REGENERATION OF THE VEGETATION IN DUEKOUÉ AND SCIO PROTECTED FORESTS UNDER ANTHROPOGENIC ACTIVITIES IN SOUTHWESTERN CÔTE D'IVOIRE

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Abstract

Duekoué and Scio forests are two protected rain forests in Southwestern Côte d'Ivoire. These forests have been under timber harvesting since their protection in 1929. The national Forest Service in Côte d'Ivoire had developed plantations of indigenous timber species and teak since 1996 to increase their productivities for timbers. Additionally, they host many plantations of cash crop among which coffee, cocoa and rubber are the most important. This study analyses the effects of anthropogenic disturbance on the density of the juvenile plants and of the seedlings and herbaceous plants in these forests. The aim is to understand how the crop farms and forest plantations affect the regeneration of local vegetation. Ten plots of 10 m × 10 m size were established per vegetation type and individuals with DBH < 10 cm were inventoried. The highest density of individuals with 10 cm > DBH ≥ 1 cm was found in the coffee farms of both sites while the lowest density was obtained in the rubber plantations at the Duekoué site; all the other vegetation types had medium density value. But for the individuals with DBH < 1 cm, the lowest density was found in the cocoa farms of both sites and in the teak plantations at the Duekoué site; all the other vegetation types presented the same higher density.

Key words: Classified forest, cash crops, agroforestry, vegetation regeneration, South-West Côte d'Ivoire

Résumé

Duekoué and Scio sont deux forêts protégées du Sud-Ouest de la Côte d'Ivoire. Ces forêts sont soumises à des exploitations forestières depuis leurs classements en aires protégées en 1929. La Société de développement des forêts en Côte d'Ivoire y a créé des plantations forestières à partir des essences locales et du teck, depuis 1996, pour augmenter leurs productivités en bois d'œuvre. En plus, ces forêts renferment davantage de plantations de cultures de rente prédominées par le café, le cacao et l'hévéa. Cette étude analyse les effets des actions anthropiques sur la densité des plantes juvéniles et celle des plants et des herbacées dans ces forêts. L'objectif est de comprendre comment ces plantations affectent la régénération de la végétation locale. Dix parcelles de 10 m × 10 m ont été établies par type de végétation et les individus avec un DBH < 10 cm ont été inventoriés. La plus forte densité des individus avec 10 cm > DBH ≥ 1 cm a été trouvée dans les plantations de café des deux sites tandis que la plus faible densité a été obtenue dans les plantations d'hévéa du site de Duekoué; tous les autres types de végétation avaient une valeur de densité moyenne. Mais pour les individus avec un DBH < 1 cm, la densité la plus faible a été trouvée dans les plantations de cacao des deux sites et dans les plantations de teck du site de Duekoué; tous les autres types de végétation présentaient la même densité plus élevée.

Mots clés : Forêt classée, cultures de rente, agroforesterie, régénération de la végétation, Sud-Ouest Côte d'Ivoire

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1. Introduction

The regeneration of ecosystems can be natural or artificial. Many authors who have studied the structure and composition of tropical forests showed that these were naturally a veritable mosaic in eternal evolution (Richards, 1996; Ducrey and Labbe, 1985; CTFT, 1989; Baraloto, 2001, Dong, 2011; Ma *et al*., 2016). Species successions are always observable and, even if the study of a fairly large area showed a relatively stable character, a whole dynamic of population transformations takes place there every day. The mechanism that maintains this regeneration almost always calls for the presence of clearings or gaps (Whitmore, 1978) often caused by the presence of windfall (Oldeman, 1972).

Besides the forest regeneration by seed (Kouakou, 1989), the process of natural reconstitution of forests can be through vegetative multiplication including rejection from stumps in the case of simple coppice or coppice under forest (CTFT, 1989). Multiple silvicultural methods have been applied in the tropical forests, in general, and in the dense African humid forest, in particular (Martineau, 1929, 1930a, 1930b, 1932; Martinot-Lagarde, 1961; Maître, 1987, 1991, 1992). In West Africa, selective management and improvement of natural stands are the methods which aim to assist natural regeneration while the tropical shelterwood system method aims to induce this natural regeneration (Ducrey and Labbe, 1985; CTFT, 1989). The regeneration of the tropical forest becomes artificial when plantations are established in the place of natural vegetation (CTFT, 1989). The methods of creating these forest plantations are diverse (CTFT, 1989) but are essentially based on the partial or full replacement of the original vegetation. They thus join the methods of creating cash or food crop plantations in dense tropical forest areas due to the devastating nature of the original vegetation and flora. Like natural regeneration, the artificial regeneration can be done either by seed or by vegetative propagation (Brokaw, 1985; Perfecto *et al*., 1996, 2003, 2005; Baraloto, 2003).

