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ARTICLE

Former Botanical Garden of ORSTOM (Côte d'Ivoire): What Remain after Thirty Years of Abandonment and Forest Restoration

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ABSTRACT

Botanical gardens represent important places for *ex situ* conservation. One of these botanical gardens has been abandoned in Côte d'Ivoire for 30 years. This is the former botanical garden of ORSTOM. This study was conducted to determine the level of diversity of this former garden in order to assess the opportunity for its rehabilitation. The authors carried out inventories in 18 quadrats of 500 m^2 through the vegetation to collect woody species. Dendrometric measurements (height, diameter) were also recorded to assess the structure of the site. A total of 190 species have been identified. They belong to 141 genera and 47 families. This former botanical garden contains important species because of their origin, status or particularity (threatened, endemic, rarity, etc.). A total of 19 threatened species including 2 endangered and west African endemic (*Chrysophyllum azaguieanum* J. Miège*, Placodiscus pseudostipularis*) were found at the site. Also, *Chrysophyllum azaguieanum* is declared extinct from Côte d'Ivoire. Four species are rare in the flora of Côte d'Ivoire: *Balanites wilsoniana, Chrysophyllum azaguieanum, Gilletiodendron kisantuense* and *Loesenera kalantha*. The most abundant species is *Hopea odorata*. Although this introduced species is considered globally vulnerable, it presents a risk of invasion in the forest of Côte d'Ivoire. The diameter and height structures show that all the stages of development are presented indicating a good regeneration on the site. Ultimately, this botanical garden deserves to be rehabilitated and especially urgent management of *Hopea odorata* is needed to prevent an invasion of this species.

Keywords: Botanical garden; ORSTOM; Côte d'Ivoire; Forest restoration; *ex situ* conservation

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1. Introduction

A botanical garden is an area in which plants are cultivated, maintained and reproduced for several purposes such as education, science, tourism and above all conservation [1,2]. With their living collections of plants, or seed banks, botanical gardens are important places holding genetic diversity and threatened species. The mission of conservation is increasingly crucial due to the massive loss of biodiversity. Today, more than 40% of endangered plant species are protected out of their habitats, in botanical gardens [3]. This type of protection called *ex situ* conservation has become one of the main missions and activities within modern botanical gardens worldwide. There are more than 2500 botanical gardens in the world with the majority of them located out of the (sub) tropical regions where there is nevertheless a higher concentration of biodiversity [4]. Africa is one of the poorest regions in botanical gardens, like the other tropical zones, compared to Europe or North America. Moreover, the existing botanical gardens on the African continent rarely have seed banks [5]. The advent of botanical gardens in this continent began with colonization during the 19th and 20th centuries. Thus, in West Africa, the botanical gardens of Bingerville (Côte d'Ivoire) and Abury (Ghana) were created in 1904 and 1890, respectively. After these historical botanical gardens and by far the biggest ones, some other botanical gardens were installed even after the independence. Thus, in Côte d'Ivoire, the French research agency called ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), now IRD (Institut de Recherche pour le Développement), settled a botanical garden in the village of Adiopodoumé in 1946 near Abidjan. At the end of the 1980s, ORSTOM left Côte d'Ivoire and its facilities, including the botanical garden, were given to the national center of Agronomy, the CNRA. Despite the increasingly important role of botanical gardens, in *ex situ* conservation of plants, particularly the threatened ones, the ORSTOM botanical garden was not maintained after the departure of this institution. Fortunately, the site was not destroyed. After more than thirty years of abandonment, the garden has turned into a secondary forest. At the current state of the site is difficult to find the limits of this garden from the surrounding forests based on the physiognomy of the vegetation. Moreover, very little information is available on this garden either in the CNRA archives or in the literature. Thus, little is known about its floristic composition at the moment of the departure of ORSTOM. In the absence of this historical data, are there any chances of finding species that are certain to have been planted there? For example, species from other phytogeographical regions or from other regions of Côte d'Ivoire? Can the role attributed to this botanical garden at its creation be detected from its current species composition? The abandonment of the garden and its recolonization by the local flora certainly led to more or less important changes in its specific composition. The current state of the site is the result of an ongoing ecological succession. This process can lead to the disappearance of certain species. Indeed, ecological succession occurs in different stages including invasion, competition, Co-action and Stabilization (climax) [6]. The competition stage can conduct in a change in the species and diversity [7]. Amani, B. H. K. et al. [8] showed that in Côte d'Ivoire, a secondary forest in reconstitution, after 20 years, recovers 90% of the diversity contained in an old forest. It is established that most of the plants introduced in the garden are not naturalized [9]. But in climate change conditions, it is difficult to predict the trajectories of the recovery. Studies conducted by Haeuser, E. et al. [9] under controlled conditions, have concluded that native species could be less competitive with climate warming. Such a scenario would mean that in an old botanical garden, exotic species would be more represented after years of abandonment. But it is clear that the contrary could also be obtained. Indeed, the trajectories of the succession can be under the influence of several factors including the nature of species (native and introduced) [10,11]. This paper aims at investigating the floristic richness and diversity of the former botanical garden of ORSTOM.

