Conservation of voluntary nature reserves: physical characterization of flora of the biodiversity zones of the Zuénoula sugar complex (Central West, Côte d'Ivoire)

ABSTRACT

Background: In Côte d'Ivoire, the forest cover represents barely 20% of the total. Within the framework of the protection of natural ecosystems, the creation of voluntary nature reserves is encouraged. This is the case of the Zuénoula agro-sugar complex, which, taking into account sustainable management, standards and certifications, has set up biodiversity conservation reserves. Unfortunately, due to peasant pressure linked mainly to subsistence agriculture, the management and conservation of these ecological sites poses enormous environmental problems, notably water pollution and soil degradation. This puts in danger, on the one hand, the survival of animal and plant species and, on the other hand, the delimitation of biodiversity areas in rural areas with agro-industrial vocation.
Objective: To protect and to conserve biodiversity zones of the Zuénoula sugar complex for abundant and sustainable sugar production in Côte d'Ivoire.
Methods: A study of the perimeter boundaries and floristic structure of conservation areas was conducted in vegetation formations consisting of gallery forests, riparian forests and forest islands. The perimeter boundaries were determined by mapping the ecological sites with a GPS. The floristic list was established from surface and itinerant survey methods.
Results: The three ecological sites were delimited and mapped on an area of 139.55 ha. The flora, mostly from the Guinean-Congolese region, was rich in 106 species and dominated by Mesophanerophytes. It belonged mainly to the Caesalpiniaceae, Moraceae and Sterculiaceae families. The gallery forests FG3 and FG5 were the most stable. In addition, all environments were diverse and indicated a uniform distribution of species. Six vulnerable species including *Afzeliaafricana* and *Mallotusoppositus*, two Red List species including *Miliciaexcelsa* and *Triplochitonscleroxylon* and 41 species of Least Concern including *Albiziaadianthifolia* and *Lanneanigritana* were identified.
Conclusion: The ecological reserves of Zuénoula are rich and diversified in plant species. Their implementation allows for the reduction of industrial pollution.

Keywords: Côte d'Ivoire, sugar complex, biodiversity conservation, gallery forests, forest island, riparian forest.

1. INTRODUCTION

Tropical forests play a crucial role in the major climatic balances and constitute the largest reservoir of biodiversity on the planet [1]. They provide many essential services to humans such as quality water, food and climate regulation. Across sub-Saharan Africa, natural resources continue to be central to the livelihoods of rural people. Local norms and customs influence the daily forms of resourcesuse by populations [2].

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Currently, the Ivorian forest cover represents less than 20% of its original extent [3]. Ecosystems and habitats are protected by several legal and institutional instruments. However, if the protection of ecosystems and habitats may seem easy in protected areas, it nevertheless remains difficult in rural areas where land tenure security is not mastered [4]. Indeed, many problems still remain in rural areas, especially related to customary rights on forest land and to the shortcomings and inconsistencies of land laws, which accentuates the conversion into agricultural areas [5]. This practice endangers the survival of several animal and plant species in our different regions. Indeed, since the beginning of the 20th century, the natural ecosystems which contain a great specific diversity have beenradically degraded the effect of anthropogenic disturbances such as deforestation, agriculture, urbanization and galloping demography [6].

In order to safeguard the still existing relics, Côte d'Ivoire has implemented a new approach to conservation, including incentives for the creation of voluntary nature reserves [7]. These reserves have many advantages: water purification, soil protection, mitigation of natural disasters, well-being, improved income through leisure and tourism, etc. [8].

Thus, within the framework of sustainable management and taking into account the standards and certifications in force;the sugar complex of Zuénoula(Côte d'Ivoire) has adopted a biodiversity conservation approach. It is based on the management of ecosystems through the protection of forest strips of forest and the reforestation of certain endangered species. In addition, it also has in its specifications a socialaimed at leaving certain portions of land to the local population for other crops [7]. Unfortunately, these ecological sites reserved for the conservation of biodiversity are infiltrated by the local population. Indeed, everywhere else where it ispracticed, sugarcane cultivation has many advantages in terms of multifunctionality within the framework of rural development: job creation, income and provision of services to other agricultural productions. Thus, in the regions where sugar industries are located, many populations flock [9]. These populations exert a strong pressure on the flora and fauna, including those in biodiversity conservation areas.

