forests

MDPI

Article

Enrichment of Logging Gaps with High-Value Timber Species: How Far Fertilizer, Biochar and Mammal Predation Affect Performances of *Cylicodiscus gabunensis* Harms Seedlings

Romaric Ndonda Makemba [1,2,*], Félicien Tosso [1], Christian Moupela [2], Gauthier Ligot [1], Yves Brostaux [3] and Jean-Louis Doucet [1]

[1] Forest Is Life, TERRA Teaching and Research Centre, Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
[2] Département de Phytotechnologie, Université des Sciences et Techniques de Masuku, BP 941 Franceville, Gabon
[3] Applied Statistics, Computer Science and Modelling Research Unit, TERRA Teaching and Research Centre, Gembloux Agro-Bio Tech, University of Liège, 5030 Gembloux, Belgium
* Correspondence: rndonda@uliege.be

Citation: Makemba, R.N.; Tosso, F.; Moupela, C.; Ligot, G.; Brostaux, Y.; Doucet, J.-L. Enrichment of Logging Gaps with High-Value Timber Species: How Far Fertilizer, Biochar and Mammal Predation Affect Performances of *Cylicodiscus gabunensis* Harms Seedlings. *Forests* **2022**, *13*, 1937. https://doi.org/10.3390/f13111937

Academic Editor: Benjamin L. Turner

Received: 30 September 2022
Accepted: 13 November 2022
Published: 17 November 2022

Abstract: Many commercial species are light-demanding and regenerate with difficulty in natural forest, which compromises the sustainability of logging. Okan, *Cylicodiscus gabunensis* Harms is one of the most exploited species in Central Africa and its regeneration is deficient in evergreen forest. In forest concessions, the enrichment of logging gaps with commercial species has already been tested but only for a few species. Mixed results have been obtained because the ability of seedlings to emerge from competing vegetation depends on the species, the environment and the silvicultural techniques adopted. This paper aims to determine the performance of *C. gabunensis* when planted in felling gaps. The impact of fertilization and biochar application on the performance of the seedlings was examined, as well as the role of predation played by large mammals. In 30 gaps, whose light levels were quantified, we planted nine seedlings and applied three treatments (fertilizer and biochar, fertilizer, control). The performance of the seedlings (survival, mammal damage and growth) was followed for 18 months. In another 30 gaps, the preferential consumption of *C. gabunensis* seedlings was quantified using camera traps. Seedlings had moderate and highly variable growth (1.84 cm to 2.50 cm in height and 0.201 mm to 0.267 mm in basal diameter per month, all treatments combined). Gap size and initial fertilization significantly boosted growth in diameter and survival rate. Elephants preferentially sought out *C. gabunensis* seedlings and after 18 months they destroyed 35% of the plants. Enrichment of logging gaps with *C. gabunensis* should therefore be limited to the largest gaps in forests with low elephant densities. Initial fertilization is recommended but not allowed under the sustainable management certification guidelines. We suggest that these standards should be adapted to maximize the chances of success.

Keywords: *Cylicodiscus gabunensis*; *Loxodonta cyclotis*; logging gaps; silviculture; plantation; biochar; fertilizer; mammal predation

1. Introduction

Cylicodiscus gabunensis Harms is a light-demanding timber species of African rainforests [1]. In Central Africa, most exploited trees of *C. gabunensis* species are thought to have become established between 590 and 80 years before present (BP) in abandoned fields and on relatively fertile soils [2]. Nowadays, *C. gabunensis* suffers from a lack of natural regeneration in evergreen forests [3], while its populations are heavily exploited for timber [4,5]. Other light-demanding timber species with the same light requirements as *C. gabunensis*, such as *Aucoumea klaineana* Pierre [6], *Pericopsis elata* (Harms) Meeuwen, *Terminalia superba* Engl. and Diels, *Erythrophleum suaveolens* (Guill. and Perr.) Brenan, and

Triplochiton scleroxylon K. Schum. [7], are also facing this issue, which is worsened by the selectivity of the timber market [8,9]. A decrease in exploitable volumes of those species in the coming decades seems inevitable, which threatens the sustainability of forest management.

A silviculture adapted to timber species ecology should be used to balance the lack of natural regeneration [10,11]. Efficient silviculture increases the probability that species will survive in the long term [4]. Hence, the plantations contribute to the maintenance and restoration of biodiversity after anthropogenic disturbances [12]. Several planting methods have been tested in tropical rainforests, but few studies were performed in Central Africa [4]. Doucet et al. [13] identified timber species whose seedlings are adapted to large open degraded areas such as *T. scleroxylon* and *T. superba*. *C. gabunensis* was not among those species and planting in logging gaps was suggested. In enrichment plantations with *Baillonella toxisperma* Pierre., Doucet et al. [10] reported a high survival rate of seedlings planted in logging gaps and a growth rate 10 times higher than in the forest understory. By assessing the performance of *Pericopsis elata* seedlings planted in logged forests in Cameroon, Ouédraogo et al. [14] showed that this species performed well in terms of survival and growth five years after planting. However, the performance of seedlings varied according to the type of environment (yards, logging gaps, large disturbed areas) and soil fertility. Furthermore, wildlife may cause damage to the plants, sometimes leading to their death [15–17].

The objective of this study was to overcome the lack of regeneration of *C. gabunensis* by testing the enrichment of logging considering the ecological requirements of *C. gabunensis* (light and soil fertility). Mainly, we aimed (i) to analyze growth rates and effects of fertilizer and biochar on the performance (growth and survival) of *C. gabunensis* nursery-raised seedlings; and (ii) to identify predators and the damage they cause to *C. gabunensis* seedlings.

2. Materials and Methods

2.1. Study Area

The study area is located in south-eastern Gabon, in the concession granted to the FSC-certified Precious Woods CEB Company (0°30′ S, 12°30′ E). It is composed of three forest management units (FMU 1, FMU 2 and FMU 3) covering a total area of 596,823 ha [18]. The enrichment of logging gaps was performed in FMU 2 and 3 (Figure 1). The annual rainfall is 1700 mm [19], with two distinct rainy seasons (March to May and October to December) [20], and the mean annual temperature is 25.4 °C [21]. The topography is undulating with elevation varying between 300 and 700 m [18]. The geological substrate is formed by basement Precambrian formations [22] and the soils have been identified as ferrasols [23]. Forests in the area are mostly Atlantic inland evergreen (27%, 15% and 14% of species are Fabaceae, Burseraceae and Myristicaceae, respectively) and mixed evergreen (30%, 10% and 8% of species are Fabaceae, Olacaceae and Myristicaceae, respectively) [24].

2.2. Study Species

Cylicodiscus gabunensis (Fabaceae, Caesalpinioideae) can reach a diameter at breast height (DBH) of 300 cm and a height 60 m. It is among the most exploited timber of Central Africa because of its interesting wood technological properties such as good natural durability [3]. In the study area, *C. gabunensis* shows a unimodal distribution of diameters (dominated by medium-sized trees) typical of the long-lived light-demanding species that currently suffer a lack of regeneration in evergreen forests (Figure 2). It is a hermaphroditic and non-gregarious species [1] that prefers soils rich in plant nutrients (K, P) and total nitrogen [2]. The roots of the seedlings are often covered with ectotrophic mycorrhizae for a relatively short period [26]. They are probably replaced by arbuscular endomycorrhizae during later tree growth [27]. Rhizobia are absent [28]. The winged seeds are dispersed by wind [1]. Duah-Gyamfi et al. [29] observed, in logged forests in Ghana, *C. gabunensis* seedlings both in the forest understory, in windfalls and on skid trails.

