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Dynamics of the Natural Regeneration of Vegetation in an Anthropized Forest in Côte d'Ivoire, West Africa

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Abstract: Ivorian classified forests have been highly anthropized by cocoa farming. In an attempt to provide guidance to the government on approaches to the restoration of the forest while respecting the aspirations of local populations, permanent plots were set up in the classified forest of Haut-Sassandra, and were monitored and measured for 3 years. This study was intended to analyze the evolution of the vegetation of permanent plots in the classified forest of Haut-Sassandra from 2018 to 2021. The results show that the vegetation evolves with the cessation of some agricultural activities. These plantations are colonized by pioneer species during the first three years of the abandonment of agricultural activities. Mortality rates increased by 477.59% and recruitment rates were reduced by 61.87% in regularly maintained plantations compared to their condition three years ago. However, the plantations with no agricultural activities and those which were not maintained but harvested had the highest recruitment rates of pioneer and heliophilous individuals. In sum, tree species could recolonize the classified forest of Haut-Sassandra if clearing is prohibited in cocoa farms. However, the populations could continue to harvest the pods from the cocoa trees which are already established in the classified forest of Haut-Sassandra.

Keywords: deforestation; anthropic activity; cocoa farming; floristic diversity; natural recovery

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1. Introduction

Tropical forests are important ecosystems for the world. They cover nearly 15% of the Earth's total area, and account for about 1.7 billion hectares of land [1]. They offer a rich source of medicinal plants and foods, and are a natural reservoir of biodiversity [2]. However, these forests are now disappearing. Intertropical Africa is the most affected by deforestation [3]. In Côte d'Ivoire, the high rate of deforestation in the 1990s made this country one of the leading countries in tropical Africa in terms of forest area loss [3]. During the period of conflict in Côte d'Ivoire from 2002 to 2011, forests were illegally infiltrated by populations in order to develop agricultural activities [4]. Thus, the forest cover of several protected areas disappeared in favor of agriculture. The reconstitution of these forests has become a major priority for the administrative and political authorities, who are considering relocating the populations which illegally settled in some protected areas.

Located in the center-west of Côte d'Ivoire, the classified forest of Haut-Sassandra (CFHS) is not immune to deforestation. This forest, which was one of remnants of the semi-deciduous rainforest before the conflicts in Côte d'Ivoire, has lost more than 70% of its forest cover to cocoa cultivation [4]. In order to reconstitute the forest cover of the FCHS, two reconstitution models are possible. The first one is an artificial reconstitution with the introduction of forest species, but this solution would drastically reduce the diversity of the forest species that constitute the natural ecological potential of this forest. The second is the natural reconstitution. The latter consists in promoting the natural resilience of a degraded forest until it reaches a climax state. Such an approach is therefore based on a thorough knowledge of the ecological processes of natural recovery that develop after forest degradation [5]. Indeed, the monitoring of post-cultivation ecological processes is fundamental to the maintaining floristic richness [6] and planning forest recovery [5,7].

Thereby, in order to understand the dynamics of the vegetation, a system of permanent plots was installed in 2017 in the CFHS. This system will enable follow-up of natural vegetation recovery and to propose concrete solutions for reconstituting the forest cover.. These plots were subjected to different cultural treatments, ultimately to help the manager define the most effective measures to best restore the original forest cover. The aim of this study was to analyze the evolution of woody species in permanent plots of the Haut-Sassandra classified forest from 2018 to 2021. The study is based on the hypothesis that the cessation of certain agricultural activities in the CFHS allows the natural regeneration of woody species for a better reconstitution of biodiversity.

2. Materials and Methods

2.1. Study Area

The study area is the Classified Forest of Haut-Sassandra (CFHS), located in the central-west of Côte d'Ivoire between 6.90° and 7.40° north latitude and 6.90° and 7.10° west longitude (Figure 1). It covers an area of 102,400 hectares. Its vegetation belongs to the zone of semi-deciduous dense rainforests characterized by two plant species: *Celtis* spp. and *Triplochiton scleroxylon* K. Schum [8]. The CFHS is subject to a humid tropical climate with an average annual rainfall of 1547.32 mm [8]. The soil is of the reworked ferralitic type [9], which is beneficial to agriculture.