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In order to assess the effect of this anthropogenic pressure on the forest relics preserved by the SucrivoireCompany and thus update knowledge on the biodiversity of these ecological sites, thesestudy was initiated. The general objective is to analyze the forest fragments of the integrated agricultural unit of the Zuénoula sugar complex in order to develop an action and management plan aimed at protecting and sustainably conserving the biodiversity areas. Specifically, it involves (1) mapping the ecological reserves and characterizing the existing forest plant formations and (2) determining the floristic diversity of the ecological sites of the Zuénoula sugar complex.

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2. MATERIALS AND METHODS

2.1. Study zone

The study was carried out at the sugar complex of Zuénoula (centre-west of Côte d'Ivoire). It is located between 7°30' and 7°40' North latitude and 6°5' and 6°15' West longitude [10] see Figure 1. The area benefits from an equatorial and subtropical transition climate with a dry season (November-February) and a rainy season (March-October). The average temperature varies between 26.7°C to 29°C. The average rainfall varies between 93.61 to 209.34 mm [11]. The relief is characterized by flat plateaus (200 to 400 m) with large plains, some lowlands and hills with an average altitude of 260 m [12]. The vegetation is from the Guinean domain of the mesophilic sector [13]. The soils are varied, ferralitic, hydromorphic, little evolved or browned [12].

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Figure 1: Location of the study site

2.2. Ecological Site Mapping

All the cartographic data were obtained on the basis of the work of [14] which themselves were derived in part from [15] and [16]. They were made following three steps: the acquisition and storage of geographical data, the projection and digitization of information and finally the cartographic drafting.

2.3. Study of the flora of plant formations in conservation areas

Floristic richness was determined from an intensive inventory using the surface survey method combined with a roving inventory. The area survey is a quantitative and exhaustive method consisting of inventorying in plots of fixed area, all the individuals of plants of diameter at breast height (DBH) generally higher or equal to 10 cm. This method has been used by many authors such as [17] and [18]. This inventory was carried out by randomly placing 10 plots of 20 m x 20 m (400 m^2) in each of the plant formations that make up the ecological reserves. The ecological formations were gallery forests (F1, F3, F5, and F6), riparian forests (FR1, FR2) and forest islands (IF4) see Figure 2. The itinerant inventory in addition to the first was carried out along a route, noting all the species encountered without determining their number, as recommended by [19].

Figure 2: Map of voluntary nature reserves in the Zuénoula sugar complex.

FG1-Gallery Forest 1; FG3-Gallery Forest 3; FG5-Gallery Forest 5; FG6-Gallery Forest 6; IF4-Forest Island 4; FR1-Riparian Forest 1; FR2-Riparian Forest 2.

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2.4. Methods of analysis of floristic data

2.4.1. Floristic composition and use value of species

The floristic composition allowed us to determine all the species that make up the inventoried plots. It led to the elaboration of the floristic list. The use value of the species was sought through the determination of the species with particular status on each site. These species were highlighted by comparing the floristic list obtained with that of [20] to determine the endemic species of Upper Guinea (HG) and those of [21] and [22], for the determination of rare and endangered species of the Ivorian flora [21]. The species richness of a given site is the number of species, genera and families found at that site [19]. The nomenclature was made according to the Cronquistclassification [23].

2.4.2. Biological and chorological types

Biological type is a classification proposed by [24] and [25] in order to organize all plants according to the positioning of survival organs. The terminologies used have been adapted from the work of [26] and [27]. They are Chamephytes, Epiphytes, Geophytes, Hemicryptophytes, Theophytes and Phanerophytes (Nanophanerophytes, Microphanerophytes and Megaphanerophytes).

Chorology is the study of the distribution of taxa in correlation with the history of the earth and climates [28]. The chorological type is used to define the phytogeographic distribution range of a species. The type phytogeographic distribution types were established according to the major chorological subdivisions for Africa proposed by [19].