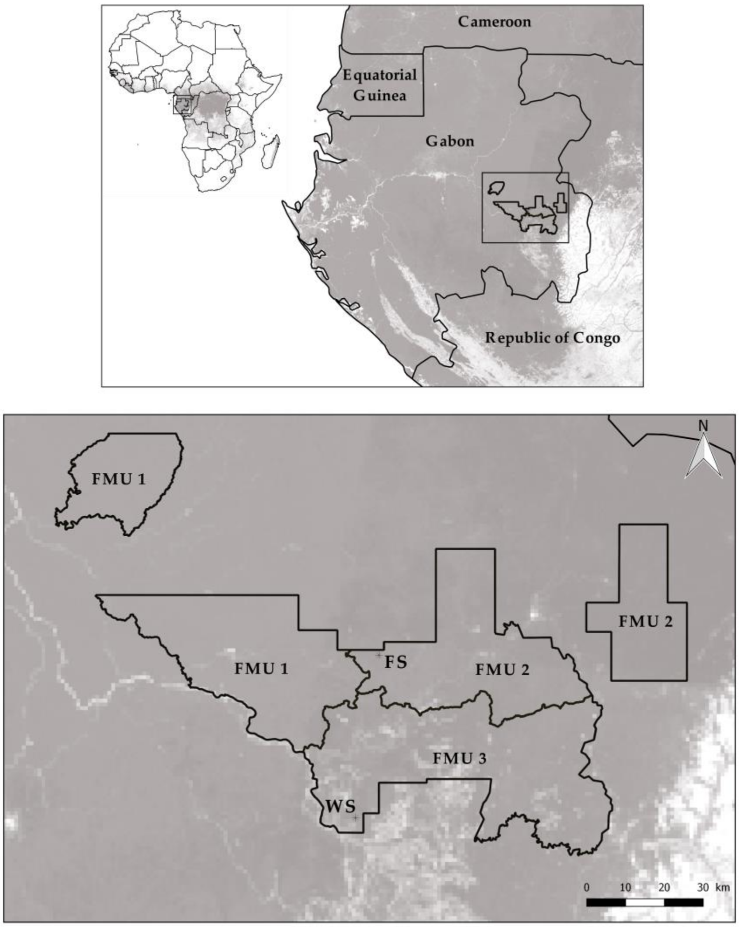

Figure 1. Location of the enrichment plantings in a logging concession in Gabon (black stars); FS: fertilizer study and WS: wildlife study. The background map corresponds to the tree cover (grey) [25].

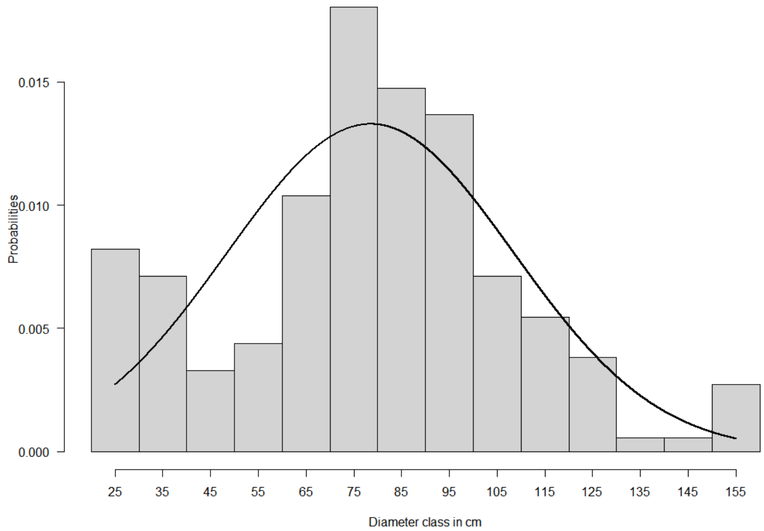

Figure 2. Diameter distribution of *C. gabunensis* stems (DBH > 20 cm) in the FMUs 2 and 3 (398,169 ha) managed by Precious Woods CEB logging company in south-eastern Gabon; (i) the x-axis shows 14 central values of the diameter classes ([20–30], [30–40], . . . , [150–160] cm), (ii) the y-axis represents the probabilities of the normal distribution for each diameter class.

2.3. Silvicultural Experiments

2.3.1. Performance of *C. gabunensis* in Logging Gaps and Effects of Fertilizers

The experiments were performed in 30 logging gaps not invaded by grasses. The logging gaps were randomly selected and were 6 months old. Each logging gap was divided into two parts: the proximal and the distal part. The proximal part of the gap, that is the area where the tree trunk had fallen down and had been off-loaded by the logging machines, and the distal part of the gap, correspond to the area delineated by the foliage crown of the tree lying on the ground. Considering that branches and leaves still covered a large part of the distal part and thus inhibited any regeneration before decomposition, only the proximal part of the gap was enriched. The proximal part of selected logging gaps was relatively small, 29 m^2 (σ = 7.2 m^2) in average, which limits the number of plants that can be introduced. Nine seedlings were planted in each gap, three treatments were applied: (i) control treatment (without NPK fertilizer or biochar), (ii) fertilizer and (iii) treatment with fertilizer and biochar. Each treatment was thus represented by three seedlings. The seedlings were arranged in rows of three seedlings distributed among the three treatments and spaced 2 m apart. To avoid the border effect, each row and column contained each treatment. The fertilizer and biochar protocols were adapted following de Lefebvre et al. [30]. The biochar was produced in kilns using untreated wood residues from wood processing plants at the site of operation. The biochar was ground and sieved to 8 mm to ensure particle size homogeneity. It was mixed with soil and introduced at planting, in holes, 500 g per plant. The fertilizer used was a mixture of NPK (15%-15%-15%). The fertilizer was applied once, 4–5 days after planting, in its granulated form. The fertilizer was applied to the soil in a 10 cm deep concentric furrow around the plant. The dosage applied was 30 g NPK (15%-15%-15%) per plant.

A total of 270 nursery-raised seedlings of *C. gabunensis* were transplanted into thirty different logging gaps in 2018. The plants were raised for 12 months in a nursery in polyethylene bags 20 cm high and 12 cm in diameter. At the time of planting, the plants were on average 64 cm (σ = 14 cm) in high and 0.5 cm (σ = 0.1 cm) in diameter (10 cm above the base of the stem).The average area of the gap was determined from the projection of peripheral tree canopies with a diameter at breast height (DBH) $\geq$ 10 cm and the presence of seedlings belonging to early pioneer species (e.g., *Musanga cecropioides* and *Macaranga* sp.) [4]. The planted area (16 m^2) was in the proximal part of the logging gaps. It was calculated using a 2 m $\times$ 2 m grid fixed to the ground with ranging poles. Prior planting, competing vegetation, coming mainly from the soil seed bank, was totally removed using a machete and the ground was cleared of any debris. Planting was carried out according to the protocol proposed by Daïnou et al. [4]. Measurements were made every 6 months during 18 months (t = 455 days). Height and basal diameter were measured with a tape and caliper, respectively. The survival and presence of damage to seedlings were also recorded. To estimate the light availability just above the *C. gabunensis* seedlings, hemispherical photographs were taken at the start of the experiment after seedling establishment. The photographs were taken at sunrise or at sunset in the centre of the plantation following the protocol of Ligot and Mackels [31]. The photographs were used to calculate several indices of light availability, including the percentage of total light above the canopy (Transtot). The photographs were thresholded with PiafPhotem software version 2 [32] and the light was calculated automatically with Gap Light Analyzer software version 2.0 [33]. In studied gaps, light levels varied between 12 to 49% with an average light level per gap of 32 % (σ = 9%). No additional maintenance was applied in the logging gaps during the experiment.

2.3.2. Wildlife Damage in Planted Logging Gaps

To identify predators of *C. gabunensis* seedlings and to assess damage to plants in enriched logging gaps, 30 BolyGuard SG2060 36 MP camera traps, equipped with 32 GB memory cards and infrared sensors were deployed in 30 gaps, one camera per gap. Planting was carried out following Daïnou et al. [4]. To test if *C. gabunensis* is consumed selectively, plantations of *C. gabunensis* were created with other timber species, depending on the availability of seedlings in the nursery of the logging company. The species planted were: *Lophira alata* Banks ex C.F.Gaertn. (15%), *E. suaveolens* (18%), *Distemonanthus benthamianus* Baill. (32%) and *Bobgunnia fistuloides* (Harms) J.H. Kirkbr. and Wiersema (34%). Five seedlings of *C. gabunensis* and four seedlings of other species were randomly planted in each gap between December 2019 to July 2021. Gaps were 10 months old. After planting, height and diameter were measured as previously described and no additional maintenance was applied in the logging gaps during the experiment. The camera traps were placed on a tree at 30–50 cm height from the ground. The camera traps were set to local time when installed (UTC+1). They were configured to take three photos and a 60 s video per trigger at 5 s time intervals [34]. Recordings were triggered by movement. Grasses and vines in the vicinity of the cameras were reduced to avoid false triggers. They operated 24 h a day for one to three months [35].