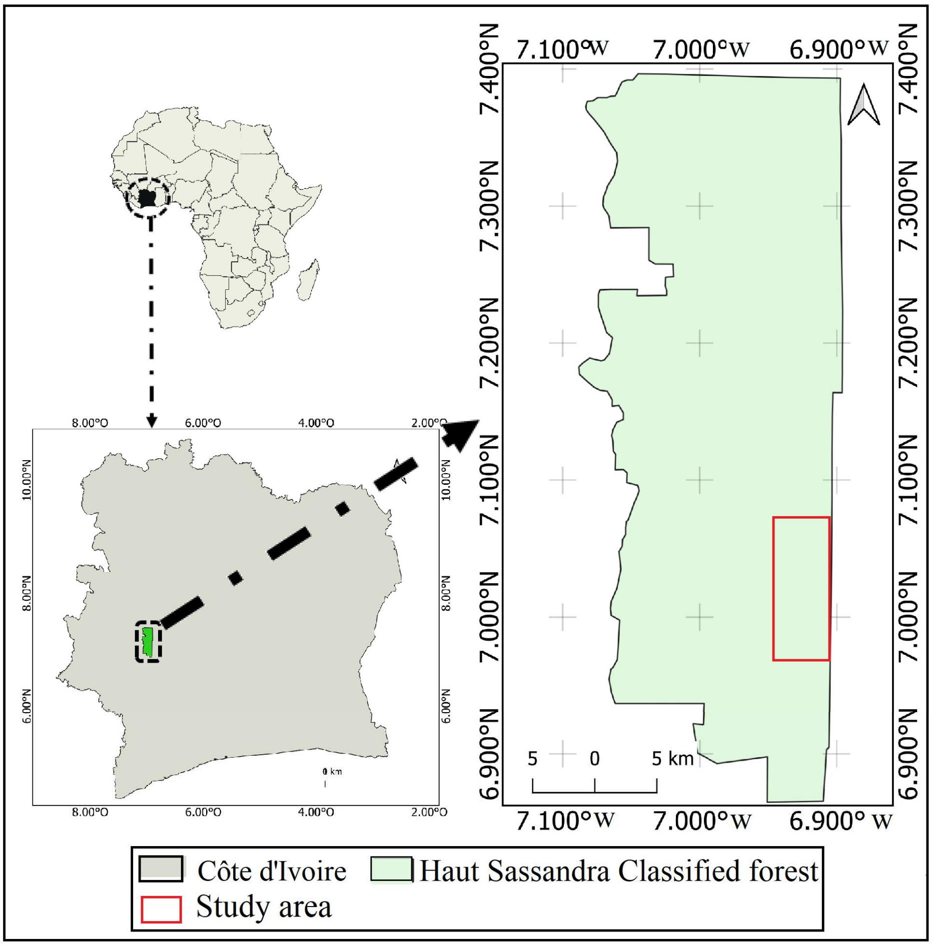

Figure 1. Locations of the Haut-Sassandra classified forest in Côte d'Ivoire, and the sampling sites.

2.2. Data Collection

The experimental setup is composed of twelve permanent plots of 50 m × 50 m. These permanent plots received four treatments (T). Each of these plots being represented by four plots of 50 m × 50 m. The first (T1) involved three cocoa plots which were subject to the usual cocoa farming activities (weeding, pod harvesting, and other agricultural activities). The second treatment (T2) also involved three cocoa plots, but maintenance was stopped and only the cocoa pods were harvested. The third treatment (T3) was applied in three other cocoa plots, and consisted of a complete cessation of cultural activities (no weeding, no pod harvesting, and other agricultural activities). The last treatment is the control and concerned three other plots installed in forest remnants. Each plot of 50 m × 50 m is subdivided into four elementary subplots of 25 m × 25 m. Thus, eqch treatment consisted of twelve elementary plots. The plots have been installed in the CFHS since 2017.

The data for this study are from three years of floristic inventory in the elementary permanent plots. For each year, all of the trees with a DBH greater than or equal to 5 cm were recorded. Each of these trees was identified and its DBH was measured. During each new inventory, trees that reached the minimum DBH of 5 cm were added to the floristic list, while dead trees were excluded.

2.3. Data Analysis

The identified species were divided into three ecological groups [10,11]: pioneers, heliophiles, and sciaphiles. This distribution will provide insight into the dynamics of the post-cultural vegetation based on the ecological group of the species. After this classification, the analyze concerned species richness, density and basal area and recruitment rate, Mortality rate.

2.3.1. Species Richness

The total number of species recorded in each inventory was evaluated in each treatment and by ecological group, using forests as a control. The APG III classification system was used for the species families.

2.3.2. Density and Basal Area

The structural parameters of the vegetation in the treatments were assessed by density (D), which is the number of trees per unit area, and by basal area (A), which is the sum of the trunk cross-sectional areas at breast height of all trees in an environment.

D = N/S, where D is the tree density, N is the number of trees counted, and S is the total area in hectares.

A = $d^2\,\pi/4$, with A being the basal area and d being the diameter at breast height.

2.3.3. Recruitment Rate

Recruitment is the passage of an individual beyond a certain diameter limit [12]. Many studies on the recruitment of young forest trees set this limit at 10 cm [13,14]. In this study, we set the limit at 5 cm in diameter. This choice was based on the time step between two inventory campaigns, which is one year. The recruitment rate (RR) was calculated using the following formula [14]:

$$\mathrm{RR}\ (\%) = 100\ \times\ \left(\frac{N_r}{N_0 + N_1}\right)$$

where RR is the recruitment rate, N_0 is the number of trees in year 0, N_1 is the number of trees in year 1, and N_r is the number of tree recruits between year 0 and 1.

2.3.4. Mortality Rate

The mortality rate (MR) is the ratio of the number of trees of DBH $\geq$ 5 cm which were dead to the number of live trees in year t [12,14].

$$\text{MR}\ (\%) = 100\ \times\ \frac{Nm}{Nt}$$

Nt is total number of trees, and *Nm* is number of dead trees in the initial population.

2.4. Statistical Analysis

For each year, the differences in the density, basal area, mortality rate, and recruitment rate were evaluated between treatments. The statistical analyses were performed in Statistical 7.1. ANOVA was used to analyze the plant density, basal area, mortality rate and recruitment rate. The means separation analysis was performed with Tukey's honest significant difference in order to test ($p < 0.05$) the differences between various treatments.

3. Results

3.1. Evolution of the Species Richness

The change in species richness showed that the forests (Control) have a higher number of woody species compared to the other treatments. However there was a low diversity of species in this forest. During the last year,, we recorded an average of 33.33 species per hectare. These species were mainly sciaphilous species.

