Floristic and structural dynamics analysis of the Gallery Forest and perspectives on forest conservation and restoration in the Sangaredi bauxite area, a semi-arid dry lowland in the northwest of the Republic of Guinea

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ABSTRACT

The Sangaredi area is located in the Boké Region, in the northwest of the Republic of Guinea in West Africa. It belongs to the Guinea-Congolese-Sudanese regional transition zone, which corresponds to the semi-arid zone of sub-forest savannah with galleries. The study area is precisely located within the mining concession of the Compagnie des Bauxites de Guinée (CBG). The local vegetation dynamics are primarily influenced by two parameters. First, the local bioclimatic conditions of the Sangaredi region, which is part of the Guinea lowland natural region, and then by human activities such as slash-and-burn shifting agriculture, and by bauxite mining activities. Based on the topography and utilizing White’s vegetation classification (1986), these studies focused on a specific vegetal community that remains relatively distinct along the lowlands and watercourses, known as the Gallery Forest. This type of forest reaches a minimum height of 10 meters, with interpenetrating canopies.

In the present study, we assessed the structure of the Gallery Forest based on the method outlined by Rabenantoandro and colleagues in 2007. This assessment involved analyzing the spatial distribution of all individuals within 0.1 ha plots, both vertically and horizontally. The aim was to establish a reference ecosystem for conservation purposes and to guide habitat restoration activities and their evaluation. The taxonomic analysis divides the 930 collected specimens into 209 species, 160 genera, and 64 families. The most represented families in terms of species are: Fabaceae, Rubiaceae, Euphorbiaceae, and Moraceae. Integrated analyses of floristic diversity, vertical and horizontal structure, as well as observations of the ecological integrity through the presence or absence of an umbrella species Pan troglodytes verus (West African Chimpanzee) at the level of each plot allowed us to define five stages of structural dynamics of the Gallery Forests: Stage 1 structural dynamics or almost Intact; Stage 2 structural dynamics or slightly degraded; Stage 3 structural dynamics or moderately degraded; Stage 4 structural dynamics or degraded; Stage 5 structural dynamics or very degraded. The results of this study aim to contribute first to a better understanding of the dynamics of the remnant of gallery forest at the local scale and then to support the development of scientifically-based habitat conservation and restoration efforts.

Keywords: Gallery forest, habitat, flora, structural analysis, chimpanzees, conservation and restoration.

INTRODUCTION

The vegetation of Guinea belongs to the floristic region known as the "Regional Center of Guinea-Congolese endemism." In particular, the Sangaredi study area belongs to the Guinea-Congolese-Sudanese regional transition zone, which corresponds to the semi-arid zone of sub-forest savannah with galleries (Chevalier, 1938). In order to avoid
The local vegetation dynamics are influenced by two main parameters. First, the local bioclimatic conditions in the Sangaredi region are influenced by the Guinean lowland natural region (National Monograph, 1997), and further impacted by human activities such as slash-and-burn agriculture, as well as bauxite mining activities (TBC, 2021). This study involves conducting detailed observations on the dynamics of the remnant of gallery forest along the river banks and valleys situated between two relief features. Apart from that, due to the presence of critically endangered umbrella species (Breckheimer et al., 2014), the gallery forest of the Sangaredi area has been described as being a critical habitat based on the IUCN red list (2023). As well, this type of vegetation is often of socio-economic and cultural importance, and most of the villages in the Sangaredi area are situated near a gallery forest (EEM, 2014).

The results of this study aim to contribute first to a better understanding of the dynamics of the gallery forest at the local scale and then to support the development of scientifically-based habitat conservation and restoration efforts.

Studies area description

The Sangaredi area is located in the Boké Region, in the northwest of the Republic of Guinea in West Africa. Facing the Atlantic Ocean, this country covers an area of 245,857 km sq. with 300 km of coastline. The studies were conducted at the landscape level of the Compagnie des Bauxites de Guinée (CBG) south Cogon mining concession in Sangaredi (Figure 1).

