
| *Terminalia superba* | 22 | 12 | 14 | 9 | 57 |
| Number of species | 14 | 15 | 14 | 6 | 15 |
| Total caterpillar host individuals | 365 | 272 | 299 | 288 | 1224 |
| Total trees | 1219 | 828 | 890 | 388 | 3325 |
| Percentage | 29.94 | 32.85 | 33.60 | 74.22 | 36.81 |

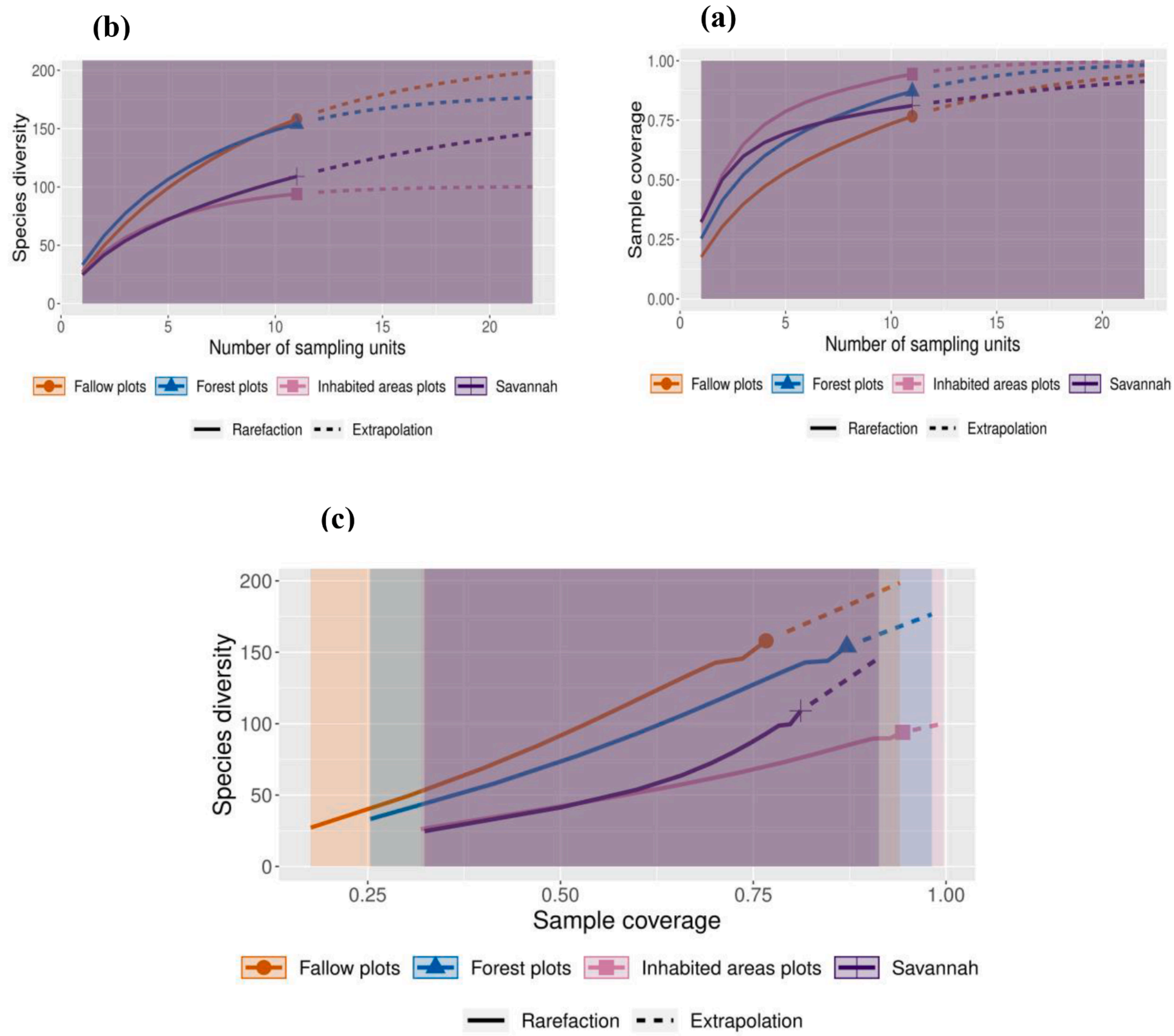


**Fig. 2.** Rarefaction curves showing tree species diversity ($q = 0$) among edible caterpillar habitats categorie. (a) Sample-size-based rarefaction and extrapolation sampling curve ; (b) Sample completeness curve; (c) Coverage-based rarefaction and extrapolation sampling curve.

more pronounced (Fig. 4c). This suggests a lack of regularity in the number individuals of edible caterpillar hosts in each habitat, with a marked imbalance in the human inhabited areas.