Among the plots installed in the plantations, those without agricultural activities (T3) recorded a high number of woody species compared to the regularly maintained (T1) and unmaintained but exploited (T2) plantations. In each of the treatments, with the exception of the control, pioneer species have the greatest number followed by the sciaphile species and heliophile species in last position. While, in the control treatment, the sciaphile species show the greatest number.

There was a strong increase in pioneer species in T3 and T2, with respective increases of 337.5% and 336.7% between 2018 and 2021 (Figure 2). In terms of heliophilic species, T2 shows a high rate of increase (101.38%). During the monitoring, the regularly maintained plantations (T1) showed a small increase in species in each ecological group.

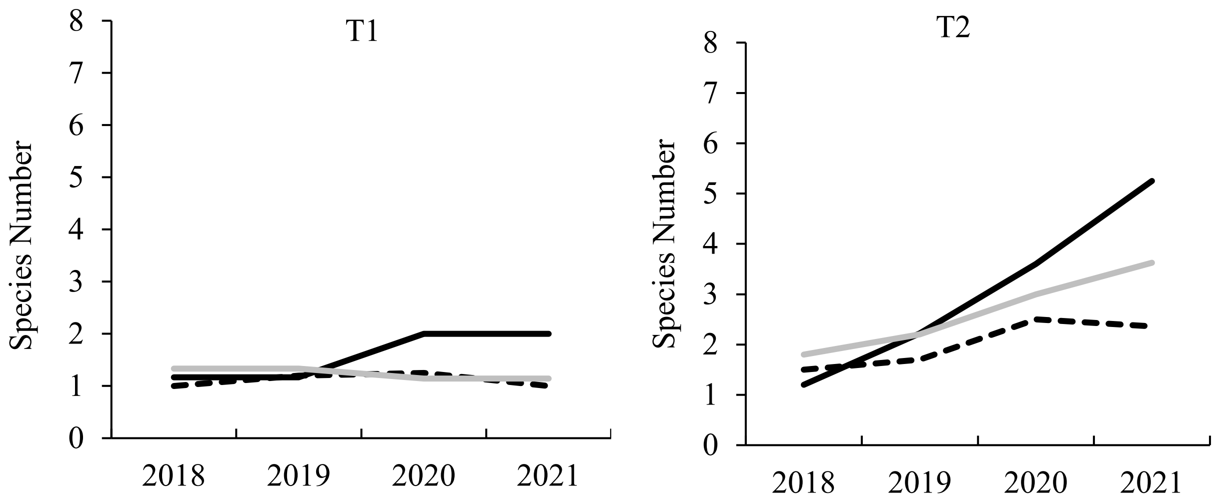

Figure 2. *Cont.*

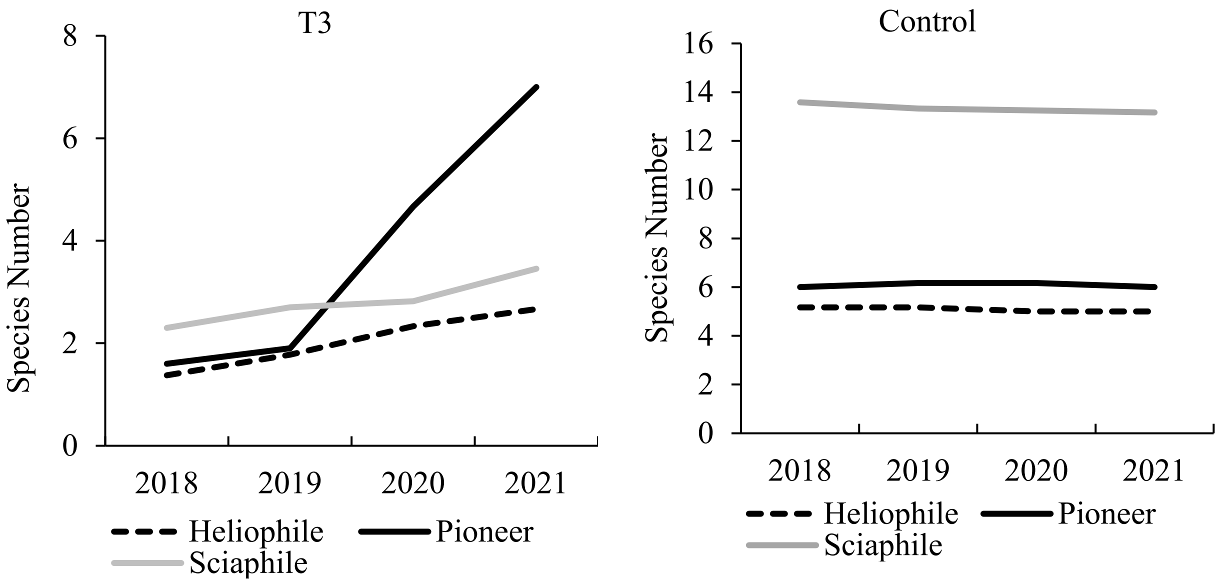

Figure 2. Evolution of the average number of species per treatment. T1 = cocoa plantations which were regularly maintained and exploited, T2 = cocoa plantations which were not maintained but exploited, T3 = cocoa plantations without activities, and Control = a forest relic.