In the Upper Guinea sub-region (White, 1986), Côte d'Ivoire has the second largest West African humid rain forest area after Liberia (Poorter *et al*., 2004). Côte d'Ivoire is also known to be among the countries that have the highest tropical deforestation rate (Sayer *et al*., 1992; Chatelain *et al*., 2004) due to human activities despite a century of policy of forest protection. There are two main categories of protected areas in Côte d'Ivoire which are the national parks where human activities are forbidden except management and research, and the classified (protected) forests whose purpose is management for sustainable logging (Kouamé, 1998). The definition and delimitation of these protected forests began in 1924 by their conservation only (de Koning, 1983; Ahimin, 2006). After the Ivorian independence in 1960, the legal status of these protected areas has been created together with a national Forest Research Institute and a national Forest Service (SODEFOR). However, forty years later, these instruments have not allowed to stop the fast degradation of Ivorian forests (Dao, 1999; Chatelain *et al*., 2004; Ahimin, 2006) that remain nowadays in some classified forests, national parks, biological reserves and in forest-fallow mosaics. Due to rarefaction of wastelands in the rain forest area, the farmers crossed the limits of protected forests within which they establish their crops and live. The politico-military crisis in Côte d'Ivoire since 2002 led to increasing the illegal occupation of its South-western protected areas mainly the classified forests of Duekoué and Scio. The vegetation of these forests consist of large and different aged coffee and cocoa farms, few rubber plantations, especially in Duekoué, and some undergrowth cleared forests created by illegal population. This mosaic is completed by some native timber species and teak plantations created by national Forest Service since 1996, and many natural forest islands (patches) of different sizes (Kouamé, 2016). In such environment, this study of the regeneration density can be a help to better understand the current situation and guide the future of the classified forests in Côte d'Ivoire for their sustainable management.

The aim of this manuscript was to analyze the regeneration density in eight dominant vegetation types generated by human activities in the two most closed protected areas belonging each to a different sub-type of rain forest in Côte d'Ivoire. These vegetation types were the coffee and cocoa farms, the rubber and teak plantations, the undergrowth cleared forests and the natural forest islands (patches). The objective of this study is to compare the densities of the juvenile plants and, of the seedlings and herbaceous plants in these vegetation types.

As the damage intensity caused by the human activities on local vegetation depend mainly on the crop nature, the hypothesis was to find a similar regeneration density in the cash crop farms and different regeneration densities in the other vegetation types.

2. Material and methods

2.1. Study area

The study was carried out in the classified forests of Duekoué (6° 30'- 6° 45' N, 7° 00'- 7° 15' W) and Scio (6° 30'-7° 00' N, 7° 30'- 8° 05'W) in South-West of Côte d'Ivoire (Fig. 1). Climate in both areas is sub-equatorial with a long wet season from February to November and a short dry season from November to January. Annual rainfall varies from 1600-1700 mm in Duekoué forest to 1700-1800 mm in Scio forest. The average monthly temperature is 25 ºC while monthly and annual potential evapotranspiration of both areas are respectively 123.5 mm and 1482 mm (Eldin, 1971). The soils belong to the remould ferrallitic group (Perraud & de la Souchère, 1970). The natural vegetation of Duekoué forest consists of a moist semi-deciduous forest defined as a tropical rain forest type in which part of the higher trees shed their leaves during the 3-4 months dry season in a region of 1350-1600 mm annual rainfall (Trochain, 1957; ORSTOM and UNESCO, 1983) interrupted by savannas areas and inselbergs (Monnier, 1983). Original vegetation of Scio forest belongs to Ivorian South-Western evergreen forest type (Kouamé, 2010; Kouamé and Zoro Bi, 2010) that spreads in the wettest forest area of the country.