From the above results, the conclusion that fallows, forests, and savannahs under protection have a high diversity of edible caterpillar host species compared to inhabited areas can be made. This conclusion was also justified when we considered the significance of the differences in diversity between the different sampling units inventoried in each habitat. In fact, there are overlaps between the fallow and forest curves and between the savannah under protection and inhabited area curves (Fig. 4a). These overlaps were also observed between the savannah under protection and forest curves (Fig. 4b) and between the savannah under protection and inhabited areas (Fig. 4c). Accordingly, the significance of differences test for a 95 % confidence interval indicated statistically significant differences at the 5 % threshold between the diversity of edible caterpillar host species in fallow and forest plots, savannah under protection and inhabited area plots, and savannah under protection and forest plots.

### 3.3. *Assessment of the availability of edible caterpillar host species in the landscape and within habitats based on the trend of diameter*

The distribution of individuals with dbh $\geq$ 10 cm per diameter class for each species of edible caterpillar host trees suggests a strong representation of individuals in diameter classes $<$ 40 cm of approximately 1038 out of 1224 individuals, accounting for 85 % of the caterpillar host individuals inventoried (Table 2). Only 186 individuals (15 %) fell into the diameter classes $\geq$40 cm. This diameter structure reveals the presence of caterpillar tree groups with decreasing exponential structural dynamics. This indicated good overall regeneration of these species. However, when considering some species, for example, *Bridelia atroviridis* and *Funtumia elastica*, which are forest species, no individuals in diameter classes $\geq$40 cm were inventoried. *Coelocaryon botryoïdes*, a forest species, had individuals only in diameter classes between 30 and 49 cm, and no individuals in 10–19 and 20–29 cm classes, indicating poor regeneration. *Milicia excelsa*, another forest species, had a significant number of individuals in the 10–19 cm diameter class and a few individuals beyond 20 cm in diameter. These results suggest that the rarity or presence of a species in a landscape is not solely due to its temperament. This explains the evenness index results for the habitat. Anthropogenic pressures may compromise not only the regeneration but also the growth of edible caterpillar host plants.