2. Materials and methods

2.1 Site location and description

The site of the botanical garden is located in the surroundings of the village of Adiopodoumé in the north of Abidjan (South-East of Côte d'Ivoire). The place is located between 05'19''16.32 N-05'19''25.68 N and 04'07''53.76 W-04'07''58.80 W (**Figure 1**). The region was initially covered by wet evergreen forests characterized by a high frequency of *Turraeanthus africanus* (Welw. ex DC) Pellegr. (Meliaceae) and *Heisteria parvifolia* Sm. (Olacaceae). Today the Banco National Park is one of the remnants of this type of forest. The region experiences high rainfall that can reach almost 2000 mm per year. The temperatures vary very little and oscillate between 24.51 °C (August) and 27.67 °C (March) [12]. In the absence of documentation on the limits of the garden, we carried out the inventory work with the help of a former technician from ORSTOM. Mr. Henri Teré worked in the botanical garden of ORSTOM for more than 25 years and had an accurate knowledge of the limits. He has published a paper on ethnobotany [13]. A reconnaissance visit was thus carried out with him so that he indicated the places supposed to be the limit of the garden. These boundaries have been georeferenced.

2.2 Methods of inventory and identification of the species

For the inventory of the species, we have settled 18 plots of 500 m^2 (25 m × 20 m) according to the physiognomy of the vegetation. In each plot, all the species were recorded. This method of inventory is usually used in the studies of African vegetation [14-16]. In addition, all individuals with a DBH (Diameter at Breast Height) greater than or equal to 3 cm were counted and the DBHs mentioned for each individual. The heights of these individuals were also recorded. The DBH was measured at 30 cm from the ground. Herbaria samples were collected for the unknown plants for their identification. These identifications were done at the herbarium of the "Centre Suisse de Recherches Scientifiques en Côte d'Ivoire" (CSRS). All the specimens collected are deposited in this herbarium registered in Index Herbariorum. (https://sweetgum.nybg.org/science/ih/herbarium-list/?NamOrganisationAcronym=CSRS).