Except the natural forest islands consisting of the remnant tropical rain forest, the other vegetation types plotted in the study were provided by human activities such as the preexistent natural forest fully or partially clearance and burning before the establishment of crops. Additionally, these farms and plantations were annually cleaned to avoid any competition between the crops and other vegetables.

In the undergrowth cleared forests, just the herbaceous stratum was removed and the trees of the higher strata were alive and would be progressively eliminated until the crops become adults. This vegetation type was in fact the first step of the cocoa farms creating strategy for illegal population in the protected forests in Côte d'Ivoire.

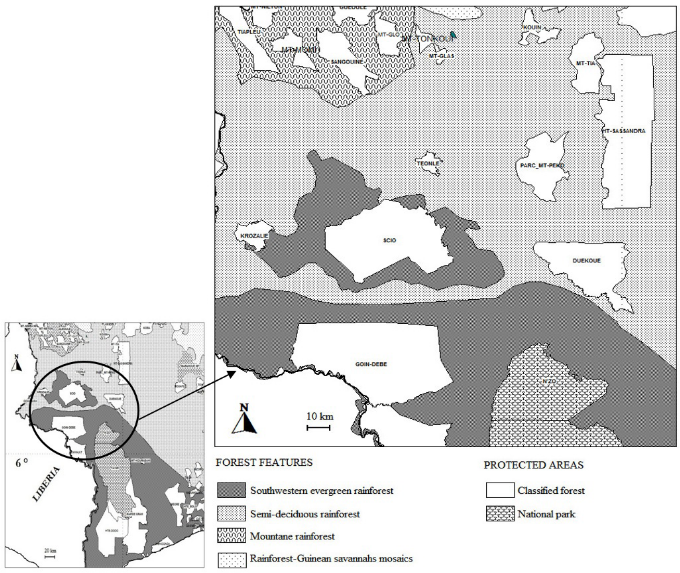

Figure 1. Localization of the study area on the maps of the protected areas and of the main floristic features distribution in Ivorian rain forest zone (Kouamé and Zoro Bi (2010)

On the left, the centre-west region of Côte d'Ivoire. On the right, the high resolution of the west region of Côte d'Ivoire with Scio and Duekoué forests on the centre-north of the map.

2.2. Data collection

The eight vegetation types plotted in this study were the coffee farms, the cocoa farms, the rubber plantations and the teak plantations at Duekoué forest site, and the coffee farms, the cocoa farms, the undergrowth cleared forests and the natural forest patches at Scio forest site.

Field data collection was carried out in eighty 100 m² (10 m × 10 m) plots, 10 per vegetation type. Homogeneity, size, repetition and availability of a vegetation type, and presence of plant individuals with DBH<10 cm were the criteria of these vegetation types selection. Within each plot, all plants individuals with diameter at 1.3 m (DBH) in the range [1 cm; 10 cm [were named and measured for their DBH; those with a DBH smaller than 1 cm were simply named and counted. The lower limit to define regeneration varied considerably. For example, authors like Hawthorne (1993, 1994), who studied the regeneration of the tropical forest, used 5 cm DBH as the lower limit of his investigations. Vroh Bi (2013) limited his studies to individuals with a minimum DBH of 2.5 cm while Tchouto (2004) and Kouamé (2016) used 1 cm as the lower limit of DBH which we considered also in his work.

2.3. Data analysis

The distribution of the data was first tested using the Shapiro Wilk's test (Bárány and Vu, 2007; Umarov *et al*., 2008), which concluded for non-normality. Afterwards, Kruskal-Wallis's non-parametric test for comparison of several independent samples (Mead *et al*., 1993; Bar-Hen, 1998; Young et Young, 1998; Fowler *et al*., 1999; Glèlè Kakaï *et al.,* 2006) was performed. Densities in the vegetation types were compared using an ANOVA test while densities in plots were analyzed using a Principal component analysis with Statistica 13.5 software.

3. Results

3.1. Juvenile plants

For the category of plants with 10 cm> DBH ≥1 cm, the natural forest patches at the Scio site presented the same density (P≥0.05) as all the other vegetation types except the coffee farms of the both sites (Tables 1 & 2) which had the highest densities (P <0.01) and the rubber plantations at the Duekoué site which showed the lowest (P <0.01) density (Tables 1 & 2). The greatest variation of density inside each vegetation type was found in the coffee farms at both sites through the highest standard deviation (Table 1).