As described by the National Monograph (1997), Guinea is divided into four natural regions and experiences a two-season tropical climate, with variations in length from one region to another. The rainy season varies from less than 3 months in the north to more than 9 months in the southeast. The annual precipitation varies from 4000 mm (coastal region) to 1300 mm (Upper Guinea) with peaks occurring in July and August. The Sangaredi area belongs to the lowland coastal eco-region of Guinea and is characterized by a tropical and humid climate with two distinct seasons:

- The dry season (mid-November to May), which is characterized by hot and dry winds (the Harmattan) which blow from the East and North-East, carrying hot air and dust from the Sahara Desert to the Gulf from Guinea
- The rainy season (May to the end of October), which brings heavy monsoon rains, high humidity and southwest winds. Rainfall is heaviest in southern Guinea, decreasing towards the northern coastal areas and the eastern interior.

The most recent and detailed publication on the geology of Guinea was authored by Mamedov (2010). However, we can provide the simplest description using Knight-Piésold and Co (2008) in EEM (2014), which subdivides the geology of Guinea into two major structures:

- Bedrock, consisting of Paleozoic sedimentary rocks, faulted and intersected by Mesozoic era diabase dolerite sills and dikes and,
- Superficial alluvial formations, made up of geologically recent deposits dating from the Tertiary era (Miocene) and the Quaternary era (Pleistocene), which contain deposits of bauxite ore, clay and lateritic crusts.

The main topographical features of Sangaredi are its high plateaus, or "bowals", deeply divided by numerous river valleys forming a dense hydro network that tends slightly to the northeast, towards the Atlantic Ocean (EEM, 2014). At their highest point, the Sangaredi plateaus rise between 220 and 240 m above sea level, while in the foothills, their height varies between 150 and 160 m. Although their summits have been flattened by erosion, their slopes are steep, with an incline of more than 8-10% (BERCA-Baara/Berd, 2003).

The term "topography" and its impact on the soil and the vegetation it supports were emphasized by Trapnel (1943). He used terms related to topography, such as "Plateau," "Upper Valley," and "Lake Basin," to describe the main soil groups in Zambia (White, 1986). Also, various authors (Richard, 1952; Hallé et al., 1978; White, 1986) describe vegetation based on its physiognomy, architecture, and structure.

Delorme (1998) states that the vegetation in the lowland maritime Guinea consists mainly of mesophilic and submesophilic forests. These forests are highly sensitive to fire and easily cleared, leading to secondary bush growth. Further inland, savannah emerges, dotted with a few large trees such as Parinari excelsa and Parkia biglobosa. Today, only islets, galleries, and a few relics of that vegetation remain.

METHODOLOGY

Gallery Forest description

In the absence of recent studies on West African vegetation description, this study is based on the African vegetation
Figure 1: Sangaredi studies area location.

types as described by White (1986). Therefore, the vegetation of the Sangaredi zone closely corresponds to Chevalier’s "subforestal savannah (1938) zone with galleries."

Nevertheless, White’s vegetation classification is currently challenging to implement on the ground due to the degradation of most wooded grassland vegetation. Much of the area has transformed into secondary shrub land and thicket as a result of clearance for farming or fallow (Couch and Lopez, 2014) and bauxite mining.

Different authors, particularly Chevalier (1938), Meave et al. (1994), Delorme (1998), and FAO (2020), define gallery forest as a type of forest that grows along streams. It is generally narrow and true in width, reaching up to 300m. From this definition, we can say that a Gallery Forest is a type of edapho-climatic homogeneous vegetation unit.

Based on the topography and White’s vegetation classification, our studies focus on observing a distinct vegetal community that runs along the lowlands and watercourses, reaching heights of over 10 m in height, with interpenetrating canopies.

Apart from that, due to the presence of the critically endangered umbrella species, the West African chimpanzee (Pan troglodytes verus), and other restricted range and threatened reptiles and amphibian species such as the critically endangered Phrynobatrachus pintoi and Hemidactylus kundaensis, the gallery forest in the Sangaredi areas has been described as a critical habitat. By adhering to Performance Standard 6 of the IFC (2012), mining operations avoid impacting gallery forests (TBC, 2021).

From all that is said above, these studies are specifically applicable to the Gallery Forest and not to the surrounding vegetation types as described by White (1986).