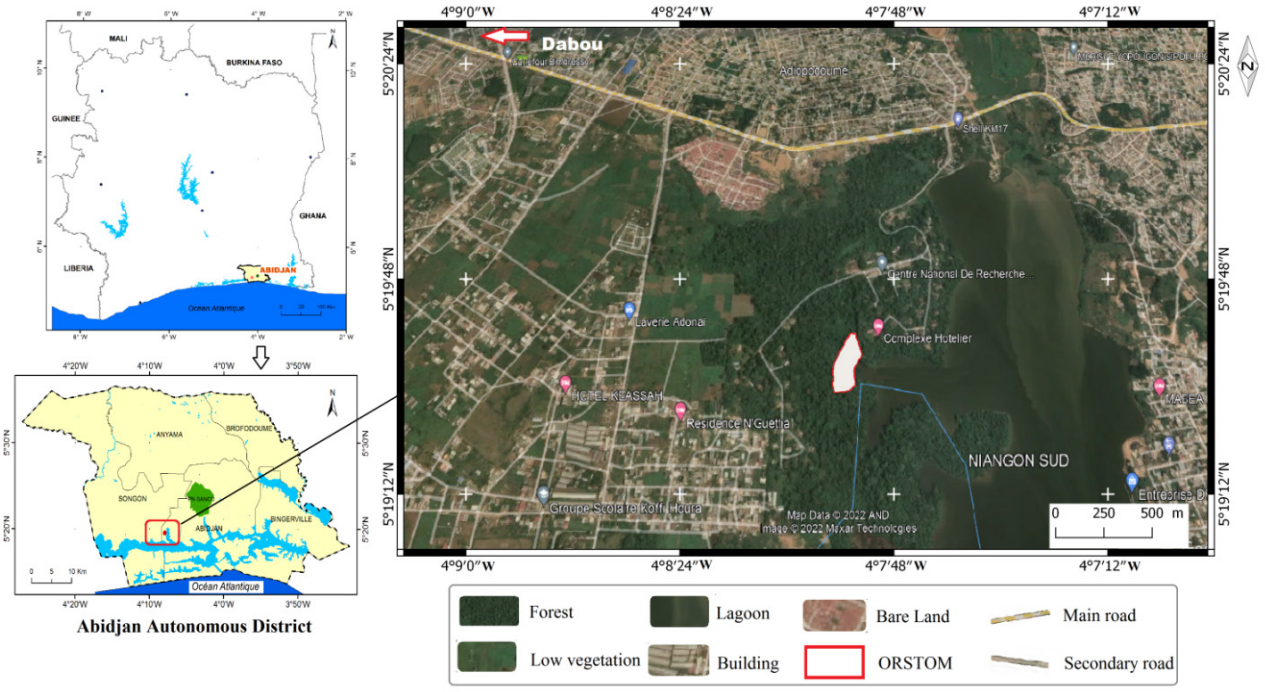

Figure 1. Location of the former botanical garden of ORSTOM.

2.3 Analysis of the diversity

A qualitative analysis of the diversity was carried out in this study. First, the taxonomic diversity was assessed through the number of species, genera and families after the identification of each plant including those that were brought into the herbarium. The nomenclature of the families adopted is that of the phylogenetic classification [17]. Then the conservation status, of each species was checked on the IUCN website (https://www.iucnredlist.org/). Also their rarity, endemism and chorology were checked [18-22]. The level of endemism considered was that of Côte d'Ivoire or West Africa. We used the chorology proposed by Aké-Assi, L. [20] as follows:

-GC: Guinean-Congolese species;

-SZ: Sudano-Zambesian species;

-GC-SZ: Common species for the Guinean-Congolese and Sudano-Zambesian phytogeographical regions;

-GCW: Endemic species of the forest area situated at the west of Togo, including Ghana, Côte d'Ivoire, Liberia, Sierra Leone, Guinea, Guinea Bissau, Gambia and Senegal.

2.4 Analysis of the structure

The vertical and horizontal structure of the vegetation can be assessed through several parameters [23-25]. The diameter classes for the analysis of the horizontal structure and the height classes for the analysis of the vertical structure were used. The diameter classes thus constituted have an amplitude of 10 cm and the height classes have an amplitude of 5 m.

3. Results

3.1 Taxonomic diversity

A total of 190 species have been inventoried on the site. These species belong to 141 genera and 47 families. The most species-rich families are those of the Fabaceae (39 spp), Malvaceae (16 spp), Euphorbiaceae (15 spp), Meliaceae (13 spp), Annonaceae (9 spp), Sapotaceae (9 spp). These families include more than 50% of all the species recorded (**Figure 2**).