The coffee farms of the both sites experienced a very higher density in comparison to the rubber plantations of Duekoué site, and a higher density compared to the cocoa farms, the undergrowth cleared forests and the natural forest patches at Scio site (Tables 1 & 2). They showed a slight higher density than the teak plantations. The cocoa farms at Duekoué site showed only a slight higher density than the rubber plantations. The densities were similar between all the other pairs of vegetation types (Tables 1 & 2).

All the vegetation types were shared into three groups by the principal components analysis among which the largest (group I) gathers the natural forest patches and the undergrowth cleared forests at the Scio site, the rubber plantations and teak plantations at the Duekoué site in conditions of low openness the vegetation (Figure 2). The coffee farms of both sites in group II were separated from the cocoa farms of both sites in group III (Figure 2).

Table 1. Densities of the juvenile plants in the vegetation types

Sites		Minimum	Maximum	Total	Mean	Standard Deviation
Duekoué forest area	Coffee farms	37	72	584	58.4ᶜ	10.3
	Cocoa farms	4	22	140	14.0ᵇ	5.1
	Rubber plantations	1	11	23	2.3ᵃ	3.1
	Teak plantations	4	18	116	11.6ᵇ	4.1
Scio forest area	Coffee farms	37	73	583	58.3ᶜ	10.9
	Cocoa farms	4	17	106	10.6ᵇ	4.7
	Undergrowth cleared forests	4	15	99	9.9ᵇ	3.5
	Natural forest islands	4	18	105	10.5ᵇ	5.0

The density is expressed by the individuals' number per 1000 m². The mean values with the same letter are similar.

Table 2. Comparison matrix of the mean densities of juvenile plants inthe vegetation types

Sites		Duekoué forest area				Scio forest area			
		Coffee	Cocoa	Rubber	Teak	Coffee	Cocoa	Undergrowth cleared	Natural forest
Duekoué forest area	Coffee		10.61	17.84	11.49	0.06	11.03	15.02	13.25
	Cocoa	ns		6.17	1.07	10.86	1.80	1.61	1.62
	Rubber	***	*		8.14	15.63	4.45	4.95	5.37
	Teak	*	ns	ns		10.69	0.53	0.99	0.56
Scio forest area	Coffee	ns	ns	***	*		11.04	14.59	13.64
	Cocoa	**	ns	ns	ns	ns		0.39	0.05
	Undergrowth cleared	**	ns	ns	ns	ns	ns		0.31
	Natural forest	**	ns	ns	ns	ns	ns	ns	

Test of Kruskal-Wallis: H (7, N = 80) = 58.47, P < 0.001. The values of ANOVA are above the diagonal while those of the degree of significance are below. ns : no significant test (P ≥ 0.05) ; * : significant test (P < 0.05) ; ** : highly significant test(P < 0.01) ; *** : very highly significant test (P < 0.001).

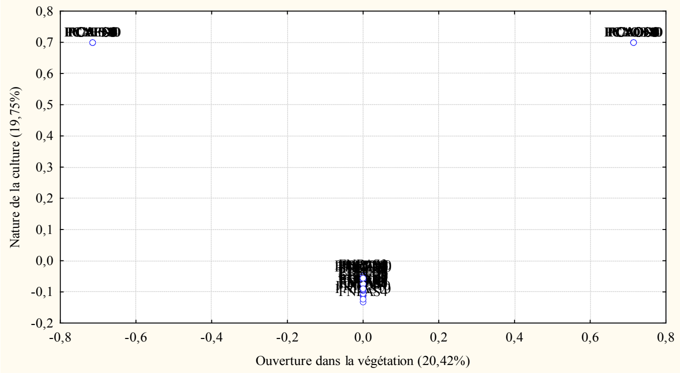

Figure 2. Representation of plots in the component plan 1-2 of the PCA according to the density of juvenile plants

Openness in vegetation expresses 20.42% while the nature of the crop is responsible for 19.75% of the variability of the PCA.

higher values of the standard deviation (Table 3).