We only focused on animals that showed interaction with the plants in the plantations (sniffing the plant or part of the plant; eating the plant or part of the plant). The recordings obtained were processed in open access databases: (1) Camera base version 1.7 [36] to assign unique identifiers to each file (photos and videos) and (2) Timelapse version 2.2.5.0 [37] for the observation of detection events and for species identification. To avoid overestimating visits of individual animal species, we considered as independent events: (i) consecutive recordings of different species, (ii) consecutive recordings of individuals of the same species taken beyond a time interval of 30 min [35,38]. A recording with multiple individuals of the same species in the same image was treated as a single individual event [34]. Each recording was viewed and all animals on the recordings were identified following Kingdon [39]. The behavior (sniffing and/or eating the plant) of each animal was recorded. The different behaviors were classified into two main categories: consumers and non-consumers. Species nomenclature followed the IUCN Red List of Threatened Species. Given the difficulties in identifying some species of the genus *Cephalophus* (*C. leucogaster*, *C. nigrifrons*, *C. callipygus and C. dorsalis*) on the recordings, we have grouped these species into a species complex (*Cephalophus* spp.).

2.4. Data Analysis

2.4.1. Assessing Effect of Fertility on Seedling Growth

To compare our results with other studies, the growth monitoring data were used to compute the average annual growth (*AAG*) in height and diameter. These ecological parameters were calculated using Equation (1):

$$AAG = (Vf - Vi)/nd \times 365.25 \tag{1}$$

where: *Vf* = final value (cm); *Vi* = initial value (mm) and *nd* = number of days between the two measurements).

To test the effect of fertility on seedling height and basal diameter growth, linear mixed models were fitted. They were used to: (i) calculate monthly seedling growth rates, (ii) test whether the growth rates (slopes of the model lines) depended on the treatment and, (iii) test the interaction of fertilization with time. For each variable to be explained (height and diameter), a linear mixed model with and without treatment–time interaction was modelled. The fixed factors were treatment, time, and/or treatment–time interaction and the random factors were seedlings and gaps. Site characteristics were not included in the model as fixed factors because we did not sample the gaps across a gradient of environmental variables. The gaps were thus considered as random replicates of the experiment. When a treatment–time interaction was detected, a trend comparison test was performed to compare line slopes (growth rates). Subsequently, we retrieved these same models and added as a co-variate the total radiations transmitted to test whether part of the differences in growth could be explained by radiations. The null hypothesis was that total light would not influence the growth in height and diameter of seedlings.

Next, to quantify seedlings' survival according to treatments in logging gaps, we estimated the survival function *S(t)* over time using the non-parametric Kaplan–Meier estimator [40,41], which is the probability of an individual seedling surviving to time t, the time since beginning of the experiment:

$$S(t) = \prod t_i \leq t(1 - d_i/n_i) \quad (2)$$

where t_i is the time interval, d_i is the number of deaths that occurred in the interval t_i, n_i is the number of seedlings that were alive at the end of the interval t_i, and Π is the product operator across all cases less than or equal to t. We tested whether treatments significantly differed in terms of survival in logging gaps using log-rank tests.

2.4.2. Identification of Consumers of *C. gabunensis* Seedlings in Logging Gaps

A generalized linear mixed-effects model was fitted to test whether *C. gabunensis* seedlings were subject to directed predation. The variable to be explained was damage. The model had a fixed factor (seedling species) and a random factor (gaps). A Tukey post hoc test was performed in case of significant p-values.

The records obtained from pictures and videos allowed some descriptive analyses. The number of independent records per photo-captured species was recorded in each logging gap to calculate the average number of visits per species. The behavior associated with the species was described in detail and allowed the calculation of proportions by type of behavior for a given species. The duration of visits involving seedling consumption was calculated according to Tosso et al. [42].

All statistical analyses were performed within the open-source environment R (R version 4.1.2) [43]. The 'lmer' and 'glmer' functions of the 'lme4' package were used, for the fitting of mixed models [44] and for the fitting of generalized mixed effect models [45], respectively. The t-values were computed to test the significance of a fixed factor, with the p-values provided by the 'lmerTest' package [46]. The slope comparisons and post hoc analysis of the Tukey method were performed using the 'emmeans' package [47], with the 'emtrends', 'pairs' and 'emmeans' functions, respectively.

3. Results

3.1. Performance of C. gabunensis in Logging Gaps and Impact of Fertilizer

All treatments considered, the average annual growth rate was 31.7 cm.yr^{-1} (σ = 37.4 cm) in height and 3.4 mm.yr^{-1} (σ = 2.4 mm) in basal diameter. The height growth rate of the control plants averaged 1.84 cm per month, while it was 2.08 and 2.50 cm per month for the fertilized and fertilized with biochar treatments, respectively, but the differences were not significant (chi-square = 4.184, Df = 2, p = 0.123) (Figure 3; Tables A1 and A2). The diameter growth rates were 0.201 mm, 0.267 mm and 0.259 mm per month for control, fertilized and fertilized with biochar treatments, respectively. They were significantly different (chi-square = 11.87, Df = 2, p = 0.003). The differences were significant between the control seedlings and the seedlings that had received fertilizers alone (t = −3.178, Df = 672, p = 0.004) and between control and biochar fertilized seedlings (t = −2.779, Df = 676, p = 0.015). No significant difference was observed between seedlings with fertilizer and those with fertilizer and biochar (t = 0.4, Df = 671, p = 0.916) (Tables A1 and A3). We tested whether the addition of the transmitted radiation in the models could explain part of the seedling growth rates. The null hypothesis was accepted for the height growth rate (chi-square = 0.183, Df = 1, p = 0.669) suggesting that total transmitted radiation does not have a significant impact (Table A4). Conversely, the null hypothesis was rejected for the growth rate in diameter (chi-square = 25.027, Df = 1, p < 0.001). This means that light had an effect on the growth rate in diameter. Furthermore, the time–light interaction coefficient was positive. This indicates a positive effect of light on the diameter growth of the plants (Table A5).

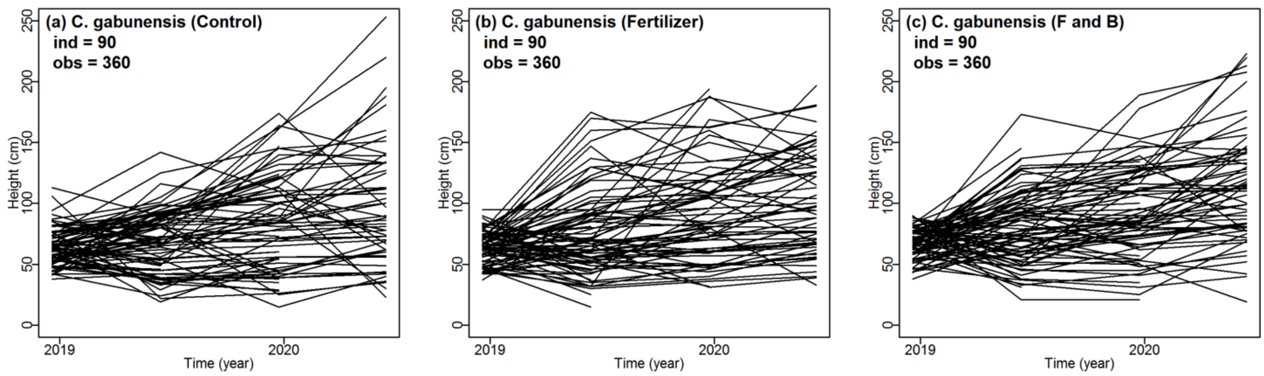

Figure 3. Height growth trajectory related to the installation date (between 2018 and 2020) for each seedling of *C. gabunensis* in logging gaps according to treatment; (**a**) control seedlings, (**b**) seedlings with fertilizer and (**c**) seedlings with fertilizer and biochar (F and B). Number of monitored seedlings (ind) and total number of measurements (obs) are given for each treatment. The discontinuous height trajectory for several seedlings is due to stem break events.