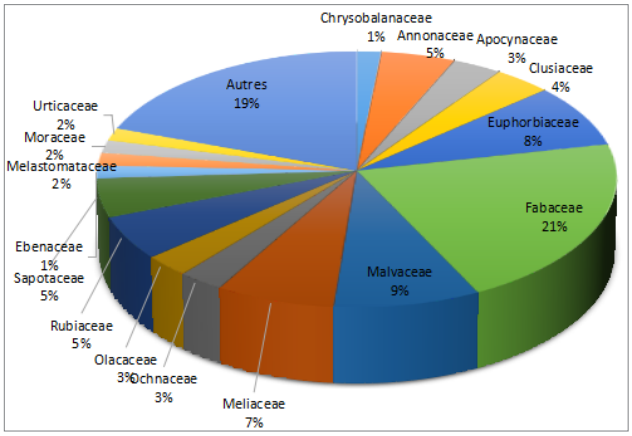

Figure 2. Proportions of species in the families listed in the former botanical garden of ORTOM.

3.2 Chorologie and endemism

We found 134 Guinean-Congolese (GC) species which represent 70.52% of the species. There are a total of 12 GC-SZ species and only 1 SZ species. Twenty-two (22) endemic species of the Upper Guinean forest were recorded at the site (**Table 1**). Some of these species have been inventoried, until now, in only two or three countries in West Africa. Indeed, *Chrysophyllum azaguieanum* J. Miège (**Figure 3**) is known in Côte d'Ivoire and Ghana. *Loesenera kalantha* Harms has been observed in Liberia and the west of Côte d'Ivoire.

3.3 Introduced species

Among the species, 6 do not belong to the natural flora of Côte d'Ivoire. They have been introduced in the garden definitely from other countries. These are: *Hopea odorata* Roxb, *Laurus nobilis* L., *Fatsia sp*, *Xylopia sp*, *Olea europaea* L.and *Aucoumea klaineana* Pierre (**Figure 3**). *Aucoumea klaineana* is also a threatened (vulnerable) species from central Africa. Twenty individuals, the majority of which were in the young or subadult stages, were counted. This shows that the first individual introduced reproduces and its seeds germinate. Moreover, this individual has been observed with inflorescences (**Figure 3**).

Table 1. West African endemic species in the former botanical garden of ORSTOM in Côte d'Ivoire.

Species	Family
Berlinia occidentalis Keay	Fabaceae
Calpocalyx aubrevillei Pellegr.	Fabaceae
Chrysophyllum azaguieanum J.Miège	Sapotaceae
Coelocaryon oxycarpum Stapf	Myristicaceae
Cola caricifolia (G. Don) K. Schum	Malvaceae
Copaifera salikounda Heckel	Fabaceae
Daniellia thurifera Benn.	Fabaceae
Dialium aubrevillei Pellegr.	Fabaceae
Diospyros liberiensis A.Chev. ex Hutch. & Dalziel	Ebenaceae
Drypetes aylmeri Hutch. & Dalziel	Euphorbiaceae
Drypetes ivorensis Huche. & Dalziel	Euphorbiaceae
Eugenia leonensis Ingl. & Brehmer	Myrtaceae
Loesenera kalantha Harms	Fabaceae
Octoknema borealis Hutch. & Dalziel	Octoknemaceae
Placodiscus pseudostipularis Radlk.	Sapindaceae
Schumanniophyton problematicum (A. Chev.) Aubrév	Rubiaceae
Strephonema pseudocola A. Chev	Combretaceae
Tarrietia utilis (Sprague) Sprague	Malvaceae
Tetrapleura chevalieri (Harms) Baker f.	Fabaceae
Tricalysia reticulata (Benth.) Hiern	Rubiaceae
Desmostachys vogelii (Miers) Stapf	Icacinaceae
Xylia evansii Huche.	Fabaceae

Figure 3. Leaves and inflorescences of *Aucoumea klaineana,* an introduced species in the former botanical garden of ORSTOM.