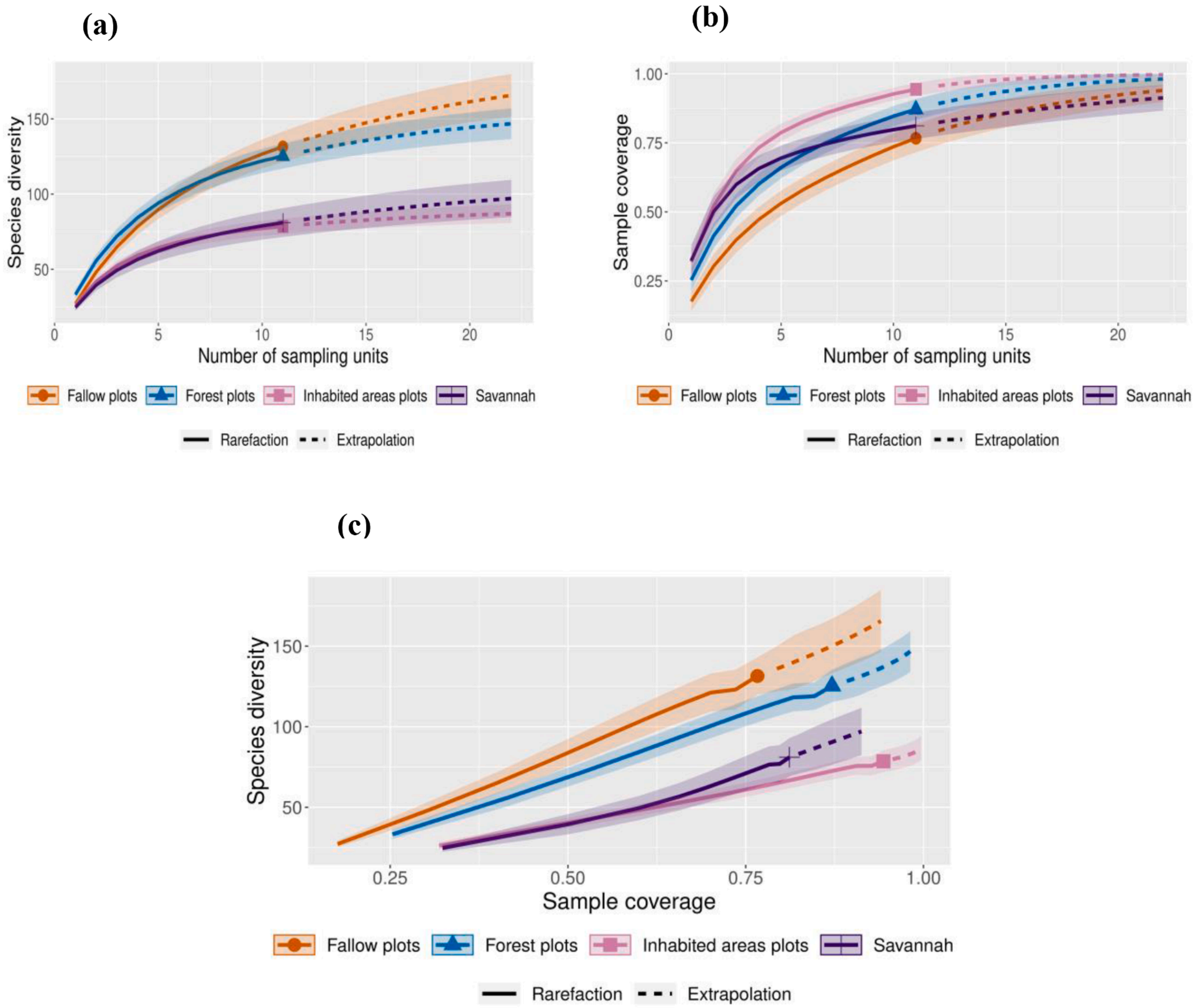


**Fig. 3.** Edible caterpillar host plants diversity ($q = 1$) in fallow lands, forests, savannahs under protection, and inhabited areas. (a) Plots of species diversity with respect to the sample units. (b) Plots of sample coverage with respect to the sample units. (c) Plots of species diversity with respect to the sample coverage. The species diversity is calculated for 11 sample units. This correspond to sample coverage 0.95 for inhabited areas, 0.90 for forests, 0.80 for savannahs under protection, and 0.75 for fallow lands. For each diversity, rarefaction is represented by solid line and extrapolation by dashed line.

## 4. Discussion

### *4.1. Floristic composition of the landscape is adequate to facilitate the availability of edible caterpillars, except in inhabited areas*

According to several studies conducted in large areas in the DRC, where edible caterpillars are collected and consumed, as well as in Central and Eastern Africa, 18 species have been found around the Yangambi Biosphere Reserve (Looli et al., 2021), 26 species in Haut-Katanga (Bomolo et al., 2017), 11 species in villages around Yaoundé in Cameroon (Ngute et al., 2019), and 11 species in Kenya (Kusia et al., 2021). Our results align with the findings of these studies, demonstrating that the floristic composition of the LBR landscape is sufficient ensure the availability of caterpillars. Only the human inhabited areas showed a scarcity of species. Thus, edible caterpillars are associated with several host plant species, the specific composition of which can vary among regions. For example, the lists of host plant species for edible caterpillars in Kongo Central Province compiled by Latham (2008) only included the following species from our study area: *Milicia excelsa, Ricinodendron heudelotii, Hymenocardia acida, Petersianthus macrocarpus*, and *Bridelia atroviridis*. However, our study area is in a phytogeographical zone close to the area where Latham conducted his studies. The results of our study in the LBR landscape thus provide information about edible caterpillar host species in the forested part of Kongo Central Province. In addition to *Spondias mombin*, all inventoried edible caterpillar host tree species in this study were reported as trees in the Mayombe Forest (Lubini, 1997). Additionally, caterpillar plants inventoried in the LBR landscape were found in several other locations in the Congo Basin across various habitats (Table 3). This led Lubini (1997) to conclude that the flora of the LBR landscape is characterised by numerous species with extensive distribution and multi-regional African species widely distributed in the GuineoCongolian region.