The cocoa farms of the both sites showed a very lower density than the rubber plantations and a lower density in comparison of the coffee farms of both sites (Tables 3 & 4). The teak plantations experienced a very weaker density than the rubber plantations and a poorer density in comparison of coffee farms of the both sites and the undergrowth cleared forests (Tables 3 & 4). The cocoa farms at Scio site showed a slight poor density than the undergrowth cleared forests. All the other pairs of vegetation types showed similar densities (Tables 3 & 4).

The plots were shared within two groups among which the smallest was made up of the coffee farms of both sites (Figure 3) under conditions of weak vegetation closure. The second group includes all the other vegetation types, which appear to have more closed vegetation (Figure 3).

Table 3. Densities of the seedlings and herbaceous plants in the vegetation types

	Sites	Minimum	Maximum	Total	Mean	Standard Deviation
Duekoué forest area	Coffee farms	811	1383	10810	1081^{b}	201.0
	Cocoa farms	108	894	4109	411^{a}	267.9
	Rubber plantations	908	3639	18504	1850^{b}	882.6
	Teak plantations	109	545	2512	251^{a}	145.2
Scio forest area	Coffee farms	746	1526	10665	1067^{b}	204.0
	Cocoa farms	126	449	2699	270^{a}	92.6
	Undergrowth cleared forests	615	1445	10315	1032^{b}	281.8
	Natural forest islands	266	3540	11303	1130^{ab}	1148.0

The density is expressed by the individuals' number per 1000 m^2. The mean values with the same letter are similar.

Table 4. Comparison matrix of the mean densities of the seedlings and herbaceous plants in the vegetation types

	Sites	Duekoué forest area				Scio forest area			
		Coffee	Cocoa	Rubber	Teak	Coffee	Cocoa	Undergrowth cleared	Natural forest
Duekoué forest area	Coffee		6.42	3.10	10.71	0.24	12.20	0.39	0.15
	Cocoa	ns		6.47	1.64	6.37	1.63	5.52	2.01
	Rubber	ns	***		7.50	3.36	7.31	5.01	1.60
	Teak	**	ns	***		9.01	0.37	7.20	2.50
Scio forest area	Coffee	ns	ns	ns	**		12.16	0.31	0.18
	Cocoa	**	ns	***	ns	**		7.89	2.54
	Undergrowth cleared	ns	ns	ns	**	ns	*		0.24
	Natural forest	ns	ns	ns	ns	ns	ns	ns	

Test of Kruskal-Wallis: H (7, N = 80) = 54.09, P < 0.001. The values of ANOVA test are above the diagonal while those of the degree of significance are below. ns : no significant test (P≥0.05) ; * : significant test (P<0.05) ; ** : highly significant test(P<0.01) ; *** : very highly significanttest (P<0.001).

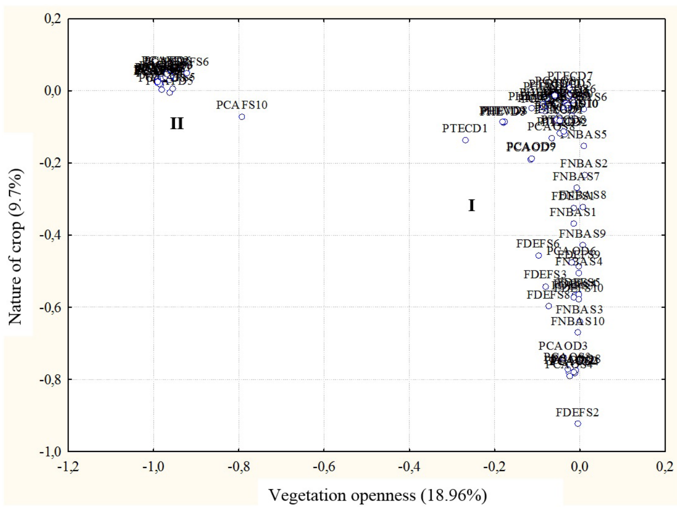

Figure 3 Representation of plots in the component plan 1-2 of the PCA according to the density of seedlings and the herbaceous plants

Openness in vegetation expresses 18.96% while the nature of the crop is responsible for 9.7% of the variability of PCA.