3.4 Abundance of the species

The most abundant species of this site are: *Hopea odorata* (76 ind.), *Pycnanthus angolensis* (60 ind.), *Tarrietia utilis* (Sprague) Sprague (52 ind.), *Quassia gabonensis* Pierre (37 ind.), *Carapa procera* (34 ind.), *Strombosia pustulata* Oliv. (23 ind.), *Berlinia confusa* (22 ind.) and *Aucoumea klaineana* (20 individuals). Apart from these species with 20 or more individuals, we noted 14 species with the number of individuals varying from 10 to 19. Among these species *Lophira alata* Banks ex CF Gaertn. and *Mitragyna ledermannii* (K. Krause) Ridsdale with 19 individuals each. We have counted 95 species with 2 to 9 individuals. A total of 73 species (38.42%) were represented by only one individual. It is important to highlight the fact that among the 8 most abundant species 3 are introduced species including *Hopea odorata* which have the highest number of individuals (76 individuals).

3.5 Threatened and rare species

A total of 19 threatened species were found at the site (**Table 2**). Among them, 2 species are en-

dangered and 17 are vulnerable. Also, the two endangered species are endemic to the west African Guinean Forest. These are *Chrysophyllum azaguieanum* J. Miège and *Placodiscus pseudostipularis* Radlk (**Figure 4**). Four species are rare in the flora of Côte d'Ivoire: *Balanites wilsoniana, Chrysophyllum azaguieanum, Gilletiodendron kisantuense* and *Loesenera kalantha*.

3.6 Horizontal structure

The diameter structure of the species in the botanical garden has an "inverted J" shape (**Figure 5**). The number of individuals decreases from small diameter classes to large diameter classes. Thus, individuals with a diameter between 0 cm and 10 cm are the most represented. These individuals represent more than 70% of the plants inventoried. Less than 1% of individuals have a diameter greater than 100 cm. This shows that young individuals are more numerous than adult individuals.

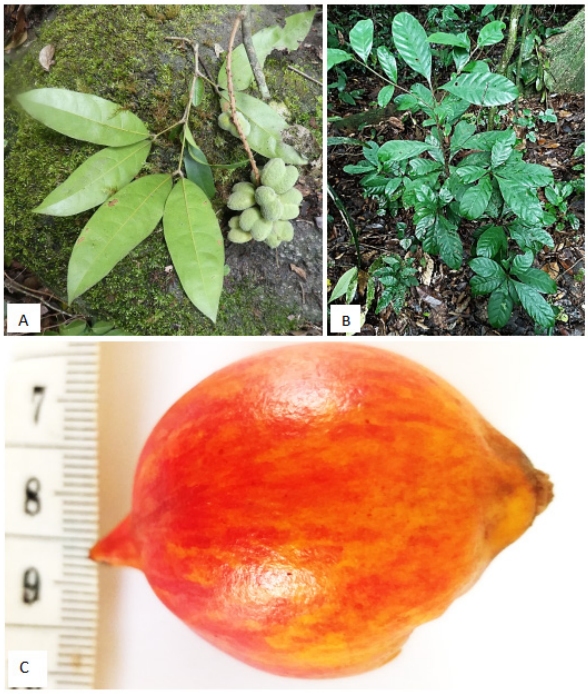

Figure 4. Two west african endemic and endangered plants: A. Leaves and fruits of *Placodiscus pseudostipularis* Radlk.; B, C. Young individual and fruit of *Chrysophyllum azaguieanum* J. Miège.

Table 2. Threatened and or rare plant species inventoried in the former botanical garden of ORSTOM in Côte d'Ivoire.