3.2. *Survival of C. gabunensis Seedlings in Logging Gaps*

At the end of the experiment (18 months), we observed that seedling mortality increased over time for all treatments. *C. gabunensis* seedlings combined with fertilizer or fertilizer and biochar had better survival rates compared to the control *C. gabunensis* seedlings (Figure 4). There was a significant difference in overall seedling survival depending on the treatment (Figure 4: Fertilizer vs. control: log-rank test $X^2 = 8.1$ with $p = 0.004$; Fertilizer plus biochar vs. control: log-rank test $X^2 = 4.6$ with $p = 0.03$). The use of NPK fertilizer with or without biochar seems to contribute to a better survival of seedlings. *C. gabunensis* seedlings with fertilizer and fertilizer plus biochar (each with 61 out of 90 (67.8%) showed significantly higher survival than control *C. gabunensis* seedlings with 56 out of 90 (62.2%) surviving plants.

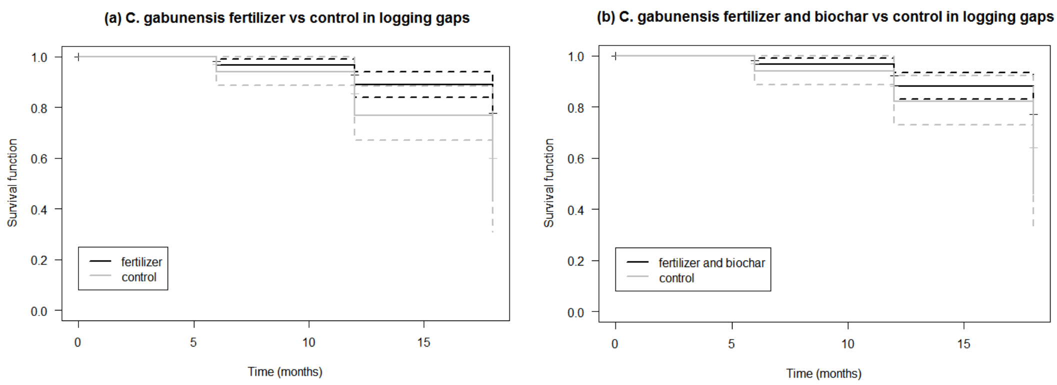

Figure 4. Kaplan–Meier estimates survival over time of *C. gabunensis* seedlings with their 95% confidence limits, as a function of treatment in logging gaps. (**a**) *C. gabunensis* seedlings with fertilizer vs. control *C. gabunensis* seedlings; and (**b**) *C. gabunensis* seedlings with fertilizer and charcoal vs. control *C. gabunensis* seedlings.

3.3. *Predation of C. gabunensis Seedlings in Logging Gaps*

Assessing the effect of herbivory in enriched logging gaps showed that the consumption of *C. gabunensis* seedlings and other species was statistically different. *C. gabunensis* seedlings were consumed more than seedlings of other species ($Z = 5.7$, $p < 0.0001$). The 1406 camera-days yielded 418 independent detection events, split between photos and videos (5% photos and 95% videos). The detections included 12 terrestrial mammal and one bird species (Table A6). The detected mammal species included taxa with strong conservation concerns, such as the critically endangered elephant (*Loxodonta cyclotis* Matschie, 1900), gorilla (*Gorilla gorilla gorilla* Savage, 1847), chimpanzee (*Pan troglodytes troglodytes* lumenbash, 1775) and buffalo (*Syncerus caffer nanus* Boddaert, 1785; near threatened) which were also detected. Species that showed at least one interaction with seedlings in the gaps were: (i) the *Cephalophus* species complex with 146 detections, (ii) *Cephalophus silvicultor* Afzelius, 1815 (76 detections), (iii) *Gorilla gorilla* (14 detections) and (iv) *Loxodonta cyclotis* (64 detections). Species of the *Cephalophus* complex visited the plantations the most, with an average of 4.87 visits (σ = 4.39) per plantation and spent about 1.5 min per visit. *C. silvicultor* visited the plantations, with an average of 2.57 visits (σ = 3.18) per plantation and spent about 3.4 min per visit consuming the plants. The gorilla (*Gorilla gorilla*) had the lowest number of visits (0.47 on average; σ = 0.73), with an average time of 1.25 min. Compared to the other species detected, *Loxodonta cyclotis* did not have a very high average number of visits (2.13 visits on average; σ = 1.57) but it spent more time in the plantations (about 6 min) (Table 1).

Table 1. List of detected species involved in seedling consumption with: the number of detections, number of visits (average ± SD) and duration of consumption on the visits (average ± SD) within the plantations.

Species	Total Number of Detections	Average Number of Visits	Average Duration of Visits (min)
Cephalophus sp.	146	4.87 ± 4.39	1.5 ± 0.71
Cephalophus silvicultor	76	2.53 ± 3.18	3.4 ± 2.88
Gorilla gorilla	14	0.47 ± 0.73	1.25 ± 0.5
Loxodonta cyclotis	64	2.13 ± 1.57	5.8 ± 4.64

Loxodonta cyclotis was the most damaging species in the plantations (Figures 5 and 6). In 39% of the cases, it consumed plants of *C. gabunensis* and other species. Damage ranged from complete leaflet tearing and stem breakage to complete soil tearing of *C. gabunensis* seedlings (Table A7; Figure 5). The other species detected were only interested in the leaflets of *C. gabunensis* seedlings. *Cephalophus* sp., *Cephalophus silvicultor* and *Gorilla gorilla* consumed seedling leaflets during 1.37%, 6.58% and 28.57% observation events, respectively (Figure 5).

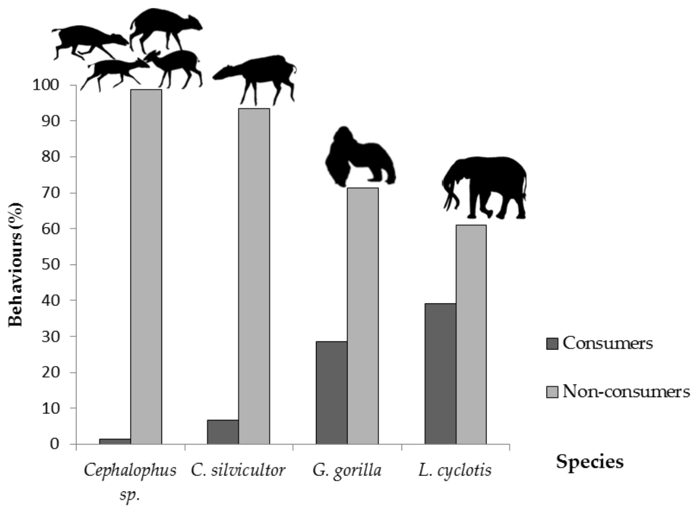

Figure 5. Distribution of behavior for each species of interest.

Figure 6. Consumers of *C. gabunensis* seedlings in plantations; (**a**–**e**): *L. cyclotis*; (**f**): *G. gorilla*.

4. Discussion

4.1. Growth and Mortality of C. gabunensis Seedlings in Logging Gaps

In logging gaps, we obtained average annual growth rates of 31.7 cm and 3.4 mm in height and diameter, respectively. These values were rather low. Doucet et al. [13] introduced the species in multispecies plantations (subplots of 25 plants) in south-east Cameroon. These plantations were carried out in areas of degraded forest where the forest understory was removed by machete and only a few large trees were retained. Under moderate shade, mean diameter growth (after 690 days of observation; number monitored: n = 102) was 5.1 mm.yr$-^{1}$ (σ = 0.8 mm). In the same country, in a nursery, in bags with enriched forest soil substrates, *C. gabunensis* seedlings show growth in height between 30 and 40 cm after 8 to 10 months [4]. The results of this study showed that the height growth rate of *C. gabunensis* seedlings was higher when fertilizer was applied in combination with biochar, although these results were not significantly different from the control treatment (Tables A1 and A2). Neither the application of fertilizers alone nor the mixture of fertilizer and biochar had a significant influence on the height growth of *C. gabunensis* seedlings. The lack of significance of the growth rate in height in our study could probably be explained by the variability of heights because of wildlife breaking the stems of the plants, which could confuse the signal (Figure 3; Table A1). It is also possible that fertilizers may not influence height growth of the seedlings [48], but this seems unlikely for *C. gabunensis* seedlings, which prefer relatively fertile soils for their establishment [2]. The effect of light on the growth of *C. gabunensis* seedlings followed the same path as the effect of fertilization in this study. The light had no significant effect on the growth rate in height, while for the growth rate in diameter the effect was significant. This means that the growth in diameter tended to increase with increasing light. In evergreen forest, Daïnou et al. [4] suggest annual height growth is less than 50 cm in logging gaps, whereas it is higher in plantations on log yards where annual height growth is between 50 and 100 cm. This suggests that the conditions for plant growth are better in this type of environment. In Cameroon, *P. elata*, a light-demanding species established as a result of past human disturbance similar to *C. gabunensis* [2,49], was introduced into logging gaps that were either left without maintenance or cleared [14]. Over a period of 5 years, seedlings in gaps without any maintenance showed a relatively lower average annual growth in diameter (2.8 $mm.yr^{-1}$, σ = 1.4 mm) compared to that obtained in our study over a relatively short period. Meanwhile, the height performance of the seedlings was much better (44.8 $cm.yr^{-1}$ σ = 23.5 cm) in both the sites with and without maintenance [14].