2.4.3. Floristic diversity of conservation areas

Floristic diversity is the distribution of species on a given surface. Its evaluation was made according to the diversity index of [29] and the equitability index of [30]. Shannon's *H*' index is used to quantify and compare the floristic diversity of plant formations. It takes into account the number of species and their abundance [31]. The values of *H'* vary between 0 and lnS (maximum diversity). For environments containing only one species, H' is equal to zero, while for those containing a high number of species, *H'* is high and tends towards lnS. The Pielou index (E) expresses the regularity and equitable distribution of individuals among species [32]. It allows to appreciate the changes in the structure of a community. This index varies from 0 to 1. When it tends towards 0, it describes a state of dominance of individuals of one species over the others. If E tends towards 1, then the distribution of individuals between species is regular. Thesetwo indices have the formula :

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With ni-number of individuals of species i; N-total number of individuals; S-total number of species

. **2.4.4. Statistical data analysis**

ArcGis 8.0 software was used to determine areas and maps of ecological sites. Geographical coordinates were transferred for mapping. Families, genera, and species were analyzed from the general floristic list. A factorial correspondence analysis (FCA) coupled with a hierarchical ascending classification was used to group the species and to establish the relationship between the set of inventoried species, the biodiversity zones and the status of these species.

3. Results

3.1. Mapping of the ecological reserves of the sugar complex

The voluntary forest reserves covered a total area of 139.55 hectares. Three types of forest vegetation were identified: the Forest Island (FI), the Gallery Forests (FG) and the Riparian Forests (FR) see Figures 3 and 4. The IF4 forest plot (Figure 3) is located to the east of the Sugar Estate and near the pivot 05

(irrigation system). It covers an area of 7.28 hectares. The specific species were: *Erythrophleumsuaveolens*, *Ficusexasperata* and *Opiliaceltidifolia*. The second type consisted of gallery forests, FG1; FG3; FG5 and FG6 (Figure 4). The gallery forest FG1 (22.07 hectares) was located to the east of the sugar domain and completely downstream of pivot 5. Its specific species where: *Costusdubius*, *Cussoniaarborea*, *Glyphaeabrevis*, *Lanneaacida* (Figure 4A). The gallery forest FG3 located at the bottom of pivot 13 was the largest; it extended over an area of 60.5 hectares and had the following specific species: *Combretumracemosum*, *Dalberginawelwitschii*, *Millettiazechiana*, *Telosmaafricanum* and *Xylopiaaethiopica* (Figure 4B). The Gallery forest FG5 (11.6 hectares) was located between pivot 1 and pivot 3. Species specific to this forest formation were: *Abruscanescens*, *CeltismildbraediiCissusaralioidesand Hymenocardiaacida* (Figure 4C). The Gallery forest FG6 (3.79 hectares) was located at the bottom of pivot 36 with specific species: *Amphimaspterocarpoides*, *Borassusaethiopium* and *Mondiawhitei* (Figure 4D). The third type of vegetation formation was the riparian forests that bordered the Marahouériver (Figure 5): FR1 (24.52 hectares) and FR2 (10.23 hectares). Species specific to the FR1 forest were, *Acacia mimosoides*, *Cassia mimosoides*, *Myrianthusserratus* and *Parinaricongensis* (Figure 5A). The riparian forest FR2 was located just below pivot 46 and the specific species were: *Acridocarpussmeatmannii* and *Annonasenegalensis* (Figure 5B).

Figure 3: Map of Forest Island 4 (FI4).