Category of threat	Species	Family
Endangered	Chrysophyllum azaguieanum J.Miège	Sapotaceae
	Placodiscus pseudostipularis Radlk.	Sapindaceae
Vulnerable	Aucoumea klaineana Pierre	Burseraceae
	Bombax brevicuspe Sprague	Malvaceae
	Copaifera salikounda Heckel	Fabaceae
	Entandrophragma angolense (Welw.) C.DC.	Meliaceae
	Entandrophragma cylindricum (Sprague) Sprague	Meliaceae
	Entandrophragma utile (Dawe & Sprague) Sprague	Meliaceae
	Garcinia kola Heckel	Clusiaceae
	Guarea africana Welw. ex C. DC.	Meliaceae
	Guarea cedrata (A. Chev.) Pellegr.	Meliaceae
	Hopea odorata Roxb.	Dipterocarpaceae
	Hymenostegia neoaubrevillei J.Leonard	Fabaceae
	Lophira alata Banks ex CF Gaertn.	Ochnaceae
	Nesogordonia papaverifera (A. Chev.) Capuron ex N. Hallé	Malvaceae
	Pterygota bequaertii De Wild.	Malvaceae
	Schumanniophyton problematicum (A. Chev.) Aubrév	Rubiaceae
	Synsepalum aubrevillei (Pellegr.) Aubrév. & Pellegr	Sapotaceae
	Turraeanthus africanus (Welw. ex C. DC.) Pellegr.	Meliaceae

3.7 Vertical structure

The height distribution of species in the botanical garden gives a negative exponential form (**Figure 6**). Indeed, the smallest class of high (0-10 cm) concentrates the highest number of individuals. There is a predominance of individuals of low height. More than 70% of individuals have a height less than 20 m. There are very few individuals with a height greater than 40 m. This structure indicates the good regeneration of the species.

Figure 5. Distribution of the individuals of the former botanical garden of ORSTOM in the diameter classes.

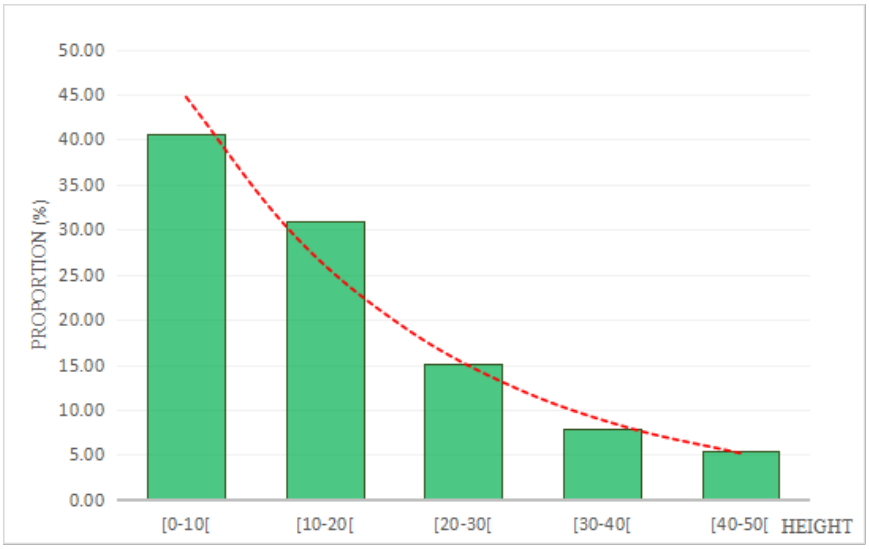

Figure 6. Distribution of the individuals of the former botanical garden of ORSTOM in the height classes.

4. Discussion

4.1 Richness and conservation value of the former botanical garden of ORSTOM

This study leads to the inventory of 190 species belonging to 141 genera and 47 families in the site of the former botanical garden of ORSTOM in Côte d'Ivoire. If the species observed are the result of the influence of the neighboring forest, there is evidence of introduced species in the garden. For instance, *Aucoumea klaineana* Pierre, *Hopea odorata* Roxb, *Laurus nobilis* L., and *Olea europaea* L. are not native of the flora of Côte d'Ivoire. The absence of

historical documents on the garden makes it impossible to know whether certain species have disappeared. After more than 30 years of abandonment, the former botanical garden of ORSTOM contains species of extreme importance for conservation. The West African Guinean forest is one of the hotspots of biodiversity [26] meaning that it has a rich biodiversity, a high rate of endemism but also a high rate of deforestation. In this context, threatened, rare and endemic species need more attention in terms of *ex situ* conservation. The former botanical garden of ORSTOM seemed to play this role regarding the number of threatened (18), rare (4) and endemic (22) species inventoried and it is clear that some species have disappeared. Indeed, we found in this garden, evidence of native cultivated species of the ivorian flora. This concerns species that are restricted to the western area of the country such as *Balanites wilsonia, Loesenera kalantha* and also *Chrysophyllum azaguieanum* J.Miège, which is considered extinct from Côte d'Ivoire [22]. Indeed, the presence of these species on this site shows that they were cultivated there as part of the enrichment of the garden. That is why we choose to call them "native cultivated species" rather than introduced species.