### *4.2. Importance diversity of fallow lands, forest, savannahs under protection and individual distribution of edible caterpillar hosts plants*

Land use has a strong influence on species diversity in a given area. This study showed that fallow land, forests and savannahs under protection are more diverse than vegetation in inhabited areas. A similar study by Osen et al. (2021) in vanilla agroforests in Madagascar showed a higher level of tree species diversity than that of fallow communities. It is generally known that human actions can improve or alter the quality of an ecosystem. This is a situation observed in the LBR landscape, where slash-and-burn agriculture practices, in a context of demographic growth, are altering the quality of natural ecosystems. The fact that this study reveals a high diversity of edible caterpillar host species in fallows

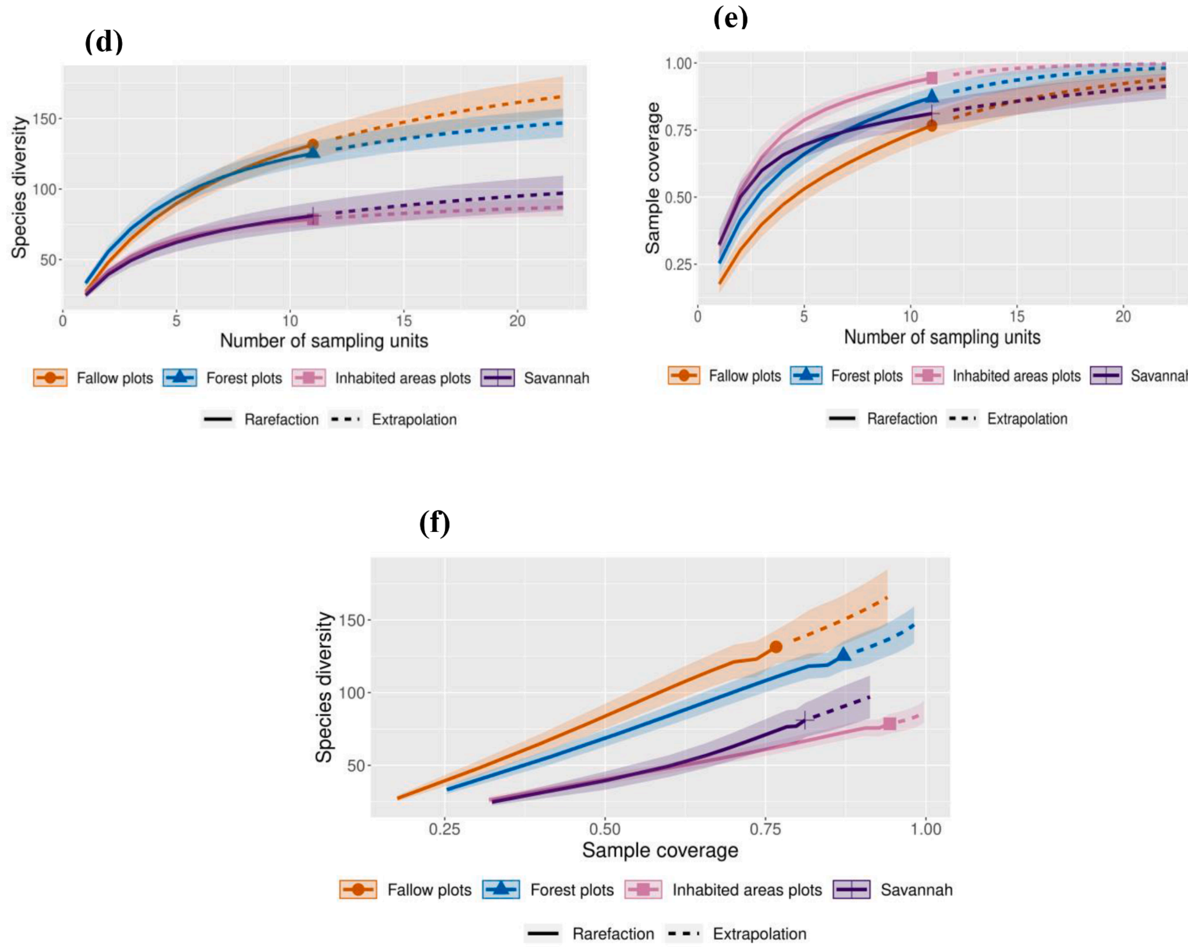


**Fig. 4.** Simpson evenness ($q = 2$). (a) and (b) The coverage curves are concave for all sample units showing the increasing functions and overlaps between the fallow and forest curves, between the savannah under protection, and inhabited areas curves, and between the savannah under protection curve, and the forest. (c) The sample coverage ratios and diversity show convex shapes, decreasing profile and overlap between the savannah under protection curve and that of inhabited areas. The layers represent confidence interval of 95 % and the overlaps the statistical significant differences at 5 % threshold.