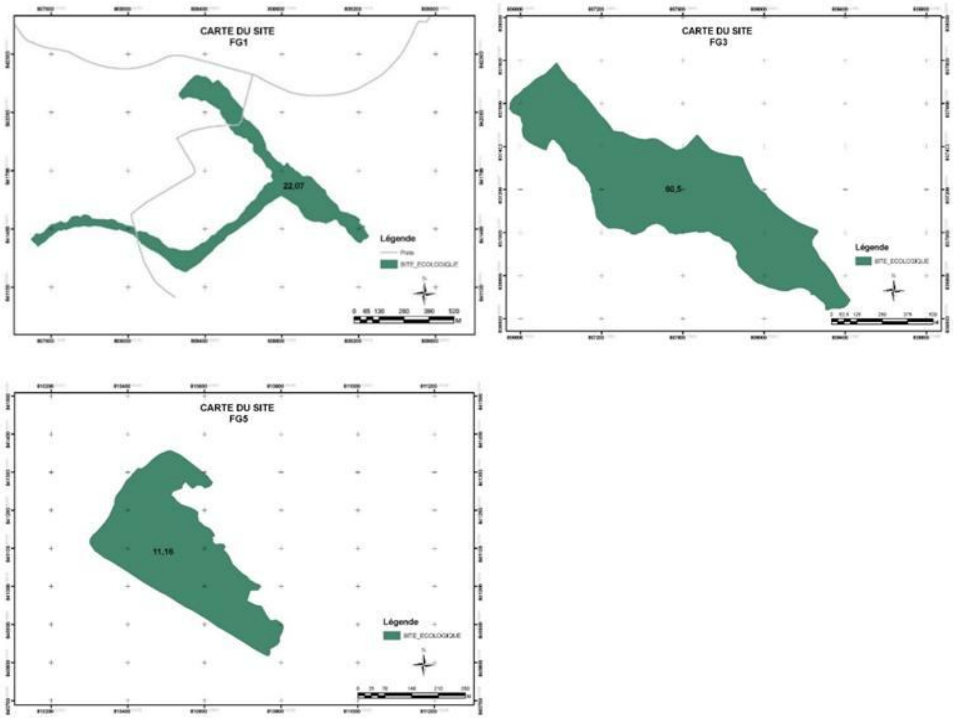

Figure 4: Map of gallery forests identified on the voluntary reserves of the Zuénoula sugar complex.

A-Gallery Forest 1 (FG1); B-Gallery Forest 3 (FG3); C-Gallery Forest 5 (FG5); D-Gallery Forest 6 (FG6).

Figure 5: Map of riparian forests identified in the voluntary reserves of the Zuénoula sugar.

A-Riparian Forest 1 (RF1); B-Riparian Forest 2 (RF2).

3.2. Biological characteristics of plant formations

3.2.1. Floristic richness of the nature reserves

The floristic inventory identified 106 species distributed among 90 genera and 37 botanical families (see Appendix). The most important families in terms of number of species were,Caesalpiniaceae, Moraceae

and Sterculiaceae with 7 species each (Figure 6). In this flora, 19 frequent species were noted, including *Ceibapentandra*, *Cola cordifolia*, *phoenix reclinata* and *Spondiasmombin*. In addition, 15 species exploitable timber including *Triplochitonscleroxylon*, *Antiaristoxicana* and *Terminaliasuperba* were inventoried. Finally, 51 species have been recognized as having a special status. Among them, six species, *Afzeliaafricana*, *Albiziaferruginea*, *Mallotusoppositus*, *Nesogordoniapapaverifera*, *Pouteriaalnifolia*, *Pterygotabequaertii* were vulnerable. Only one species, *Raphiasudanica* was near threatened. Two timber species, *Miliciaexcelsa* and *Triplochitonscleroxylon*presented a minor risk. Finally, the species *Uvariatortilis* was the only endemic of Upper Guinea.

Figure 6: Distribution by family of species recorded at the Zuénoula sugar complex.

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3.2.2. Biological and chorological types of ecological plant formations

The biological spectrum of all species showed that mesohanerophytes with 64.08% were the most dominant.Geophytes with 2.91% representativeness were the least numerous (Figure 7). Megaphanerophytes represented 10% of Phanerophytes and 9.71% of the total flora with species such as *Celtismildbraedii*, *Miliciaexcelsa*, *Ceibapentandra* and *Parkiabiglobosa*. Mesophanerophytes represented 66% of Phanerophytes and 64.08% of the total flora; the most frequent species were *Olaxsubscorpioidea*,

Mangiferaindica and *Phoenix reclinata*. Microphanerophytes represented 19% of the Phanerophytes and 18.45% of the total flora and had as species, *Cola laurifolia*, *Azadirachtaindica* and *Ficusexasperata*. Nanophanerophytes represented 5% of the Phanerophytes and 4.85% of the total flora and had as species, *Cassia mimosoides*, *Costusdubius* and *Annonasenegalensis*.

The flora list is dominated by species from the Guinean-Congolese (GC) zone with 49%, followed by species from the area straddling the Guinean-Congolese and South Zambezian zones with 37%. Species from the Soudano-zambezi zone and those endemic to the western block of Togo were under-represented with 1% and 5% respectively (Figure 8).

Figure 7: Biological spectrum of species recorded in the voluntary forest reserves of the Zuénoula sugar complex.

mp-Microphanerophyte; mP-Mesophanerophyte; MP-Meganerophyte; np-Nanophanerophyte; G-Geophyte.

Figure 8: Chorological spectrum of species inventoried in the voluntary forest reserves of the Zuénoula sugar complex.