**Sampling methods**

By using the methodology applied in the remnant coastal forests of Madagascar (Rabenantoandro et al., 2007), thirty-two flora monitoring plots were distributed along the remnants of the gallery forest from three perspectives:

- All existing permanent 0.1 ha Plots that have been installed by The Missouri Botanical Garden within gallery forest (Philipson et al., 2020).
- The cartography of the limit of gallery forest and buffer zone (EEM, 2016).
- Knowledge of gallery forest by the local botanist.
Figure 2: Plot sampling unit of 0.1 ha quadrat.

Plot samples

Based on the method outlined in Rabenantoandro et al. (2007), which involves direct observation of canopy structure, each plot consists of a 0.1 ha quadrat measuring 20 m × 50 m (Figure 2), as employed by Châtelain et al. (1996) and Fuller et al. (1998). One of the advantages of using this method in a Gallery Forest is that vegetation structure and density can be easily observed over distances of 20 m.

Each study plot was located using a GPS unit, and its orientation was recorded with a compass. The plots were then marked out using string, a tape measure, and surveys were conducted using a meter, graduated stick, and laser meter.

In tropical forest ecosystems, trees with a diameter at breast height (DBH) of at least 10 cm are generally considered to be of reproductive age, whereas smaller individuals of woody species are regarded as juveniles (Gentry, 1993).

Floristic surveys

According to Lisowski (2013), the flora of Guinea comprises 2,923 species of flowering plants (Angiosperms), including both spontaneous and introduced, belonging to 1251 genera and 169 families. No spontaneous gymnosperm is represented in the Guinean flora.

Floristic analysis

Preliminary identification of plant specimens is done in the field, and then the specimens are sent to the Herbarium of Conakry. Duplicates are forwarded to major research institutions with specialists working on the flora of Guinea, including the Missouri Botanical Garden in Saint Louis (USA), the Muséum National d'Histoire Naturelle in Paris (France), and the Royal Botanic Gardens at Kew (UK).

The in-situ species identification and status assessment have primarily been conducted using the Lisowski book (2013) and the Missouri Botanical Garden’s TROPICOS database (http://mobot.mobot.org/W3T/Search/vast.html). Only material whose species have been positively identified was used for the floristic analyses presented here.

Shannon diversity index

The relative frequency (FR) of the measured woody plant species, with DBH ≥ 10cm, was determined using the following mathematical formula:

\[
FR (%) = \frac{Ni}{N} \times 100
\]

The floristic diversity essential for characterizing the
habitat studied was measured by the Shannon index (H'). The value of the Shannon diversity index typically ranges between 0 and 4.5, and rarely exceeds this range (Frontier and Pichod-vale, 1998; Margalef, 1972; Magurran, 1988). The mathematical expression of the Shannon index is as follows:

\[ H' = - \sum_{i=1}^{s} \left( \frac{N_i}{N} \log \frac{N_i}{N} \right) \]

Ni: represents the number of individuals of the species i. N: is the number of individuals of all species combined.

The large groups of vegetation encountered around the watercourses studied with their progressive or regressive phases were identified using White's classification of different plant formations (1983). The higher the value of H', the higher the diversity of species in a particular community. The lower the value of H', the lower the diversity. A value of H = 0 indicates a community that only has one species.

The Shannon Equitability Index is a way to measure the evenness of species in a community. The term "evenness" simply refers to how similar the abundances of different species are in the community.

**Structural surveys**

The physiognomy of a vegetation type is the sum of its structural components (Gounot, 1969). In the Sangaredi area, various aspects of the structure of the Gallery Forest have been analyzed by several authors using different sampling techniques such as transects (Couch and Lopez, 2014) and plots (Philipson and Lowry, 2020).

In the present study, we evaluated the structure of the Gallery Forest by considering the overall spatial distribution of all individuals within 0.1 ha plots, both vertically and horizontally (that is, in all three dimensions) in order to establish a reference ecosystem for conservation value and for evaluating habitat restoration activities (Aronson et al., 1995, 2002). There is considerable debate over the appropriate methods required to obtain a representative sample of the structure and organization of tropical forest ecosystems (Emberger and Godron, 1968; Gounot, 1969; White, 1983; Dajoz, 1985; Châtelain et al., 1996; Fuller et al., 1998). For the purpose of the present studies, objective sampling would be feasible because full-time local permanent botanists on the ground have a thorough understanding of the landscape dynamics. Therefore, by applying the methodology of Rabenantoandro et al. (2007), field data were compiled and analyzed using Excel spreadsheet ®.