3.2. Evolution of the Vegetation Structure

3.2.1. Evolution of the Density

The mean density values in the twelve elementary plots varied from year to year within each treatment (Figure 3). Considering all individuals, a high density was observed in forests. However, these environments show the lowest change in mean density, which increased from 961.33 trees/ha initially to 1084 trees/ha after three years, which is only an increase of 12.76%. The highest change in mean density was obtained in the unmaintained but harvested plantations, and in those without agricultural activities (T3). The density increased from 33.33 trees/ha initially to 425.33 stems/ha after three years in the unmaintained but harvested plantations (T2), which is an 1176% increase. In plantations without agricultural activities, the density evolved from 61.33 trees/ha initially to 768 trees/ha after three years, which is an increase of 1152.17%. The regularly maintained plantations showed the lowest average densities.

In terms of heliophilic species, plantations without agricultural activities (T3) and those which were not maintained but harvested (T2) showed the greatest evolution in mean density compared to the other treatments. In T3, the average density of heliophilic species evolved from 14.66 trees/ha in 2018 to 217.33 trees/ha in 2021, which is an increase of 1381, or 81%. In T2, this density increased from 12 trees/ha initially (2018) to 138.66 trees/ha after three years (2021), which is a 1055.55% increase. The regularly maintained plantations (T1) had the lowest average densities of heliophilous individuals.

Pioneer species strongly colonize cocoa plantations without agricultural activities (T3) and those which were not maintained but harvested (T2). The density of pioneer individuals increased from 10.66 trees/ha initially to 482.66 trees/ha after three years, which is an increase of 4424.99%. In T2, the density of pioneer individuals increased from 9.33 trees/ha initially to 229.33 trees/ha after three years, which is an increase of 2357.14%. The T1 plots have the lowest average density of pioneer individuals.

For sciaphilous species, the forest plots recorded the highest density throughout the monitoring period. In this treatment, the density of sciaphiles evolved from 637.33 trees/ha initially to 752.66 trees/ha after three years, which is an increase of 18.41%. The T1 plots show a decrease of 11.11% in the average density of sciaphilous individuals compared to the other treatments (Figure 3).

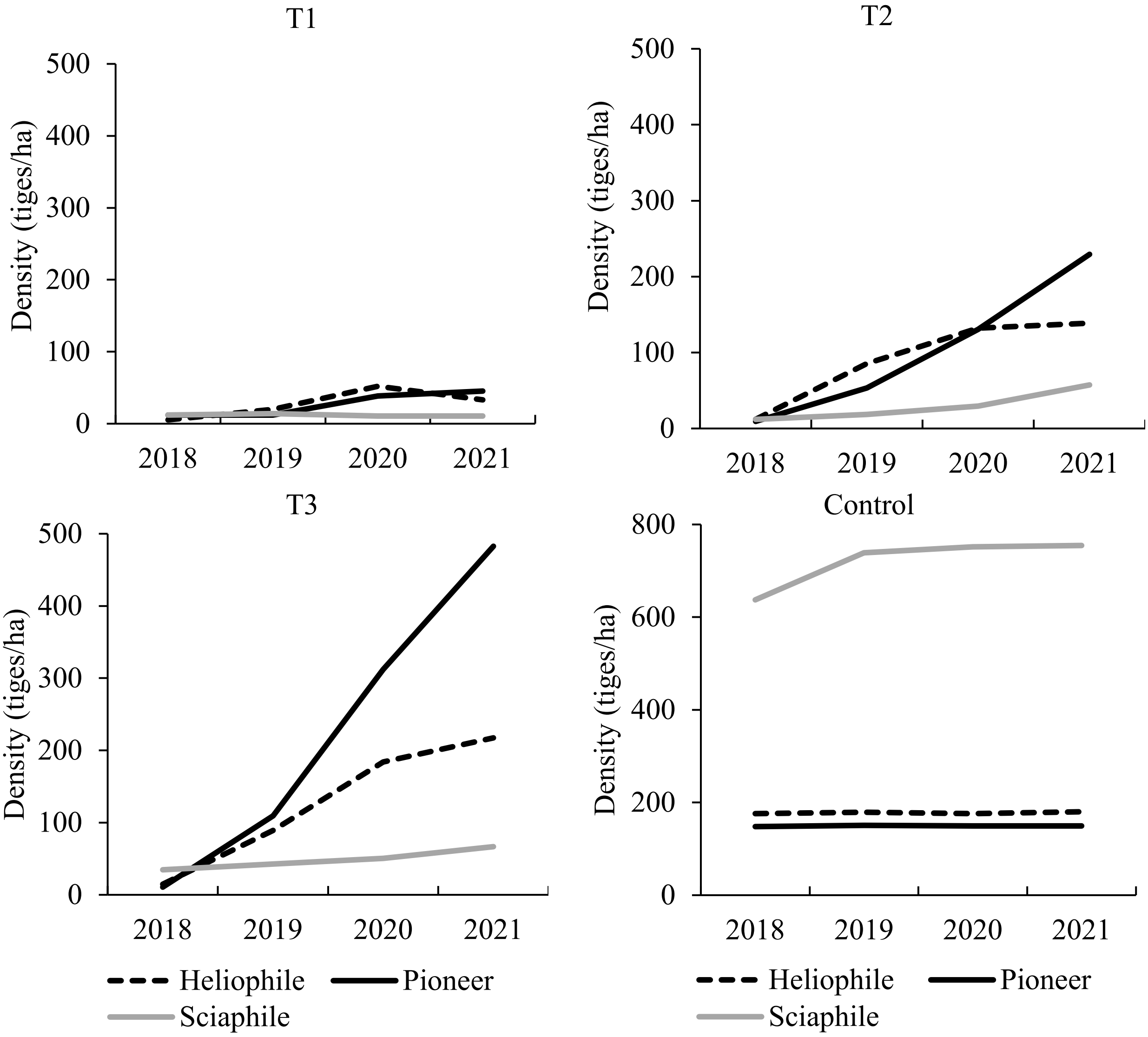

Figure 3. Evolution of the average tree density by treatment. T1 = cocoa plantations which were regularly maintained and exploited, T2 = cocoa plantations which were not maintained but exploited, T3 = cocoa plantations without activities, and Control = a forest relic.