GC-taxon of the Guinean-Congolese region; GCW-taxon endemic to the forest block in western Togo; I-taxon introduced or cultivated; SZ-taxon of the Sudan-Zambezi region; GC-SZ-taxon of the transition zone between the Guinean-Congolese region and the Sudan-Zambezi region.

3.2.3. Floristic diversity of ecological reserves

The average Shannon index for all ecological sites was 2.43. It varied from 2.04 to 2.70 across environments (Figure 9A). The highest values were observed in FG3 and FG5 with 2.70 and 2.68 index respectively. The lowest value was observed in FG6 (2.04). From one ecological site to another, the Shannon index showed a significant difference (*F = 5, 343; P = 0.0046*). The equitability index showed a mean value of 0.92 (Figure 9B). It ranged from 0.90 to 0.93 with the highest values in IF4 (0.94) and the lowest in FG1 (0.90). The Piélou index values did not show any significant difference from one ecological sites to another (*F = 0.751; P = 0.619*).

Figure 9: Variation of Shannon (A) and Piélou (B) indices according to the ecological sites of the Zuénoula sugar complex

FG1, FG2, FG3 FG5 and FG6-forests 1, 3, 5 and 6; IF4-forest block 4; FR1-Riparian forest 1; FR2-Riparian forest 2

3.2.4. Relationship betweenspecies and ecological sites

The projection of plant formations and species on the axes (X, Y, Z) revealed three distinct groups. These groups were distributed in a factorial plan formed by the first three components F1, F2, F3. These axes explained 58.66% of the observed variability with 21.64% applied to the F1 axis, 19.70% applied to the F2 axis and 17.32% applied to the F3 axis. Group 1 was associated with riparian forests FR1 and FR2. Group 2 was associated with gallery forests FG5 and FG3 and then with the forest island IF4. Group 3 was associated with gallery forests FG1 and FG6 (Figure 10). The hierarchical bottom-up classification presented the clustering of species and plant formations into three groups. These groups were located at distances of 0.15, 0.15 and 0.05 respectively (Figure 11). Group 1 contained the Riparian forests FR1 and FR2 made up the species, *Bombaxbuonopozense*, *Cola laurifolia*, *Salaciasthulmanniana*, *Paullina pinnata* and *Terminaliaglaucescens*. Group 2 contained the Gallery forests FG3, FG5 and the forest island IF4. It is composed of the species, *Berliniagrandiflora*, *Spondiasmombin*, *Mezoneurumbenthamianum*, *Pterocarpussantalinoides* and *Periplocanigrescens*. Group 3 contained the gallery forests FG1 and FG6 and was composed of the species, *Cissuscymosa*, *Brideliamicrantha*, *Albizia spp.*, *Newbouldialaevis* and *Trichiliaprieureana*.

Figure 10: Diagram of plant formations of species from the ecological sites of the Zuénoula sugar complex

Figure 11: Ascendinghierarchical classification of speciesfrom the ecological sites of the Zuénoulasugarcomplex

G1-group 1; G2-group 2; G3-group 3

4. Discussion

The cartography of the ecological reserves has made it possible to produce their various maps. The total area of these sites is 139.55 hectares. It can be said that the botanical study of ecological

reserves that associated the mapping constitutes a first step in safeguarding biodiversity [33]. Indeed, the cartographic study made it possible to verify and confirm the limits of the plant formations, because its limits were not well known either by the managers or by the local populations. This contributes to the safeguarding of the integrity as it is done for sacred forests in Côte d'Ivoire and Benin. Indeed, according to [34], this approach is essential and a priority in the definition of a forest management framework because the absence of clear and tangible benchmarks facilitates their erosion. Comparing our results with those of [35], who found a total area of 120.24 hectare for these same sites, we note that the areas of the different sites are higher. This difference can be explained by the protection of the sites.