**Vertical structure**

A 50 m transect (Y axis) was established in the middle of every plot. At 2-meter intervals, a measuring pole (X-axis) was held vertically, and each point of contact of the X-axis with the vegetation was recorded (Figure 3). This simplified version of the Châtelain et al. (1998) method, adapted by Rabenantoandro et al. (2007), enables the visual establishment of a vegetation profile, including openings in the canopy and the recognition of different vegetation layers (Gautier et al., 1994).

A diagram of the vertical structure can then be used to estimate the percentage of vegetation cover in the canopy or in a given layer below the canopy (Gounot, 1969). By plotting height classes along the vertical X axis and distance along the transect using the horizontal Y axis, each point of contact with the vegetation is recorded by filling in the corresponding cell in the diagram (Figure 3).

Using an Excel spreadsheet and the following formula, the average height of the canopy (HcA), in meter, is calculated by dividing the maximum values of the canopy height at each plot (HcO) by the total number of observation points (No).

\[ HcA (m) = \frac{HcO}{No} \times 100 \]

**Figure 4** shows the distribution of trees with DBH ≥ 10 cm, within the vertical sampling plot, to enable visualization of the relationship between species density and vertical structure.

**Canopy height and DBH**

Within each 0.1 ha plot, all trees with a DBH ≥ 10 cm had their height estimated, DBH measured along the 50 m Y axis, and a preliminary scientific name was allocated. For species whose identity could not be determined with certainty in the field, a voucher specimen was prepared if fertile material (that is, with flowers and/or fruits). Otherwise, the tree was marked for later collection of a fertile voucher. The average height and DBH values calculated for all individuals of each identified tree species within plots were used in the analyses.

**RESULTS AND INTERPRETATION**

**Flora diversity**

The taxonomic analysis divides the 930 collected specimens into 209 species, 160 genera and 64 families. The most
represented families in terms of species are shown in Table 1. The general floristic list is presented in Appendix II.

The relative frequency analysis of woody species at DBH ≥ 5 cm of the studied plots shows that *Elaeis guineensis* (FR% = 24.94%) is the most common species. It is a spontaneous heliophilous species characteristic of a secondary formation. It is followed by *Cola nitida* (FR% = 7.67%), *Pterocarpus santalinoides* (FR% = 5.87%), *Santiria trimera* (FR% = 4.91%), and *Anthostema senegalense* (FR% = 3.95%).

The Shannon diversity index varies between 0.56 and 2.64 for the 32 plots studied (Figure 5). Seven plots are the most diverse with an index between 2 and 2.99, twenty-one have an index between 1 and 1.99, and three plots are the least diverse with an index between 0 and 0.99. The highest values were recorded in plots BAL 21 (H' = 2.64), PARG 06 (H' = 2.56) and HAM 32 (H' = 2.40). The lowest values were recorded respectively in plots BOU 01 (H' = 0.56), KAG 10 (H' = 0.84) and SIT 31 (H' = 0.86). The floristic list is presented in the appendix.

### Structuraldynamic

An analysis of the distribution of plots using an ascending hierarchical classification (AHC) of XLSTAT, based on
different canopy height classes, made it possible to highlight the similarities and dissimilarities between them. Also to better appreciate the relief of the proximity tree of these plots according to their distances on two and three factorial planes (Figure 6) at a truncation of 25 using the “Complete Link” aggregation method. This dendrogram reveals three “Clusters” from the right of the Figure y-axis to the left:

- Cluster C₁ (Left)
- Cluster C₂ (Right)
- Cluster C₃ (Middle)

The dendrogram clearly demonstrates the grouping of plots by similarities and dissimilarities into 3 clusters (Cn) and 6 subclusters (CnSn). Table 2 shows the distribution of plots by cluster and sub-cluster.

By using mixed Excel Figures, the superposition of the Shannon diversity index (H’) with the hierarchical ascending classification (HAC) analysis of the various height classes enabled the clear visualization of a positive correlation between the floristic diversity of each plot and the three height class clusters Cₙ(Figure7).