3.2.2. Evolution of the Basal Area

The forest plots have the highest average basal area values in all of the ecological groups. Considering all individuals, the highest basal area values were obtained in plantations without agricultural activities (T3) and those which were not maintained but harvested (T2). The evolution of the basal area also shows a high rate of increase in T3 (221.22%) and T2 (316.36%). T1 has the lowest average values of basal area.

Considering the heliophilic individuals, T3 has the highest average values of basal area. However, the greatest change in basal area was obtained in T2. The average basal area in these plantations increased from 0.30 m^2/ha initially to 1.58 m^2/ha after three years, which is an evolution of 425.52%. The plots in T1 have the lowest average basal area values in this ecological group.

In terms of pioneer individuals, T3 still records the highest average basal area values and the highest rate of evolution. In this treatment, the average basal area increased from 0.61 m^2/ha initially to 2.88 m^2/ha after three years, which is an increase of 368.65%. T1 has the lowest average basal area values for pioneer individuals (Figure 4).

In terms of sciaphilic individuals, T3 still records the highest average values of basal area. However, T2 shows the highest rate of increase in basal area. In this treatment, the average basal area increased from 0.34 m^2/ha initially to 0.91 m^2/ha after three years, which is an increase of 165.80%. Regularly maintained plantations (T1) showed a 19.36% decrease in the average basal area of sciaphiles compared to the other treatments (Figure 4).

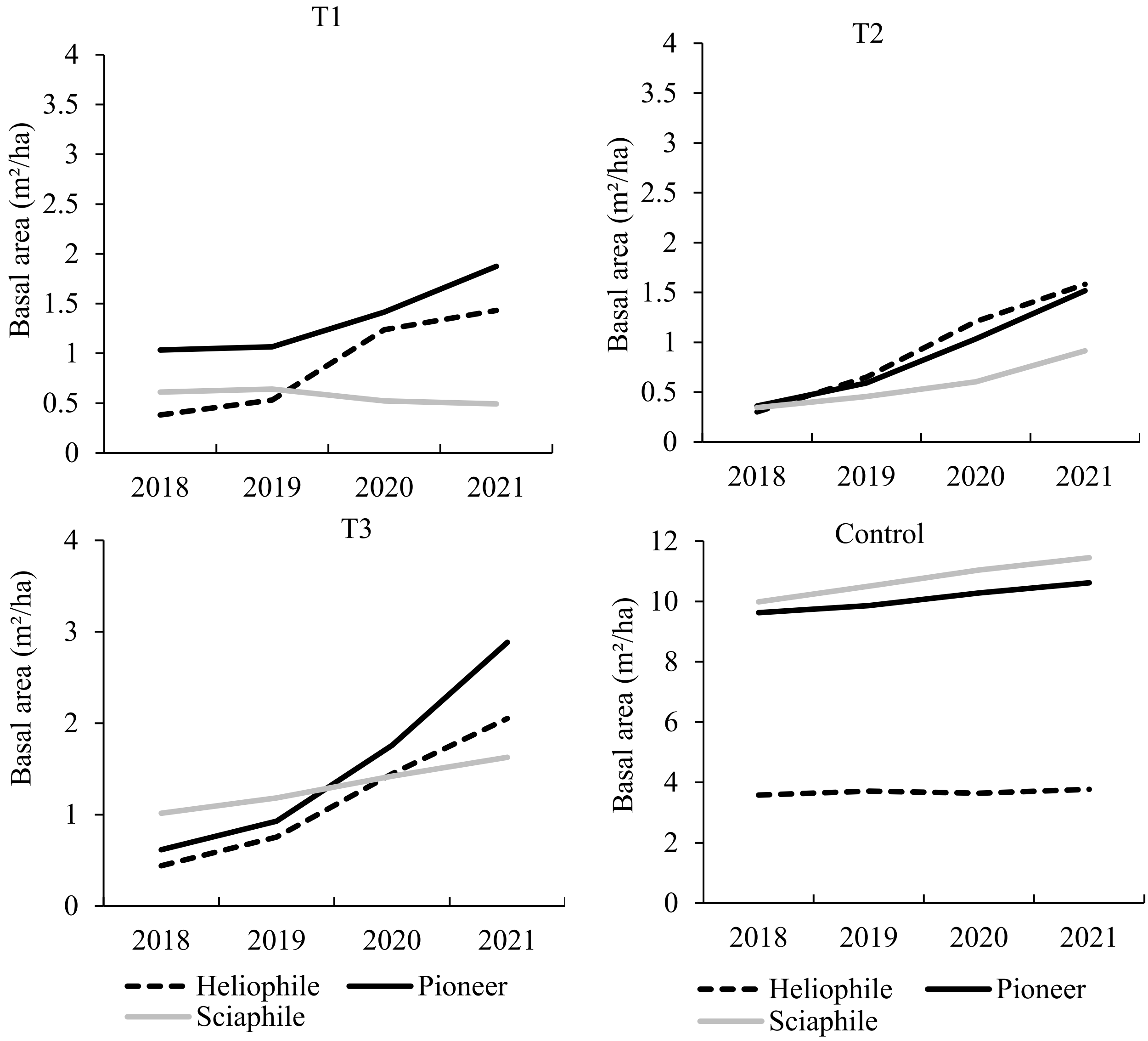

Figure 4. Change in the average basal area of the trees by treatment. T1 = cocoa plantations which were regularly maintained and exploited, T2 = cocoa plantations which were not maintained but exploited, T3 = cocoa plantations without activities, and Control = a forest relic.