The study made it possible to draw up a floristic list of 106 species divided into 90 genera and 37 families. These species belong mostly to the families Caesalpiniaceae, Moraceae and Sterculiaceae, Euphorbiaceae, Rubiaceae, Anacardiaceae, Mimosaceae and Euphorbiaceae. The abundance of species in these families testifies to a floristic reshuffling of the ecological sites of Zuénoula. Indeed, the ecological zone to which the sugar complex belongs is in the guinean-congolese forest domain, which is the preferred zone for Rubiaceae [27]. These species found in all the sites are also indicative of lowlevel of plant diversity. Indeed, this value of floristic richness remains lower than that obtained by [35] who identified 471 species on all sites. This difference could be due to a larger number of ecological sites inventoried by these authors who visited 14 of them, equivalent to twice the number of our study. Moreover, the difference may also be due to the nature of the species surveyed. Indeed, our study was based only on the ligneous flora, whereas the first authors were interested in all the plant flora. We also note that the low number of ecological sites is a consequence, among other things, of the declassification of areas of good fertility for the cultivation and production of sugarcane.

The species encountered in our study belong in majority to the guinean-congolese zone with 49% of presence. According to [36], the high proportion of these species in the floristic procession of a forest is proof that it belongs to the guinean-congolese region. [37] states that the guinean-congolese flora is very

pure, with 80 to 90% of endemic species. This high value could be a sign of a good reconstitution of the vegetation in the plots studied.

All the environments inventoried are diversified with regard to the different indices calculated. This translates a good stability of the ecological environments. These indices are even very high, thus reflecting great stability of the conservation zones. Indeed, according to [38], when the specific diversity is high, the links between the different components of the biocenosis are complex. This complexity increases the stability of the system due to the many interactions between the different populations. Stability in gallery forests in particular, that of FG3 and FG5 is greater compared to other ecological environments. The equitability index indicates a uniform distribution of species across sites. Thus, the taxa found on the ecological sites of the Zuénoula Sugar Complex are equitably distributed in the environments inventoried, as the indices are close to unity.

The presence of special-status species clearly confirms the biodiversity conservation role played by these sites. The presence of these species in the different categories seems to be linked for some to an important and uncontrolled commercial exploitation, coupled with a weak natural regeneration. For other species, it would be a reduction of habitats mainly due to human activities such as bush fires which are recurrent during the infiltration of the population for the manufacture of charcoal.

The factorial correspondence analysis made it possible to categorize the environments and group them according to species. The first group 1 is characterized by riparian forests, which are located on the banks of the Marahoué River with little human activity. The floral procession is dominated by *Cola laurifolia* which is a species present on the banks of rivers and in West Africa. Group 2 is made up of gallery forests FG3, FG5 and the forest island IF4. These forests are delimited by hydromorphic zones (lowlands) exploited by the population for market gardening. The species encountered in this group are in the form of trees. The presence of forest species such as *Lecaniodiscuscupanioides*, *Erythroxylumsuaveolens* characteristic of the humid semi-deciduous forest shows that these forests have kept their climatic

conditions which allow the installation and development of these species [39]. Group 3 is composed of gallery forests FG1 and FG6. These forests are bordered by cash crop plantations (coffee, cocoa, cashew) and food crops (cassava). They are subject to strong anthropic pressure (bush fires, hunting, frog fishing). The presence of *Borassusaethiopium* and *Raphiasudanica* species, which are savannah species, attests to the degradation of these forests.

Conclusion

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The study carried out in the voluntary nature reserves of SucrivoireZuénoula made it possible to establish a mapping of the sites of the voluntary nature reserves. There are seven voluntary nature reserves whose location, boundaries and area are known. These biodiversity areas cover a total area of 139.55 hectares. The flora is rich in 106 species, distributed among 37 families and 91 genera. The most important families are Sterculiaceae, Fabaceae and Caesalpiniaceae. Within the ecological reserves, 51 species with special status of the IUCN have been reported. This flora is dominated by phanerophytes of the guinean-congolese zone. Plant diversity in the ecological reserves of the sugar complex shows a strong stability and dissimilarity between them indicating that the flora of each reserve is exclusive. The unique characteristics of the different reserves have made it possible to classify them into groups according to the species they contain. These results confirm the importance of preserving these reserves and better studying them better in order to enhance their role in biodiversity conservation. Moreover, in the current context of climate change, these ecological sites promote a microclimate in the area and capture part of the carbon released by the SUCRIVOIRE plant. Therefore, the threats to the preservation of these sites must be identified in order to carry out an adapted development. During our field investigations, traces of aggression on these sites were observed. Indeed, the populations living on the complex and the nomadic herdsmen penetrate these sites for hunting, tree cutting, bush fires and the installation of plantations.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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