**Table 2**
Distribution of individuals of edible caterpillar host trees by diameter class in landscape.

| | Diameter classes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | 10–19 cm | 20–29 cm | 30–39 cm | 40–49 cm | 50–59 cm | 60–69 cm | 70–79 cm | 80 cm and above | Total |
| *Albizia gummifera* | 58 | 20 | 4 | 0 | 0 | 0 | 1 | 2 | 85 |
| *Bridelia atroviridis* | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| *Celtis mildbraedii* | 12 | 12 | 9 | 6 | 8 | 3 | 3 | 1 | 54 |
| *Coelocaryon botryoïdes* | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 3 |
| *Croton sylvaticus* | 94 | 21 | 9 | 8 | 2 | 0 | 0 | 0 | 134 |
| *Ficus mucuso* | 17 | 3 | 1 | 1 | 0 | 0 | 0 | 2 | 24 |
| *Funtumia elastica* | 28 | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 38 |
| *Hymenocardia acida* | 9 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| *Lannea welwitschii* | 47 | 20 | 7 | 8 | 2 | 0 | 0 | 0 | 84 |
| *Macaranga spinosa* | 48 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 58 |
| *Milicia excelsa* | 10 | 2 | 0 | 5 | 4 | 2 | 0 | 1 | 24 |
| *Petersianthus macrocarpus* | 6 | 4 | 4 | 5 | 1 | 0 | 0 | 0 | 20 |
| *Ricinodendron heudelotii* | 91 | 71 | 38 | 26 | 26 | 24 | 9 | 14 | 299 |
| *Spondias mombin* | 242 | 55 | 20 | 4 | 0 | 1 | 0 | 2 | 324 |
| *Terminalia superba* | 24 | 14 | 5 | 3 | 3 | 4 | 2 | 2 | 57 |
| *Total* | 691 | 247 | 100 | 67 | 46 | 34 | 15 | 24 | 1224 |

Legend. The individuals inventoried for each species are represented in eight diameter classes with a range of 10 cm. There is a significant concentration of edible caterpillar host individuals in diameter classes <40 cm and a low representation of individuals inventoried in diameter classes ≥40 cm.

and savannahs under protection is justified by the fact that in this landscape, fallows lands and savannahs are protected by populations for honey production and natural regeneration of forest species; which favours the development of pioneer species (Dejace, 2019; Djiofack et al., 2024). Studies have also shown the importance of fallow lands, and savannahs in supplying useful plants for rural populations (Nguenang et al., 2010; Dangai et al., 2020). A habitat with diversified and evenly distributed individuals within the species indicates the presence of

**Table 3**
Edible caterpillar host species from the Luki biosphere reserve region, with their habitats referenced elsewhere in the Congo Basin.

| Species | Habitat | References |
|---|---|---|
| *Albizia gummifera* | SF, PF | Lubini (1997); Lisingo et al. (2010) |
| *Bridelia atroviridis* | SF, J, PF | Lisingo et al., 2010; Looli et al. (2021); Latham (2008) |
| *Celtis mildbraedii* | PF | Lubini (1997) |
| *Coelocaryon botryoïdes* | SF | Lubini (1997) |
| *Croton sylvaticus* | SF | Lubini (1997); Looli et al. (2021) |
| *Ficus mucuso* | SF | Lubini (1997); Lisingo et al., 2010 |
| *Funtumia elastica* | SF, IH | Lubini (1997); Lisingo et al. (2010) |
| *Hymenocardia acida* | S, J | Lubini (1997); Lisingo et al. (2010); Latham (2008) |
| *Lannea welwitschii* | SF | Lubini (1997) |
| *Macaranga spinosa* | S, J | Mabossy-Mobouna et al. (2022) |
| *Milicia excelsa* | S, SF | Lubini (1997); Dzokou et al. (2022); Latham (2008) |
| *Petersianthus macrocarpus* | PF, SF, S, J, IH | Lubini (1997); Lisingo et al. (2010); Yabuda et al. (2019); Ngute et al. (2019); Latham (2008); Looli et al. (2021); Mabossy-Mobouna et al. (2022); Dzokou et al. (2022) |
| *Ricinodendron heudelotii* | S, SF, PF, J, IH | Lubini (1997); Lisingo et al. (2010); Yabuda et al. (2019); Latham (2008); Looli et al. (2021); Mabossy-Mobouna et al. (2022); Dzokou et al. (2022) |
| *Spondias mombin* | NS | Mabossy-Mobouna et al. (2022) |
| *Terminalia superba* | SF, J | Lubini (1997); Ketchatang et al. (2017) |