3.3. Recruitment Rate

Considering all individuals, plantations without agricultural activities (T3) and those which were not maintained but harvested (T2) had the highest recruitment rates of woody individuals during the three years of monitoring compared to the other treatments. From 58% between 2018 and 2019, the recruitment rate increased to 123.77% between 2019 and 2020, and then decreased to 77.44% between 2020 and 2021. Furthermore, in T2, the recruitment rate—which was 101.89% between 2018 and 2019—increased to 106.64% between 2019 and 2020, and then declined to 81.88% between 2020 and 2021. The forest plots (Control) and regularly maintained plantations (T1) had the lowest recruitment rates during the monitoring (Figure 5).

When considering heliophiles, the highest recruitment rates of woody individuals were obtained in T3 and T2. The recruitment rate—which was 107.67% between 2018 and 2019 in T3—increased to 115.93% between 2019 and 2020, before dropping to 52.91% between 2020 and 2021. In T2, the recruitment rate—which was 73.51% between 2018 and 2019—increased to 90.59% between 2019 and 2020, before decreasing to 40.74% between 2020 and 2021. The forest plots had the lowest recruitment rates of sunbirds during monitoring.

In terms of pioneer individuals, T3 and T2 had the highest recruitment rates. The recruitment rate was 126.41% between 2018 and 2019 in T3. This rate increased to 146.76% between 2019 and 2020, and then to 89.75% between 2020 and 2021. In T2, the recruitment rate was 116.71% between 2018 and 2019. It increased to 122.46% between 2019 and 2020, before decreasing to 89.41% between 2020 and 2021. The forest plots had the lowest recruitment rates of pioneer individuals during the monitoring.

Considering sciaphiles, the forest plots recorded the highest recruitment rate between 2018 and 2019, with 58.41%. However, between 2019 and 2020, and between 2020 and 2021, T2 recorded the highest recruitment rate, with 81.07% and 100.69%, respectively. No sciaphilic individuals were recruited in T1 during the monitoring.