The rate of seedling diameter growth increased significantly under the addition of fertilizer alone or with biochar. By examining the survival and growth of two tropical tree species in Amazonia under six nursery treatments over a six-month period, Lefebvre et al. [30] showed a positive effect of the addition of biochar and fertilizer on the height and diameter growth of the seedlings of *Guazuma crinita* Mart. and *Terminalia amazonia* (JF Gmel.) Exell. Similar patterns were also observed in southern Africa [50]. In combination with unsterilized forest soil, NPK fertilizers and foliar fertilizer (a solution consisting of: 41.5 g/L N, 58.2 g/L P, 1409 mg/L Zn, 1409 mg/L Cu, 2818 mg/L Fe, 1409 mg/L Mn, 198 mg/L Mo, 2818 mg/L B, 2.2 mg/L Auxin and 0. 006 mg/L Cytokinins) Sileshi et al. [50] showed the positive effect of artificial fertilizers inputs on the growth in height, diameter and biomass allocation of *Uapaca kirkiana* seedlings in a nursery after 11 months. Román-Dañobeytia et al. [51] demonstrated, in Amazonia, that the addition of a biofertilizer (a macro- and micronutrient-rich solution resulting from the fermentation of organic and mineral matter at a rate of 55 and 555 L/ha) significantly increased monthly seedling growth in height and diameter during annual monitoring of the growth of native species in former gold mining areas. For one of the species studied (*Ceiba pentandra*), growth rates in seedling diameter and height were improved by adding dilute or pure biofertilizer in both bare-root planting and transplanting methods. However, in their study, the authors treated the plants with biofertilizer every 15 days for the first 6 months, whereas the increase in growth observed in our study was based on a single application of fertilizer after transplanting the plants in logging gaps. The combination of fertilization and cleaning after planting would thus probably improve the growth performance of *C. gabunensis* seedlings in logging gaps, as has been achieved for other tree species [14,30,52].

Plant survival was significantly lower in control seedlings compared to plants with fertilizers alone and with fertilizer plus biochar in the logging gaps. Indeed, it has been shown in previous studies that fertilizer inputs to the soil reduce the probability of plant mortality compared to substrates without fertilizers [50]. In a study carried out in south-eastern Cameroon, Doucet et al. [13] introduced *C. gabunensis* seedlings into multispecies plantations (in plots of 25 seedlings). These plantations were established in degraded forest areas under moderate shade, with a survival rate of 83% after 690 days (number of plants monitored: n = 102). In our study, the survival rate was close to 80% at 455 days for the fertilizer only and fertilizer plus biochar treatments, while it was lower for the control treatment. Field observations revealed that mortality was mainly caused by wildlife damage within the plantations, as observed by many authors in plantations of varying ages [53,54].

4.2. Predators of C. gabunensis Seedlings in Logging Gaps

Very little information is available on the damage caused by wildlife to vegetation of African moist forest. For example, little is known about the damage caused by elephants in their biotope compared to their role as seed dispersers [55]. Some studies mentioned the damage caused by wildlife in plantations [4]. Brunck [15], for example, reports that antelopes were damaging several tree species in plantations in Congo. This damage, described as severe, could lead to the death of plants in plantations/plots when caused by elephants and/or buffalo in Gabon [15,17]. In the same country, Brunck et al. [16] found that in some plantations four to five years old, mortality due to elephants affected more than half the plants. Fayolle et al. [54] also observed high mortality of *Milicia excelsa* (Welw.) C.C.Berg stems in plantations that could be linked to herbivory. In addition, Leroy-Deval [53] reported significant damage by elephants in five to six-year-old Okoumé (*A. klaineana*) plantations in Gabon. The results of this study show that *C. gabunensis* seedlings were significantly more consumed than other species in logging gaps. In addition, indirect observations identified four main animal species involved in predation on *C. gabunensis* seedlings: *Cephalophus* sp., *C. silvicultor*, *G. gorilla* and *L. cyclotis*. In this study, *L. cyclotis* was the main consumer of seedlings and preferentially consumed those of *C. gabunensis*. *Loxodonta cyclotis* took longer in the plantations and caused more impetuous damage to the plants than other species. Based on the evidence from our photographic and video observations, the consumption of *C. gabunensis* seedlings by *L. cyclotis* was not always systematic. Some individuals sniffed the *C. gabunensis* plants without consuming them. Because adult *C. gabunensis* trees are frequently debarked by *L. cyclotis* [56], it is likely that the pachyderm has a particular interest for *C. gabunensis*. Scalbert et al. [57] listed *C. gabunensis* among the most frequently debarked species and Holvoet [58] attributed this behavior to self-medication. It is likely that the animals consumed the seedlings of this species as a parasite killer because *C. gabunensis* is frequently used in traditional medicine for this purpose [3]. Studying the ecophysiology of forest elephants in Gabon, Ngama [59] showed that parasitized forest elephants had a diet heavily dominated by the leaves of plant species whose medicinal properties are recognized by local human populations. This suggests that the forest elephant selects its food not only for its nutritional value, but also for its medicinal properties, as suggested by our study. In western Uganda, elephants regularly frequent logging gaps, resulting in a slower regeneration than in unlogged areas [60,61]. In such areas the direct impact of elephants is greater than that of herbaceous plants [62]. It is likely that within logging gaps, elephants trample seedlings [63,64] and break stems [65]. Seedlings that manage to survive this damage may experience a slowdown in growth. Indeed, felling gaps and skidding trail networks caused by logging operations could encourage the proliferation of herbaceous plants and facilitate the movement of elephants in the logged areas [60]. This would probably increase breakage of seedlings and saplings and slow their growth. Therefore, in areas with high wildlife densities, a balance must be struck between stimulating plant growth by clearing and preserving wildlife damage. In temperate forest managed for production, this is also a crucial issue [66–69].

5. Conclusions

In this study, we obtained moderate growth rates of *C. gabunensis* in logging gaps. Impacts of elephants were important and, by breaking or consuming the most vigorous stems, they reduce the average growth rates of the population. We also emphasized a positive influence of the light on the seedling performance. The planting of *C. gabunensis* should thus be only recommended in large gaps and in areas with low elephant densities. Numerous studies have shown that without plantings, populations of many light-demanding species populations will collapse in the next decades. In central Africa, very few logging companies implement planting programs in natural forests and most of them are FSC-certified. The use of fertilizer in forests is not allowed by the FSC standards. In our experiment, we showed that a single application of fertilizer at the start of the experiment significantly increased survival and diameter growth of *C. gabunensis* while an additional impact of biochar was not detected. We therefore suggest that current certification standards should be revised to tolerate local applications of fertilizer in high-value timber species plantations.

Author Contributions: Conceptualization, R.N.M., F.T., C.M., Y.B. and J.-L.D.; methodology, R.N.M., G.L., C.M., Y.B. and J.-L.D.; software, R.N.M. and G.L.; validation, F.T., C.M., Y.B. and J.-L.D.; formal analysis, R.N.M. and Y.B.; investigation, R.N.M. and J.-L.D.; resources, R.N.M., C.M. and J.-L.D.; data curation, R.N.M. and J.-L.D.; writing—original draft preparation, R.N.M.; writing—review and editing, F.T., C.M., G.L., Y.B. and J.-L.D.; supervision, Y.B. and J.-L.D.; funding acquisition, J.-L.D. All authors have read and agreed to the published version of the manuscript.