Legend. PF: primary forest, SF: secondary forest, S: savannah, F: fallow, IH: human inhabited area; NS: not specified.

favourable conditions for their development. However, this is not the case for habitats with imbalances in species distribution (Honvou et al., 2021). Therefore, a high specific diversity of caterpillar host species within habitats is necessary, because caterpillars typically depend on various host plants. Unevenness owing to the dominance of a single species can compromise the availability of polyphagous caterpillars. This could also explain the rarity of monophagous caterpillar species that do not have a particular plant to feed on.

### *4.3. Rarity and local threat of extinction of edible caterpillar host species in the Luki biosphere reserve landscape*

The observed results regarding the structural characteristics of diameters in this study corroborate those of Opelele et al. (2022) in LBR, where a significant number of trees with dbh $<$ 40 cm were found in areas with intensive land use and trees with dbh $\geq$ 40 cm were found in areas with low land utilisation regimes. The results of the present study are also consistent with those of Essowazina et al. (2022) in the Zio Basin, Togo, where a high proportion of young individuals with diameters in the range of 10–30 cm, and the absence of mature individuals of large diameters in groups of *Pterocarpus erina, Andasonia digitata*, and *Daniella oliveri* indicated a significant human impact on ecosystems. Dzokou et al. (2022) also demonstrated that in Cameroonian forests, the diameter structure of edible caterpillar host plants showed an irregular distribution linked to the temperaments of species evolving over time and with the age of individuals, as well as due to their poor utilisation. Many other studies have shown similar results and concluded that the presence or local threats of extinction of tree species are related to poor management and the disturbance status of habitats (Vroh et al., 2014; Piba et al., 2019; Kouassi, 2019). The fact that multiple edible caterpillar host species are dwindling or facing rarity at the landscape level, along with the presence of introduced species such as *Spondias mombin* in forests, suggests potential habitat instability linked to human activities that could lead to biodiversity loss and, thus, a decline in edible caterpillars in the LBR landscape.

## 5. Conclusion

Forest ecosystems provide goods and environmental services for rural communities in tropical regions. Edible caterpillars are among the ecosystem goods harvested from LBR landscapes. The present study assessed the diversity and availability of edible caterpillars in the LBR landscape. The results revealed that edible caterpillar host plants represented 36.8 % of the inventoried trees in the landscape and belonged to 15 main species. Furthermore, the findings also showed that fallow lands, forests, and savannahs under protection were more diverse than inhabited areas. All habitats were uneven, with human inhabited areas being the most uneven. Several species recorded a number of individuals of the caterpillar host species diameters $<$40 cm, whereas a low number were recorded with diameters $\geq$40 cm; suggesting a rarety or local threat with extinction at the landscape scale. Based on the results, the initial research hypotheses were confirmed. Therefore, this study should be refined through a comprehensive evaluation of landscape stability. This would help highlight the factors supporting the unevenness, shape of the diametric structure, and rarity which could lead to the local extinction of several host plant species and the unavailability of edible caterpillars across the LBR landscape.

## CRediT authorship contribution statement

**Ernestine Lonpi Tipi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Raoul Sambieni Kouagou:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jean-Pierre Messina Ndzomo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Papy Nsevolo Miankeba:** Writing – review & editing. **Louis Looli Boyombe:** Writing – review & editing. **Joseph Lumande Kasali:** Conceptualization. **Damase Khasa:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **François Malaisse:** Writing – review & editing, Writing – original draft, Visualization, Validation, Conceptualization. **Jan Bogaert:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