**The stages of structural dynamics of the Gallery Forest**

Integrated analyses of floristic diversity, vertical and horizontal structure, as well as observations of the ecological integrity, by observing the presence or absence of the umbrella species, the *Pan troglodytes verus* or West African Chimpanzees, at the level of each plot, allowed us to define 5 stages of structural dynamics of the Gallery Forest (Table 3).

**Structural dynamics Stage 1 or almost Intact**

These are almost intact forests that have never experienced
Figure 6: Dendrogram of distribution of plots by hierarchical ascending classification of height class (HAC).

Table 2: Distribution of plots by cluster ($C_n$) and sub-cluster ($C_{nS}$).

<table>
<thead>
<tr>
<th>Plots</th>
<th>$C_1S_1$</th>
<th>$C_2S_1$</th>
<th>$C_3S_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAL 21</td>
<td>DAN 20</td>
<td>MADL 25</td>
<td></td>
</tr>
<tr>
<td>DIA 17</td>
<td>DIAM 18</td>
<td>SIT 31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FET 28</td>
<td>PARG 08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MADL 24</td>
<td>FET 29</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PARG 07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HAM 32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIT 30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$C_1S_2$</th>
<th>$C_2S_2$</th>
<th>$C_3S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KALP 16</td>
<td>GAIK 22</td>
<td>BOU 03</td>
</tr>
<tr>
<td>GAIK 23</td>
<td>KOU 26</td>
<td>FAS 13</td>
</tr>
<tr>
<td>GUE 11</td>
<td>KOU 27</td>
<td>FAS 12</td>
</tr>
<tr>
<td>KAL 14</td>
<td>LAF 19</td>
<td>KAG 10</td>
</tr>
<tr>
<td>KALP 15</td>
<td></td>
<td>BOU 02</td>
</tr>
<tr>
<td>PAR 04</td>
<td></td>
<td>PARG 06</td>
</tr>
<tr>
<td>PAR 05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$C_2S_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOU 01</td>
</tr>
<tr>
<td>PARG 09</td>
</tr>
</tbody>
</table>
Figure 7: Correlation between Shannon index ($H'$) and canopy height class cluster HAC (Cluster $C_1=3$; Cluster $C_2=2$; Cluster $C_3=1$).

Table 3: Description of the 5 stages of Gallery Forest dynamics.

<table>
<thead>
<tr>
<th>Structural dynamics stage/ Description</th>
<th>Ecological atmosphere</th>
<th>Plots (Clusters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 (Almost Intact) Very rare in the study area. Continuous canopy reaches 30 m high. $H' \geq 2.6$. No or very little trace of human activity.</td>
<td>Nests and traces of chimpanzee use always present. No need for ecological restoration</td>
<td>BAL 21</td>
</tr>
<tr>
<td>Stage 2 (Slightly degraded) Continuous canopy between 10 m and 20 m high. $1.7 \leq H' \leq 2.5$. Very little human activity (Example: selective tree removal).</td>
<td>Nests and traces of passage of chimpanzees often present. No need for ecological restoration</td>
<td>DIA 17; KALP 16; GAIK 23; KAL 14*; GUE 11; KALP 15; PAR 04; HAM 32;</td>
</tr>
<tr>
<td>Stage 3 (Moderately Degraded) Non-continuous canopy between 10 m and 15 m high. $H' \leq 1.8$. Human activities have affected part of its diversity and structure.</td>
<td>Rare nests and traces of Chimpanzees. Often on <em>Elaeis guineensis</em>. Requires reduction of anthropogenic pressures and passive ecological restoration</td>
<td>BOU03; FAS13; FAS 12; BOU 02; PARG 06*; GAIK 22; FET 28; DAN 20; MADL 24*; MADL 25*</td>
</tr>
<tr>
<td>Stage 4 (Degraded) Non-continuous canopy less than 10 m high. $H' \leq 1.7$. Habitat that has lost the continuity of its forest structure.</td>
<td>No Chimpanzee nests. Requires reduction of anthropogenic pressures and active ecological restoration</td>
<td>SIT 31; PARG 08; FET 29; PARG 07; DIAM 18; KOU 26; KOU 27; MADL 25; PAR 05</td>
</tr>
<tr>
<td>Stage 5 (Very degraded) Habitat whose entire segments of its forest structure have disappeared due to human action. $H' \leq 1.6$</td>
<td>No Chimpanzee nests. Requires active ecological restoration</td>
<td>BOU 01; PARG 09; LAF 19; FAS 13; SIT 30; KAG 10*</td>
</tr>
</tbody>
</table>
significant human activities that could destroy or disrupt their natural structure. These areas serve as refuge sites for the main species of wildlife, such as felines and large primates. Particularly, the West African chimpanzees set up their nests there. The Forest Gallery in stage 1 is very rare in the study area and is often found on very steep sites. The emergent canopy can reach more than 30 m in height, with a canopy closure of 80 to 95%, and some openings or windthrows. In terms of conservation and ecological restoration, the reference structure should have a Shannon diversity index $H' \geq 2.6$ and should include species characteristic of low-altitude tropical forests, such as *Parkia bicolor*. In this category, we can include the plot of cluster C$_{3}$, BAL 21, located towards Lougal forest, which features a significant presence of tree individuals with the DBH class between 40 and 50 cm.