Funding: The research was supported by the Precious Forests Foundation and Precious Woods CEB (Okan Project).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We are grateful to DynAfFor project, under contract nos. CZZ1636.01D and CZZ1636.02D administered by the Agence Française de Développement (AFD), financed by the French Facility for Global Environment (FFEM) and executed by the ATIBT/CIRAD/Nature+/Gembloux Agro-Bio Tech consortium. We thank the Precious Forests Foundation and Precious Woods CEB for funding our work (we thank especially, Frédéric Ober, Jean Mounguengui, Philippe Jeanmart, David Zakamdi). We would like to thank all those who participated in the production and collection of the data in the field: Stévy Nna Ekome, Lucie Maus, Jean-Bosco Bokomba, Augustin Assam, Jean Arnisse Mboulamab, Davy Fonteyn and Morgane Scalbert. Special thanks to Adeline Fayolle for her support in data processing. We are grateful to the Centre national de la Recherche Scientifique (CENAREST) and l'Herbier National du Gabon for giving authorization to do research in Gabon.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Average height and diameter and associated standard errors as a function of time steps. F and C = Fertilizer and biochar.

Treatment	Time (Months)	Mean Height (cm)	Standard Error	Mean Diameter (cm)	Standard Error
Control	0	64.04	1.65	0.49	0.01
Fertilizer	0	63.00	1.40	0.49	0.01
F and C	0	66.17	1.37	0.51	0.01
Control	6	69.18	2.83	0.64	0.02
Fertilizer	6	77.19	3.95	0.75	0.03
F and C	6	81.44	3.43	0.81	0.03
Control	12	84.48	4.75	0.78	0.02
Fertilizer	12	91.31	4.69	0.91	0.04
F and C	12	92.65	4.26	0.92	0.03
Control	18	99.05	6.52	0.85	0.03
Fertilizer	18	100.87	5.22	0.96	0.04
F and C	18	113.84	5.76	0.97	0.04

Table A2. Effect of treatment on the growth rate in plant height.

	npar	AIC	BIC	logLik	Deviance	Chisq	Df	Pr(>Chisq)
m0	6	8645.6	8674.3	−4316.8	8633.6	/	/	/
m1	8	8645.4	8683.8	−4314.7	8629.4	4.1841	2	0.1234

Table A3. Effect of treatment on the growth rate in plant diameter.

	npar	AIC	BIC	logLik	Deviance	Chisq	Df	Pr(>Chisq)
m2	6	−334.86	−306.07	173.43	−346.86	/	/	/
m3	8	−342.73	−304.34	179.36	−358.73	11.87	2	0.002645

Table A4. Effect of light on the growth rate in plant height.

	npar	AIC	BIC	logLik	Deviance	Chisq	Df	Pr(>Chisq)
m4	7	8647.0	8680.6	−4316.5	8633.0	/	/	/
m5	8	8648.8	8687.2	−4316.4	8632.8	0.183	1	0.6688

Table A5. Effect of light on the growth rate in plant diameter.

	npar	AIC	BIC	logLik	Deviance	Chisq	Df	Pr(>Chisq)
m6	7	−346.23	−312.64	180.11	−360.23	/	/	/
m7	8	−369.25	−330.87	192.63	−385.25	25.027	1	5.652×10^{-7}

Table A6. List of detected species with the IUCN status ('Least Concern' [LC], 'Near Threatened' [NT], 'Vulnerable' [VU], 'Endangered' [EN], or 'Critically Endangered' [CR]), and number of detections by species.

Species	IUCN Status	No. of Detections
Philantomba monticola simpsoni Thunberg, 1789	LC	4
Cephalophus ogilbyi crusalbum Grubb, 1978	NT	9
Cephalophus silvicultor Afzelius, 1815	NT	76
Cephalophus sp.	/	146
Pan troglodytes Btroglodytes Blumenbash, 1775	NT	47
Civettictis civetta Schreber, 1776	LC	20
Loxodonta cyclotis Matschie, 1900	CR	64
Genetta sp.	/	15
Gorilla gorilla gorilla Savage, 1847	CR	14
Unidentified bird species	/	4
Panthera pardus pardus Linnaeus, 1758	VU	2
Potamochoerus porcus Linnaeus, 1758	LC	4
Syncerus caffer nanus Boddaert, 1785	NT	13

Table A7. List of detected species with their behaviors.

Behaviours	*C. silvicultor*	*Cephalophus* sp.	*L. cyclotis*	*G. gorilla*
Pulling up a *C. gabunensis* plant and eat their leaves	-	-	1	-
Circulating	24	27	9	8
Interacting with camera	3	8	2	-
Playing	-	-	1	-
Eating other vegetation	33	71	20	1
Eating *C. gabunensis* leaves and breaking the plant	-	-	5	-
Eating *C. gabunensis* leaves without breaking the plant	5	2	13	4
Sniffing other plants and eating their leaves	-	1	-	-
Sniffing other plants without eating	-	1	2	-
Sniffing *C. gabunensis* plants and eating their leaves	-	-	6	-
Sniffing *C. gabunensis* plants without eating their leaves	3	6	3	-
Sniffing vegetation on the ground	8	30	1	-
Staying static	-	-	1	1

References

1. Meunier, Q.; Moumbogou, C.; Doucet, J.-L. *Les Arbres Utiles Du Gabon*; Les Presses agronomiques de Gembloux: Gembloux, Belgique, 2015.
2. Ndonda Makemba, R.; Moupela, C.; Tosso, F.; Brostaux, Y.; Drouet, T.; Oslisly, R.; Freycon, V.; Doucet, J.-L. New Evidence on the Role of Past Human Activities and Edaphic Factors on the Fine-Scale Distribution of an Important Timber Species: Cylicodiscus Gabunensis Harms. *For. Ecol. Manag.* **2022**, *521*, 120440. [CrossRef]
3. Ndonda Makemba, R.; Tosso, D.F.; Moupela, C.; Daïnou, K.; Doucet, J.-L. Cylicodiscus gabunensis Harms: Une espèce prisée dans le commerce international (synthèse bibliographique). *Biotechnol. Agron. Société Environ.* **2019**, *23*, 188–202. [CrossRef]