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**Appendix A. List of caterpillar plants in the Luki Biosphere Reserve landscape according to 578 respondents (Lonpi et al., 2023)**

| No | Families | Scientific names | Vernacular names Kiyombe | Answers | Frequency of citation (%) |
|---|---|---|---|---|---|
| 1 | *Fabaceae* | *Acacia auriculiformis* A.Cunn. ex Benth. | Acacia | 16 | 0,8 |
| 2 | *Rubiaceae* | *Aidia ochroleuca* (K.Schum.) E.M.A.Petit | Kolokoto ou Tsani phembe | 1 | 0,0 |
| 3 | *Fabaceae* | *Albizia gummifera* (J.F.Gmel.) C.A.Sm.* | Kasa kasa | 46 | 2,3 |
| 4 | *Apocynaceae* | *Alstonia boonei* De Wild | Tsongoti | 1 | 0,0 |
| 5 | *Anacardiaceae* | *Anacardium occidentale* L. | Diboto | 2 | 0,1 |
| 6 | *Sapotaceae* | *Autranella congolensis* (De Wild.) A.Chev. | Nkungulu | 1 | 0,0 |
| 7 | *Phyllanthaceae* | *Bridelia atroviridis* Müll.Arg.* | Kinduindui | 29 | 1,4 |
| 8 | *Phyllanthaceae* | *Bridelia ferruginea* Benth. | Muindu tseke | 15 | 0,7 |
| 9 | *Meliaceae* | *Carapa procera* DC. | Nkazu khumbi | 5 | 0,2 |
| 10 | *Cannabaceae* | *Celtis mildbraedii* Engl.* | Nemba | 138 | 7,0 |
| 11 | *Myristicaceae* | *Coelocaryon botryoïdes* Vermoesen* | Nlomba | 73 | 3,6 |
| 12 | *Malvaceae* | *Cola acuminata* (P. Beauv.) Schott & Endl. | Nkazu | 3 | 0,1 |
| 13 | *Rubiaceae* | *Crossopteryx febrifuga* (Afz. ex G. Don) Benth | Nkankati | 16 | 0,8 |
| 14 | *Euphorbiaceae* | *Croton sylvaticus* Hochst. ex Krauss* | Dibimbi | 220 | 11,0 |
| 15 | *Burseraceae* | *Dacryodes edulis* (G.Don) H.J.Lam. | Nsafu | 1 | 0,0 |
| 16 | *Moraceae* | *Ficus capensis* Thunb. | Kuya | 6 | 0,3 |
| 17 | *Moraceae* | *Ficus mucuso* Welw. ex Ficalho* | Kimbidi | 25 | 1,2 |
| 18 | *Apocynaceae* | *Funtumia elastica* (P.Preuss) Stapf* | Mupheve ou Ndimbu-Ndimbu | 21 | 1,0 |
| 19 | *Sapindaceae* | *Ganophyllum giganteum* (A.Chev.) Hauman | Kididila | 1 | 0,0 |
| 20 | *Phyllanthaceae* | *Hymenocardia acida* Tul.* | Mvete | 76 | 3,7 |
| 21 | *Anacardiaceae* | *Lannea welwitschii* (Hiern) Engl.* | Nkumbi | 53 | 2,6 |
| 22 | *Euphorbiaceae* | *Macaranga spinosa* Müll.Arg.* | Nsiasia | 88 | 4,3 |
| 23 | *Anacardiaceae* | *Mangifera indica* L. | Manga | 14 | 0,7 |
| 24 | *Euphorbiaceae* | *Maprounea africana* Müll.Arg. | Nsele nsele | 5 | 0,2 |
| 25 | *Bignoniaceae* | *Markhamia tomentosa* (Benth.) K. Schum. ex Engl. | Ndawa | 2 | 0,1 |
| 26 | *Moraceae* | *Milicia excelsa* (Welw.) C.C. Berg.* | Mkambala | 24 | 1,2 |
| 27 | *Fabaceae* | *Millettia versicolor* Welw. ex Baker. | Lubota | 3 | 0,1 |
| 28 | *Urticaceae* | *Musanga cecropioïdes* R. Br. | Nsenga | 9 | 0,4 |
| 29 | *Rubiaceae* | *Nauclea latifolia* Sm. | Tumbi lolo | 7 | 0,3 |
| 30 | *Euphorbiaceae* | *Neoboutonia africana* Müll.Arg. | Longamaza | 2 | 0,1 |
| 31 | *Fabaceae* | *Pentaclethra macrophylla* (P.Beauv.) Liben | Mvaza | 2 | 0,2 |
| 32 | *Lecythidaceae* | *Petersianthus macrocarpus* (P.Beauv.) Liben* | Minzu | 241 | 12,0 |
| 33 | *Fabaceae* | *Piptadeniastrum africanum* (Hook.f.) Brenan | Nsinga | 2 | 0,1 |
| 34 | *Fabaceae* | *Prioria balsamifera* (Vermoesen) Breteler | Tola | 3 | 0,1 |
| 35 | *Anacardiaceae* | *Pseudospondias microcarpa* (A. Rich.) Engl. | Nzuza | 9 | 0,4 |
| 36 | *Hypericaceae* | *Psorospermum febrifugum* Spach | Mvala | 3 | 0,1 |
| 37 | *Fabaceae* | *Pterocarpus tinctorius* Welw. | Nkula | 2 | 0,1 |
| 38 | *Euphorbiaceae* | *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel* | Nsanga nsanga | 452 | 22,0 |
| 39 | *Anacardiaceae* | *Spondias mombin* L.* | Mingiengie | 349 | 17,0 |
| 40 | *Myristicaceae* | *Staudtia kamerunensis* Warb. | Nsunzu Menga | 1 | 0,0 |
| 41 | *Malvaceae* | *Sterculia tragacantha* Lindl. | Nkole-Nkole | 3 | 0,1 |
| 42 | *Combretaceae* | *Terminalia superba* Engl. & Diels.* | Limba | 45 | 2,2 |
| 43 | *Cannabaceae* | *Trema orientalis* (L.) Blume | Nsengi nsengi | 13 | 0,6 |
| 44 | *Moraceae* | *Trilepisium madagascariensis* DC. | Nsekenia | 1 | 0,0 |
| 45 | *Phyllanthaceae* | *Uapaca guineensis* Müll.Arg. | Nsanvi | 2 | 0,1 |
| 46 | *Rutaceae* | *Zanthoxylum gilletii* (De Wild.) P.G.Waterman. | Nungu tsende | 1 | 0,0 |
| | Total | | | 2.032 | 100 |