**Structural dynamics stage 2 or slightly degraded**

Slightly degraded at their edges by shifting agriculture, moderate logging and bush fires. We note the presence of some windthrows leaving openings in certain places in the emerging canopies. These openings encouraged the growth of *Olyra latifolia* (dense forest grasses) in the undergrowth. Emergent canopies are composed of trees ≥ 20 m in height with canopy covers that vary in the range of 50 to 80%. The Shannon diversity index ($H'$) is between 1.7 and 2.5 and the species are mainly dominated by species characteristic of primary forests such as *Elaeis guineensis*, *Erythrophleum suaveolens*, *Pterocarpus santalinoides*, *Anthostema senegalense*, *Hallea stipulosa*, *Elaeis Guineans*, *Ricinodendron heudelotii*, *Parkia bicolor*, *Samanea dinklagei*, *Carapa procera*, *Santiria tricera*, *Uapaca heudelotii*, *Pentadesma butyracea*, *Lecaniodiscus cupanioides* and *Cola reticulata*.

The Stage 2 structure is still well frequented by chimpanzees and does not yet require active ecological restoration with a good presence of trees with the DBH class between 40 cm and 50 cm. The corresponding plots are mainly of C$_{3}$ and C$_{3}$ sub-clusters, namely DIA 17; KALP 16; GAIK 23; KAL 14*; GUE 11; KALP 15; PAR 04 and HAM 32.

**Structural dynamics stage 3 moderately degraded**

Stage 3 corresponds to the Gallery Forest with fairly advanced degradation. It results from the degradation of stages 1 and 2 following shifting agriculture, bush fires and repeated logging. This stage is characterized by the presence of a more or less high density of woody species whose height is between 5 m to 10 m high. The canopy is discontinuous with a low density of trees at height ≥ 20 m and with a dominance of individuals whose DBH≥10 cm.

The concerned plots are essentially from the C$_{3}$ sub-cluster of the dendrogram, namely BOU 03; FAS 13; FAS 12; BOU 02; PARG 06*; GAIK 22; FET 28; DAN 20; MADL 24*; MADL 25* and have emergent canopy coverage that varies from 40 to 60%. The canopy is mainly composed of *Elaeis guineensis*, *Erythrophleum suaveolens*, *Anthostema senegalense*, *Lecaniodiscus cupanioides*, *Dialium guineense*, *Myrianthus serratus*, *Hallea stipulosa* and *Afzelia african*. At this stage, the dominance of *Elaeis guineensis*, a heliophilous and scarring species, is well marked. As for the undergrowth, it is dominated by *Aframumum sp.*, *Chromolaena odorata* and a few woody regeneration of species from the emerging canopy. The Shannon diversity index $H' \leq 1.8$. Chimpanzee nests are quite rare at this point. However, traces of warthogs digging for tubers, bulbs and rhizomes have been identified in some places. By stopping the intensity of anthropogenic pressures, stage 3 Forest Galleries can still be easily restored by natural regeneration. This is so-called passive ecological restoration. Fallows on Gallery Forest for more than 5 years can be classified in this category.