4. Daïnou, K.; Tosso, D.F.; Bracke, C.; Bourland, N.; Forni, E.; Hubert, D.; Kankolongo, M.; Loumeto, J.J.; Louppe, D.; Ngomanda, A. *Guide Pratique Des Plantations d'arbres Des Forêts Denses Humides d'Afrique*; Les Presses Universitaires de Liège: Agronomie Gembloux, Belgique, 2021.
5. Eba'a Atyi, R.; Hiol Hiol, F.; Lescuyer, G.; Mayaux, P.; Defourny, P.; Bayol, N.; Saracco, F.; Pokem, D.; Sufo Kankeu, R.; Nasi, R. *Les forêts du bassin du Congo: État des Forêts 2021*; Center for International Forestry Research (CIFOR): Bogor Regency, Indonesia, 2022.
6. Obiang, N.L.E.; Ngomanda, A.; Hymas, O.; Chézeauxl, É.; Picard, N. Diagnosing the Demographic Balance of Two Light-Demanding Tree Species Populations in Central Africa from Their Diameter Distribution. *For. Ecol. Manag.* **2014**, *313*, 55–62. [CrossRef]
7. Morin-Rivat, J.; Fayolle, A.; Favier, C.; Bremond, L.; Gourlet-Fleury, S.; Bayol, N.; Lejeune, P.; Beeckman, H.; Doucet, J.-L. Present-Day Central African Forest Is a Legacy of the 19th Century Human History. *Elife* **2017**, *6*, e20343. [CrossRef]
8. Doucet, J.-L.; Kouadio, Y.L. Le Moabi, Une Espèce «phare» de l'exploitation Forestière En Afrique Centrale. *Parcs Réserves* **2007**, *62*, 25–31.
9. FRMi. *Vision Stratégique et Industrialisation de La Filière Bois Dans Les 6 Pays Du Bassin Du Congo, Horizon 2030*; Rapport Stratégique Régional; FRMi: Montpellier, France, 2018.
10. Doucet, J.-L.; Kouadio, Y.L.; Monticelli, D.; Lejeune, P. Enrichment of Logging Gaps with Moabi (Baillonella Toxisperma Pierre) in a Central African Rain Forest. *For. Ecol. Manag.* **2009**, *258*, 2407–2415. [CrossRef]
11. Grogan, J.; Landis, R.M.; Free, C.M.; Schulze, M.D.; Lentini, M.; Ashton, M.S. Big-Leaf Mahogany S Wietenia Macrophylla Population Dynamics and Implications for Sustainable Management. *J. Appl. Ecol.* **2014**, *51*, 664–674. [CrossRef]
12. Marien, J.-N.; Mallet, B. Nouvelles Perspectives Pour Les Plantations Forestières En Afrique Centrale. 2004. Available online: https://agritrop.cirad.fr/522570/ (accessed on 29 September 2022).
13. Doucet, J.-L.; Daïnou, K.; Ligot, G.; Ouédraogo, D.-Y.; Bourland, N.; Ward, S.E.; Tekam, P.; Lagoute, P.; Fayolle, A. Enrichment of Central African Logged Forests with High-Value Tree Species: Testing a New Approach to Regenerating Degraded Forests. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2016**, *12*, 83–95. [CrossRef]
14. Ouédraogo, D.-Y.; Fayolle, A.; Daïnou, K.; Demaret, C.; Bourland, N.; Lagoute, P.; Doucet, J.-L. Enrichment of Logging Gaps with a High Conservation Value Species (Pericopsis Elata) in a Central African Moist Forest. *Forests* **2014**, *5*, 3031–3047. [CrossRef]
15. Brunck, F. Parasites Des Plantations Forestières d'Afrique Tropicale et de Madagascar et Mesures de Protection. *BOIS FORETS Trop.* **1965**, *103*, 17–25.
16. Brunck, F.; Grison, F.; Maître, H.-F. *L'okoumé Aucoumea klaineana Pierre: Monographie*; JOUVE; CIRAD-CTFT: Nogent-sur-Marne Cedex, France, 1990; ISBN 978-2-85411-015-9.
17. Fuhr, M.; Delègue, M.-A.; Nasi, R.; Minkoué, J.-M. *Dynamique et Croissance de l'Okoumé En Zone Côtière Du Gabon*; CIRAD-Forêt: Montpellier, France, 1998; Volume 16.
18. TEREA. *Plan d'aménagement de La Concession Forestière Sous Aménagement Durable de La Société Precious Woods -CEB 2000-2024. CEB*; TEREA: Libreville, Gabon, 2015.
19. Moupela, C.; Doucet, J.-L.; Daïnou, K.; Tagg, N.; Bourland, N.; Vermeulen, C. Dispersal and predation of diaspores of Coula edulis Baill. in an evergreen forest of Gabon. *Afr. J. Ecol.* **2014**, *52*, 88–96. [CrossRef]
20. Cabaillé, G.; Fontès, J. Les Inventaires Forestiers Au Gabon: Applications à La Phytogéographie. *BOIS FORETS Trop.* **1978**, *177*, 15–33.
21. Noce, S.; Caporaso, L.; Santini, M. A New Global Dataset of Bioclimatic Indicators. *Sci. Data* **2020**, *7*, 398. [CrossRef] [PubMed]
22. Martin, D.; Chatelin, Y.; Collinet, J.; Guichard, E.; Sala, G.-H.; Le Rouget, G. *Les Sols Du Gabon: Pedogenese, Repartition et Aptitudes: Cartes a 1: 2.000. 000*; ORSTOM: Paris, France, 1981.
23. Jones., A.; Breuning-Madsen, H.; Brossard, M.; Dampha, A.; Deckers, J.; Dewitte, O.; Gallali, T.; Hallett, S.; Jones, R.; Kilasara, M.; et al. *Soil Atlas of Africa*; European Commission: Luxembourg, 2013; ISBN 978-92-79-26715-4.
24. Réjou-Méchain, M.; Mortier, F.; Bastin, J.-F.; Cornu, G.; Barbier, N.; Bayol, N.; Bénédet, F.; Bry, X.; Dauby, G.; Deblauwe, V. Unveiling African Rainforest Composition and Vulnerability to Global Change. *Nature* **2021**, *593*, 90–94. [CrossRef] [PubMed]
25. Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **2013**, *342*, 850–853. [CrossRef] [PubMed]
26. De La Mensbruge, G. *La Germination et Les Plantules Des Essences Arborées de La Forêt Dense Humide de La Côte d'Ivoire. Publication N°26.*; Centre Technique Forestier Tropical: Nogent-sur-Marne, France , 1966.
27. Onguene, N.A.; Kuyper, T.W. Mycorrhizal Associations in the Rain Forest of South Cameroon. *For. Ecol. Manag.* **2001**, *140*, 277–287. [CrossRef]
28. Tedersoo, L.; Laanisto, L.; Rahimlou, S.; Toussaint, A.; Hallikma, T.; Pärtel, M. Global Database of Plants with Root-Symbiotic Nitrogen Fixation: NodDB. *J. Veg. Sci.* **2018**, *29*, 560–568. [CrossRef]
29. Duah-Gyamfi, A.; Kyereh, B.; Adam, K.A.; Agyeman, V.K.; Swaine, M.D. Natural Regeneration Dynamics of Tree Seedlings on Skid Trails and Tree Gaps Following Selective Logging in a Tropical Moist Semi-Deciduous Forest in Ghana. *Open J. For.* **2014**, *04*, 49–57. [CrossRef]
30. Lefebvre, D.; Román-Dañobeytia, F.; Soete, J.; Cabanillas, F.; Corvera, R.; Ascorra, C.; Fernandez, L.E.; Silman, M. Biochar Effects on Two Tropical Tree Species and Its Potential as a Tool for Reforestation. *Forests* **2019**, *10*, 678. [CrossRef]
31. Ligot, G.; Mackels, B. *Photographies Hémisphériques*; Université de Liège: Gembloux, Belgique, 2011; p. 27.