Legend. *: Species included in the study. Some plants may have been identified as caterpillar trees in the ethnobotanical survey, yet they are not necessarily food sources for caterpillars. This explains why some species were mentioned only once and others 2 or 3 times (Lonpi et al., 2023). Fifteen species have a citation frequency equal to or greater than 1 %.

## Appendix B. Typical habitats of the 15 caterpillar host plants

| Forest | | | | Savannah | | Fallows / Inhabited Area |
|---|---|---|---|---|---|---|
| Primary Forest | | | | Bush Savannah | Grass Savannah | |
| Forest with *Gilletiodend-ron kisantuense* | Forest with *Gossweilero-dendron basalmi-ferum* and *Hylodendron gabunense* | Forest with *Ganophyl-lum giganteum* and *Staudtia stipitata* | Forest with *Corynan-the paniculata* and *Xylopia welwerthii* | | | |
| *Celtis mildbraedii* | *Funtumia elastica* | *Celtis mildbraedii* | *Celtis mildbraedii* | *Hymenocardia acida* | Species of forest pathways and ruderal species adventitious to crops | *Terminalia superba* |
| *Ricinodendron heudelotii* | *Ricinodendron heudelotii* | *Pertersian-thus macrocarpus* | *Pertersian-thus macrocar-pus* | *Macaranga spinosa* | | *Macaranga spinosa* |
| | *Lannea welwitschii* | *Funtumia elastica* | *Funtumia elastica* | | | |
| | | *Coelocaryon botryoïdes* | *Coelocaryon botryoïdes* | | | |
| | | *Lannea welwitschii* | *Lannea welwitschii* | | | |
| Secondary Forests | | | | | | |
| Secondary forest with*Terminalia superba* | | Secondary forest with *Xylopia aethiopica* | | | | |
| *Terminalia superba* | | *Funtumia elastica* | | | | |
| *Ricinodendron heudelotii* | | *Milicia excelsa* | | | | |

(*continued on next page*)

(*continued*)

| Forest | | Savannah | | Fallows / Inhabited Area |
|---|---|---|---|---|
| Primary Forest | | Bush Savannah | Grass Savannah | |
| *Milicia excelsa* | *Terminalia superba* | | | |
| *Funtumia elastica* | *Bridelia atroviridis* | | | |
| *Petersianthus macrocarpus* | *Lannea welwitschii* | | | |
| *Lannea welwitschii* | *Croton sylvaticus* | | | |
| *Albizia gummifera* | *Ficus mucuso* | | | |
| *Macaranga spinosa* | *Ricinodendron heudelotii* | | | |

Legend. The table is established based on the study by Lubini (1997). Apart from *Hymenocardia acida, Macaranga spinosa* and *Terminalia superba*, no other caterpillar host species were listed in savannahs and fallows/inhabited area.

## Data availability

Data will be made available on request.

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