4.2 Breeding capacity of native cultivated species

The native cultivated species such as *Balanites wilsonia and Loesenera kalantha* are rare in their area of distribution [27]. Only two individuals of each were recorded indicating that they do not have easy reproduction which could explain their rarity in nature. However, 9 individuals of *Chrysophyllum azaguieanum* were observed, with two individuals in a reproductive state. Yet according to Aké-Assi, L. [21] only one individual of this species had been introduced into the garden and as the specimen Aké Assi 12019 has been collected from this individual in 1973, it is clear that this individual has been introduced before this date. In other words, in 2022, one can say that the individual is at least 50 years old. In any case the number of individuals of this species is low. During the inventory we found only one fruit on the first individual. A year later, monitoring revealed the presence of numerous flowers on the two adult individuals, but when the fruits matured, only 7 fruits were observed. It seems that in the current environment of this botanical garden, *Chrysophyllum azaguieanum*is facing a reproductive problem. We suspect the absence of its pollinator which is not formally known for the moment.

4.3 Abundance of the species and risk of invasion

Among the 8 most abundant species, 3 are introduced species, not part of the original flora of Côte d'Ivoire: *Hopea odorata* (76 individuals), *Quassia gabonensis* Pierre (37 ind.), *Aucoumea klaineana* (20 ind.). Therefore, *Hopea odorata* is the most abundant species on the site. The second and third most abundant native species are *Pycnanthus angolensis* (60 ind.), *Tarrietia utilis* (Sprague) Sprague (52 ind.), respectively. *Hopea odorata* is a vulnerable species according to the IUCN categories and is orinated from the South-East Asia [28]. The species is also a fast-growing species and is appreciated for its wood. These are certainly the reasons that led to its introduction in Côte d'Ivoire in the 70s. However, it should be noted that this species could be invasive in the forest ecosystems in Côte d'Ivoire. We have also observed many young individuals of this species. The invasive potential of *Hopea odorata* was observed by Tiébré, M.S. et al. [28] in the Banco National Park. These authors found in their study site, that 97% of the individuals identified belonged to *Hopea odorata*. The invasive potential of the species could be explained by its high capacity of dispersion even if the germination rates observed in Côte d'Ivoire are around 30% [29]. The abundance of *Pycnanthus angolensis* and *Heritiera utilis* can be explained by the edaphic conditions and the ecological strategy of these species. Indeed, they are both species that prefer humid zones and are light demanders [30]. These conditions were well met on the site of the former botanical garden of ORSTOM. This type of environment is also suitable for *Carapa procera*. This is why there are 34 individuals of this species on the

site, which is therefore the fifth most abundant species and the third among native species. *Aucoumea klaineana* is a pioneer and light-demander species, which often colonizes places after deforestation by forming pure stands. In their distribution area (Gabon and Congo basin) *Aucoumea klaineana* and *Quassia gabonensis* often grow in the same places and conditions, especially sandy soils [31] so that they can characterize a type of forest.

5. Conclusions

This study has shown that 30 years of forest restoration have not led to the disappearance of all the species preserved in the ORSTOM botanical garden. The current rate of loss of biodiversity makes botanical gardens more essential than ever in the tropics. Given the conservation status of many species, this garden had a clear mission: to preserve endangered plant biodiversity. It remains a site of high conservation value. This is why its rehabilitation and strengthening are desirable.

Conflicts of Interest

The authors declare no conflict of interests.

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