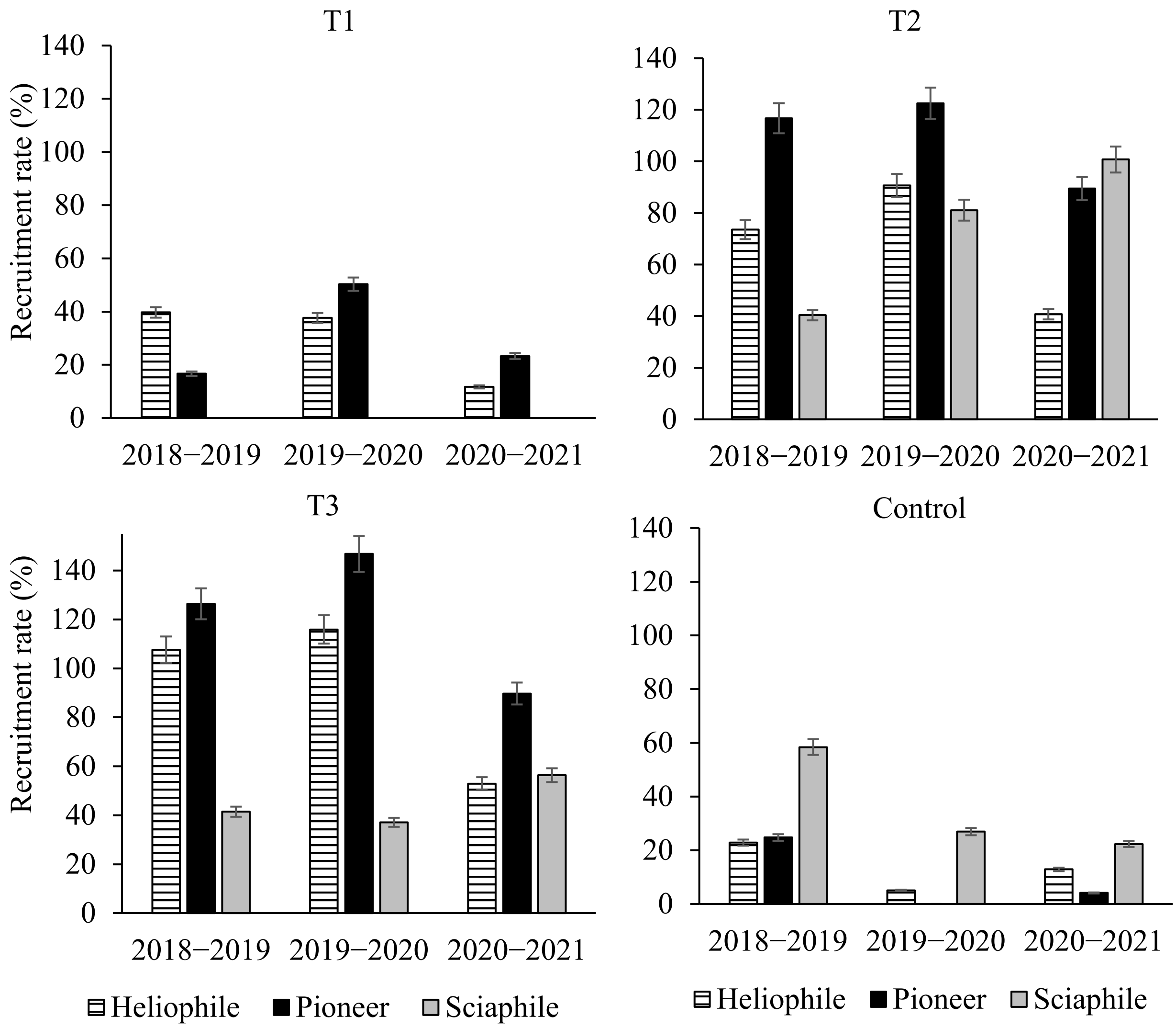

Figure 5. Tree recruitment rate by treatment. T1 = cocoa plantations which were regularly maintained and exploited, T2 = cocoa plantations which were not maintained but exploited, T3 = cocoa plantations without activities, and Control = a forest relic.

3.4. Mortality Rate

The forest plots (Control) had the lowest mortality values for all species and ecological groups.

Considering all individuals, regularly maintained plantations (T1) had the highest mortality rate compared to other treatments. The mortality trend showed a strong increase in dead individuals between 2018 and 2019, and between 2020 and 2021 in T1. This rate increased from 2.17% to 7.27%, and then to 12.58% over the periods 2018–2019, 2019–2020 and 2020–2021, respectively (Figure 6).

At the level of heliophiles, low mortality was recorded in T3 and T2 during the monitoring. However, T1 shows a high mortality between 2019 and 2020, with a rate of 20%. T3 and T2, with 11.32% and 11.85%, respectively, recorded high mortality rates of pioneer individuals during the second year of monitoring (2019–2020). In terms of sciaphiles, T1 recorded high mortality rates compared to the other treatments between 2019 and 2020 (6.87%) and 2020 and 2021 (14.58%).