32. Adam, B.; Benoit, J.C.; Sinoquet, H.; Balandier, P.; Marquier, A. PiafPHOTHEM: Un Logiciel de Seuillage de Photographies Hémisphériques. Centre Technique Forestier Tropical: Nogent-sur-Vernisson, France, 2013; p. 7.
33. Frazer, G.W.; Canham, C.D.; Lertzman, K.P. Gap Light Analyzer (GLA): Imaging Software to Extract Canopy Structure and Gap Light Transmission Indices from True-Colour Fisheye Photographs, Users Manual and Program Documentation. 1999. Available online: https://www.scienceopen.com/document?vid=4956bf51-5c3a-45ce-bf58-7d9e0f903afb (accessed on 29 September 2022).
34. Caravaggi, A.; Gatta, M.; Vallely, M.-C.; Hogg, K.; Freeman, M.; Fadaei, E.; Dick, J.T.; Montgomery, W.I.; Reid, N.; Tosh, D.G. Seasonal and Predator-Prey Effects on Circadian Activity of Free-Ranging Mammals Revealed by Camera Traps. *PeerJ* **2018**, *6*, e5827. [CrossRef]
35. O'Brien, T.G.; Kinnaird, M.F.; Wibisono, H.T. Crouching Tigers, Hidden Prey: Sumatran Tiger and Prey Populations in a Tropical Forest Landscape. In *Proceedings of the Animal Conservation Forum*; Cambridge University Press: Cambridge, UK, 2003; pp. 131–139.
36. Tobler, M. Camera Base Version 1.7, User Guide. 2015. Available online: https://Www.Atrium-Biodiversity.Org/Tools/Camerabase/ (accessed on 13 May 2022).
37. Greenberg, S. Timelapse Quick Start Guide. A Minimalist Guide to Downloading and Using Timelapse to Tag Image and Video Files. 20 May. Available online: https://Saul.Cpsc.Ucalgary.ca/Timelapse/Pmwiki.Php?N=Main.Download2 (accessed on 20 May 2022).
38. Meek, P.D.; Ballard, G.; Claridge, A.; Kays, R.; Moseby, K.; O'brien, T.; O'connell, A.; Sanderson, J.; Swann, D.E.; Tobler, M. Recommended Guiding Principles for Reporting on Camera Trapping Research. *Biodivers. Conserv.* **2014**, *23*, 2321–2343. [CrossRef]
39. Kingdon, J. *The Kingdon Field Guide to African Mammals*, 2nd ed.; Bloomsbury Publishing: London, UK, 2015.
40. Harrell, F.E. *Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis*; Springer: Berlin/Heidelberg, Germany, 2001; Volume 608.
41. Goel, M.K.; Khanna, P.; Kishore, J. Understanding Survival Analysis: Kaplan-Meier Estimate. *Int. J. Ayurveda Res.* **2010**, *1*, 274–278. [CrossRef] [PubMed]
42. Tosso, F.; Cherchye, G.; Hardy, O.J.; Daïnou, K.; Lognay, G.; Tagg, N.; Haurez, B.; Souza, A.; Heuskin, S.; Doucet, J.-L. Characterization of Animal Communities Involved in Seed Dispersal and Predation of Guibourtia Tessmannii (Harms) J.Léonard, a Species Newly Listed on Appendix II of CITES. *Afr. J. Ecol.* **2018**, *56*, 468–476. [CrossRef]
43. R Core Team. *R: A Language and Environment for Statistical Computing*; R Core Team: Vienna, Austria, 2021.
44. Bates, D.; Mächler, M.; Bolker, B.; Walker, S. Fitting Linear Mixed-Effects Models Using Lme4. *arXiv* **2014**, arXiv:Prepr. ArXiv14065823.
45. Zhang, H.; Lu, N.; Feng, C.; Thurston, S.W.; Xia, Y.; Zhu, L.; Tu, X.M. On Fitting Generalized Linear Mixed-Effects Models for Binary Responses Using Different Statistical Packages. *Stat. Med.* **2011**, *30*, 2562–2572. [CrossRef]
46. Kuznetsova, A.; Brockhoff, P.B.; Christensen, R.H.B. LmerTest Package: Tests in Linear Mixed Effects Models. *J. Stat. Softw.* **2017**, *82*, 1–26. [CrossRef]
47. Lenth, R.V.; Buerkner, P.; Herve, M.; Jung, M.; Love, J.; Miguez, F.; Riebl, H.; Singmann, H. Package 'Emmeans':Estimated Marginal Means, Aka Least-Squares Means. Version 1.8.1-1. Available online: https://www.google.com/search?q=emmeans+package+r&oq=emmeans+package+r&aqs=chrome.0.69i59j0i22i30j69i60l3.8130j0j7&sourceid=chrome&ie=UTF-8 (accessed on 13 September 2022).
48. Opuni-Frimpong, E.; Opoku, S.M.; Opoku, E.M.; Storer, A.J. Silvicultural Systems for Plantation Mahogany in Africa: Effect of Mixed Species Stands on Growth and Hypsipyla Attack of African Mahogany (Khaya Anthotheca and Khaya Ivorensis). *Ghana J. For.* **2020**, *36*, 72–88.
49. Bourland, N.; Cerisier, F.; Daïnou, K.; Livingstone Smith, A.; Hubau, W.; Beeckman, H.; Brostaux, Y.; Fayolle, A.; Biwolé, A.B.; Fétéké, F. How Tightly Linked Are Pericopsis Elata (Fabaceae) Patches to Anthropogenic Disturbances in Southeastern Cameroon? *Forests* **2015**, *6*, 293–310. [CrossRef]
50. Sileshi, G.; Akinnifesi, F.K.; Mkonda, A.; Ajayi, O.C. Effect of Growth Media and Fertilizer Application on Biomass Allocation and Survival of Uapaca Kirkiana Müell Arg Seedlings. *Sci Res Essays* **2007**, *2*, 408–415.
51. Román-Dañobeytia, F.; Huayllani, M.; Michi, A.; Ibarra, F.; Loayza-Muro, R.; Vázquez, T.; Rodríguez, L.; García, M. Reforestation with Four Native Tree Species after Abandoned Gold Mining in the Peruvian Amazon. *Ecol. Eng.* **2015**, *85*, 39–46. [CrossRef]
52. Schwartz, G.; Lopes, J.C.A.; Mohren, G.M.J.; Peña-Claros, M. Post-Harvesting Silvicultural Treatments in Logging Gaps: A Comparison between Enrichment Planting and Tending of Natural Regeneration. *For. Ecol. Manag.* **2013**, *293*, 57–64. [CrossRef]
53. Leroy-Deval, J. La Sylviculture de l'Okoumé (Maladies et Défauts de l'Okoumé). *CENTRE TECHNIQUE FORESTIER TROPICAL* **1976**, *Tome 2*, 75.
54. Fayolle, A.; Ouedraogo, D.-Y.; Ligot, G.; Daïnou, K.; Bourland, N.; Tekam, P.; Doucet, J.-L. Differential Performance between Two Timber Species in Forest Logging Gaps and in Plantations in Central Africa. *Forests* **2015**, *6*, 380–394. [CrossRef]
55. Poulsen, J.R.; Koerner, S.E.; Moore, S.; Medjibe, V.P.; Blake, S.; Clark, C.J.; Akou, M.E.; Fay, M.; Meier, A.; Okouyi, J. Poaching Empties Critical Central African Wilderness of Forest Elephants. *Curr. Biol.* **2017**, *27*, R134–R135. [CrossRef]
56. Short, J. Diet and Feeding Behaviour of the Forest Elephant. 1981. Available online: https://www.degruyter.com/document/doi/10.1515/mamm.1981.45.2.177/html (accessed on 29 September 2022).
57. Scalbert, M.; Vermeulen, C.; Breuer, T.; Doucet, J.-L. The Challenging Coexistence of Forest Elephants Loxodonta Cyclotis and Timber Concessions in Central Africa. *Mammal Rev.* **2022**. [CrossRef]

58. Holvoet, J. *Ecorcement des espèces ligneuses par l'éléphant de forêt (Loxodonta cyclotis Matschie, 1900) dans le Parc National de la Lopé (Gabon)*; Mémoire; Gembloux Agro-Bio Tech (Université de Liège): Gembloux, Belgium, 2021.
59. Ngama, S. Introduction to Elephant Ecophysiology: Principles, Methods and Case Studies on Forest Elephant (Loxodonta Africana Cyclotis) Crop Raiders in Gabon. Ph.D. Thesis, Gembloux Agro-Bio Tech (University of Liège), Gembloux, Belgium, 2018.
60. Chapman, C.A.; Chapman, L.J. Forest Regeneration in Logged and Unlogged Forests of Kibale National Park, Uganda. *Biotropica* **1997**, *29*, 396–412. [CrossRef]
61. Omeja, P.A.; Lawes, M.J.; Corriveau, A.; Valenta, K.; Sarkar, D.; Paim, F.P.; Chapman, C.A. Recovery of Tree and Mammal Communities during Large-Scale Forest Regeneration in Kibale National Park, Uganda. *Biotropica* **2016**, *48*, 770–779. [CrossRef]
62. Lawes, M.J.; Chapman, C.A. Does the Herb Acanthus Pubescens and/or Elephants Suppress Tree Regeneration in Disturbed Afrotropical Forest? *For. Ecol. Manag.* **2006**, *221*, 278–284. [CrossRef]
63. Piiroinen, T.; Valtonen, A.; Roininen, H. Vertebrate Herbivores Are the Main Cause of Seedling Mortality in a Logged African Rainforest—Implications for Forest Restoration. *Restor. Ecol.* **2017**, *25*, 442–452. [CrossRef]
64. Rosin, C.; Beals, K.K.; Belovitch, M.W.; Harrison, R.E.; Pendred, M.; Sullivan, M.K.; Yao, N.; Poulsen, J.R. Assessing the Effects of Elephant Foraging on the Structure and Diversity of an Afrotropical Forest. *Biotropica* **2020**, *52*, 502–508. [CrossRef]
65. Wing, L.D.; Buss, I.O. Elephants and Forests. *Wildl. Monogr.* **1970**, 3–92.
66. Gill, R.M.A.; Webber, J.; Peace, A. The Economic Implications of Deer Damage: A Review of Current Evidence. *For. Res. Agency Wrecclesham Surrey* **2000**, 1–49.
67. Bernes, C.; Macura, B.; Jonsson, B.G.; Junninen, K.; Müller, J.; Sandström, J.; Lõhmus, A.; Macdonald, E. Manipulating Ungulate Herbivory in Temperate and Boreal Forests: Effects on Vegetation and Invertebrates. A Systematic Review. *Environ. Evid.* **2018**, *7*, 13. [CrossRef]
68. Ramirez, J.I.; Jansen, P.A.; den Ouden, J.; Goudzwaard, L.; Poorter, L. Long-Term Effects of Wild Ungulates on the Structure, Composition and Succession of Temperate Forests. *For. Ecol. Manag.* **2019**, *432*, 478–488. [CrossRef]
69. Ramirez, J.I.; Jansen, P.A.; Poorter, L. Effects of Wild Ungulates on the Regeneration, Structure and Functioning of Temperate Forests: A Semi-Quantitative Review. *For. Ecol. Manag.* **2018**, *424*, 406–419. [CrossRef]