**Structural dynamics stage 4 or degraded**

Degradation of the Forest Gallery is very extensive following itinerant agriculture, bush fires and logging. The concerned plots are essentially those of the C$_{3}$, C$_{3}$ and C$_{3}$ sub-clusters, namely, SIT 31; PARG 08; FET 29; PARG 07; DIAM 18; KOU 26; KOU 27; MADL 25 and PAR 05. SIT 31 is a cashew plantation. The characteristic species of this stage are essentially: *Anacardium occidentale*, *Landolphia heudelotii*, *Morinda geminata*, *Harungana madagascariensis*, *Sarcocephalus exculentus*, *Chromolaena odorata*, *Mezoneuron bentamianum*, *Milletta lucens*, *Dialium guineense*, *Anthostema senegalense*, *Anisophyllae aurina*, *Hymenocardia sp.* and *Sida alata*.

From a structural point of view, we can say that stage 4 is a degraded form of stage 3. The distribution of biomass is discontinuous and mainly composed of undergrowth species whose heights vary from 1 to 3 m. These undergrowth species are dotted in places with trees ≥ 10 m high and ≥ 10 cm DBH. The Shannon diversity index $H' \leq 1.7$.

No chimpanzee nests have been identified in stage 4 habitats. Given their extensive level of degradation, ecological restoration can only be possible with the addition of topsoil and then erosion control (active restoration). Fallows on forest galleries less than 5 years old can be classified in this category.

**Structural dynamics stage 5 or very degraded**

After years of shifting agriculture, this is the final stage of degradation of La Gallérie Forestière before its transformation into meadow and bare soil. There is total
absence of trees whose height $\geq 5$ cm and DBH $\geq 10$ cm.

With a Shannon diversity index $H' \leq 1.6$, the characteristic species at this stage are those of degraded formations such as *Elaeis guineensis*, *Sarcocephalus esculentus*, *Anthostema senegalens* and *Harungana madagascariensis*.

No chimpanzee nests were seen at the plots which are mainly of the sub-clusters $C_2S_2$, $C_2S_3$, $C_3S_1$ and $C_3S_2$ including BOU 01; PARG 09; LAF 19; FAS 13; SIT 30; KAG 10*. Ecological restoration is only possible through total rehabilitation of the soil and vegetation. Figure 8 shows summarily of the profiles of the 5 different structural dynamics stages of the Forest Gallery.
Conclusion

The vegetation dynamics in the Sangaredi locality are influenced by two main parameters. First, the local bioclimatic conditions in the Sangaredi region are influenced by the Guinean lowland natural region (National Monograph, 1997), and further impacted by human activities such as itinerant slash-and-burn agriculture and bauxite mining activities (The Biodiversity Consultancy, 2020).

This study enabled us to emphasize the importance of integrated analysis involving floristic diversity, vertical and horizontal structure, and observations of the general ecological integrity. By considering the presence or absence of the umbrella species, the Pan troglodytes verus or West African Chimpanzees, at the level of each plot, we were able to define 5 stages of structural dynamics of the Forest Galleries:

- **Structural dynamics stage 1 or almost intact:** These are almost intact forests that have never experienced human activities that could destroy or disrupt their natural structure.

- **Structural dynamics stage 2 or slightly degraded:** The edges are slightly degraded due to shifting agriculture, moderate logging, and bush fires.

- **Structural dynamics stage 3 or moderately degraded:** Corresponding to the Forest Galleries with fairly advanced degradation. It results from the degradation of stages 1 and 2.

- **Structural dynamics stage 4 or degraded:** At this stage, the degradation of the Forest Gallery is very extensive due to itinerant agriculture, bushfires, and logging.

- **Structural dynamics stage 5 or very degraded:** After years of shifting agriculture, this is the final stage of degradation of the Gallery Forest before its transformation into meadow and bare soil.

The results of this study could be used in various fields, including agriculture, forest conservation and restoration, as well as in the development of ecosystem health indicators and habitat quality assessments, such as the Queensland Quality Hectare method (State of Queensland, 2020) and the Habitat Integrity Index (Kleynhans, 1996).

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