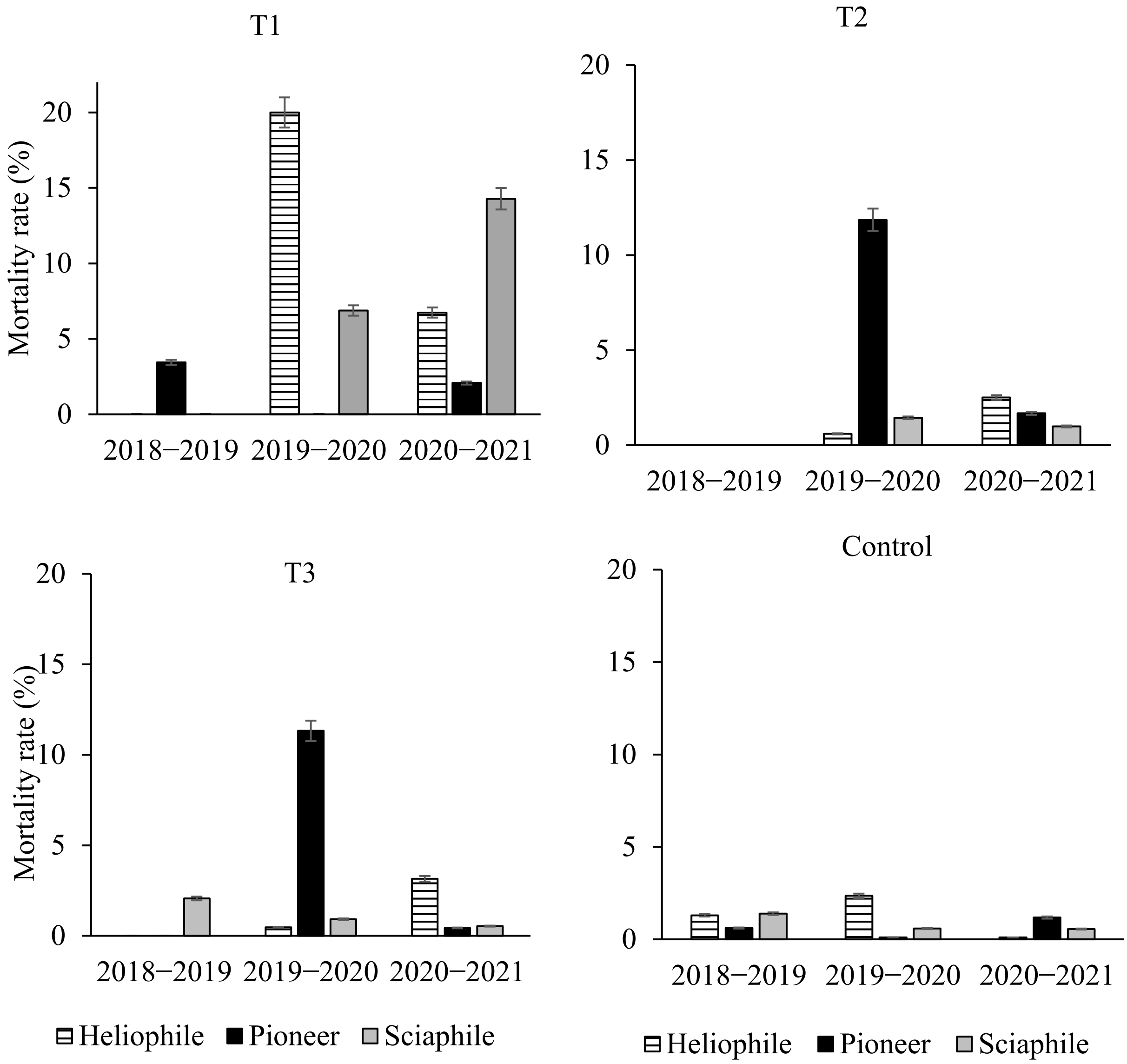

Figure 6. Tree mortality rate by treatment. T1 = cocoa plantations which were regularly maintained and exploited, T2 = cocoa plantations which were not maintained but exploited, T3 = cocoa plantations without activities, and Control = a forest relic.

4. Discussion

The results show a high number of species in the forest plots compared to the cocoa plantation plots. However, the species richness of plantations without agricultural activities (T3) and those which were unmaintained but exploited (T2) evolves more rapidly. This rapid evolution of species richness could be attributed to the cessation of weeding in these plantations, which favored the installation of other species. This result is consistent with the findings of [15], who revealed that the species richness of post-cultivation recursions in the Mikea Forest in Madagascar evolved progressively with the abandonment of human activities. Despite its small area, the high species richness of the residual forest shows characteristics of a deep forest. Residual forests are known to be shelters for a huge number of plant species in environments where anthropogenic activity has become dominant [16]. However, the species richness of pioneer species evolves strongly in plantations without agricultural activities, and in unmaintained but exploited plantations. The growth of pioneer species is the beginning of forest reconstitution. According to [17], post-cultivation dynamics reveal several stages of vegetation development that can ultimately lead to forest reconstitution. In this dynamic, the vegetation is dominated successively by one or more waves of ephemeral herbaceous plants, then by pioneer sub-shrubs, pioneer shrubs and, finally, by trees that reach large sizes.

The average density of woody plants in cocoa farms under agricultural activities (T1) remained low throughout the monitoring period. However, there was strong change in plantations without agricultural activities (T3) and plantations which are not maintained but exploited (T2). The low density of woody plants in regularly maintained cocoa farms indicates the intensity of disturbances related to farming practices. Indeed, repeated crop maintenance and the harvesting of cocoa pods by farmers prevents the establishment of plant species—particularly woody species—in the plantations. The strong increase of basal area in the plantations without agricultural activities (T3) and with minimum activity (T2) is attributable to the significant spread of pioneer woody species following the absence of weed control, resulting in a large number of individuals that develop rapidly during the first years of abandonment. The density of pioneer species increased from 10.66 stems/ha in 2018 to 482.66 stems/ha after three years (2021), representing an increase of 4424.99% in plots without agricultural activities. This result illustrates that the abandonment of cultivation allows a rapid and progressive recolonization of the environment as a precursor to the reconstitution of the forest. The authors of [15] reported a similar result in fallow lands in southwestern Madagascar, with the density of pioneer individuals increasing over time after crop abandonment.

In regularly maintained cocoa farms, there was an increase in mortality and a decrease in the recruitment rate. This high mortality confirms the removal of trees by farmers during plot maintenance to promote the high production of mature cocoa trees. Indeed, according to [18], some trees associated with plantations have a negative effect on cocoa tree development and yield. While it has been shown that the mortality rate of a stand naturally follows from its structure and age [19,20], the reduction in tree recruitment in cocoa farms shows that cocoa farming does not promote vegetation recovery. This is reflected in the low recruitment rate in regularly maintained and harvested cocoa farms during the monitoring years. In comparison, the high recruitment of pioneer and heliophilic individuals in unmaintained but harvested cocoa farms (T2) could be the result of the removal of lianas on cocoa trees by farmers during pod harvesting. According to [21], lianas disrupt tree regeneration, thereby stunting tree growth. In cocoa farms without agricultural activities (T3), the increase of the recruitment rate is due to the abandonment of agricultural activities. Finally, this study allows us to affirm that, despite the important agricultural activities affecting the CFHS, it still abounds in the dormant seeds of forest species waiting for favorable conditions to develop. Furthermore, the research of [22] on regenerating species has shown that the CFHS still contains species which are capable of initiating the natural regeneration of the entire forest.

5. Conclusions

The objective of this study was to analyze the vegetation dynamics of the permanent plots of the classified forest of Haut-Sassandra from 2018 to 2021. At the end of this study, we can note that the forest cover of the classified forest of Haut-Sassandra can be reconstituted naturally in the absence of clearing in the cocoa farms. Indeed, the species richness of farms without agricultural activities (T3) and farms without maintenance but with harvesting (T2) evolved significantly during the three years of monitoring. These farms are colonized by pioneer species during the first three years of the abandonment of agricultural activities. Mortality rates increased by 477.59% and recruitment rates were reduced by 61.87% in farms with regular maintenance after three years.

After three years of observation, there was a strong natural recovery of woody plant species in the farms without clearing. These dynamics of woody species in abandoned plantations suggest that the CFHScould regenerate if cutting and clearing are stopped in cocoa farms. However, people may continue to harvest the pods. It would also be important to analyze the spatial distribution of woody species in farms with no maintenance in order to understand intra- and interspecific interactions in the process of natural vegetation recovery, and to predict its long-term evolution.

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Conflicts of Interest: The authors have no conflicts of interest to declare that are relevant to the content of this article.

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