4. Discussion

The variation of the density between vegetation types according to the DBH categories could be explained by the phenomenon of competition for nutrient resources (Veenendaal *et al*., 1996; Delissio and Primack, 2003), space occupation (Moeur, 1997; Boyden *et al*., 2005; Brūmelis *et al*., 2009) and available sunlight (Poorter, 2001; Baraloto, 2003; Yedmel, 2014) in these vegetation types. Indeed, the nutrient resources, sunlight and space have often been identified as the main natural factors affecting the dynamics of vegetation (Brokaw, 1985; Baraloto, 2001, 2003; Boyden *et al*., 2005; Brūmelis *et al*., 2009).

The nutrient resources on which plant regeneration depends include minerals and water available in the soil (Burslem *et al*., 1995; Huante *et al*., 1995; Smith and Smith, 1996; Roggy and Prévost, 1999; Delissio et Primack, 2003). But the sunlight, especially the refracted light intensity that reaches the undergrowth of forest formations (Alexandre, 1979a & 1979b; Chazdon and Fetcher, 1988), is recognized as the most limiting factor in the growth of young plants (Perfecto *et al*., 1996, 2003, 2005; Baraloto, 2003). Thus, in very shaded undergrowth vegetation such as the cocoa farms and natural forest patches, and the mature rubber plantations, the phenomenon of negative rates of the plants growth occurs naturally due to the insufficient refracted light to ensure optimal development as reported by Brokaw (1985), Poorter (2001) and Baraloto (2001).

The decrease in density from the category of DBH < 1 cm to that of 10 cm > DBH ≥ 1 cm cocoa farms and rubber plantations is explained by this phenomenon of negative growth rates of plants in their very shaded undergrowth vegetation (Alexandre, 1982) and is responsible for the negative correlation between these two categories of plants in cocoa farms and rubber plantations.

In addition to this phenomenon, there are the effects of maintenance actions which consist in regularly cleaning of the undergrowth vegetation stratum of coffee and cocoa farms, and of rubber and teak plantations (Kouamé *et al*., 2015; Kouamé, 2016) in view to reduce the competition between adult and young plants of crops and, with individuals of other taxa for the sunlight, the nutrient resources in soil and for space. Maintenance of plantations also reduces their infestation rates by animal and plant parasites by eliminating their vectors (Harvey *et al*., 2006) which may be in their undergrowth or their immediate environments. In the other vegetation types which showed an increase in density from the category of 10 cm > DBH ≥ 1 cm to that of DBH >1 cm (Tables 1 & 3), the upper floors of their less shaded vegetation allowed the availability of sufficient sunlight in the undergrowth to stimulate the growth of the plants therein.

The exponential rise in density in all vegetation types, from the category of 10 cm > DBH ≥ 1 cm to that of DBH > 1 cm (Table 1) shows that the intensity of refracted sunlight available in their undergrowth is sufficient to ensure the explosion and survival of seedlings and herbaceous plants. This exponential increase in density from the juvenile plants to the seedlings and herbaceous plants in all plantations of both sites (Tables 1 & 3) could be attributed also to the stages of development of these plantations. Indeed, despite of the lack of data on plantations' ages, it was observed in the field that these plantations were of different ages because some were already producing for several years while others were not yet in production. In the youngest plantations, a plethora individuals of seedlings and herbaceous plants were reported by Kouamé *et al*. (2015) and Kouamé (2016) in these vegetation types. Due to the space and full sun availability in the understory of these young plantations, plenty seeds in soil germinate sudently and grow very fastly as it often reported in the regeneration in tropical forest areas (Alexandre, 1979a, 1979b; Brokaw, 1985; Kouamé and Traoré, 2002). Along the evolution of the plantations' ages, the shade of the growing canopee eliminate progessively the pionner and ligth demanding plants at the benefit of the non-pionner and shade demanding plants as reported by Hawthorne (1993, 1994) and, Kouamé and Traoré (2002). It was demonstrated that pionner plants are always invasive and very much abundant in open areas than the non-pionner plants in their environment (Alexandre, 1979a; Brokaw, 1985; Hawthorne, 1993; Kouamé and Traoré). Therefore, old plantations experience lower densities due to this progressive remplacement of pionner plants by the non-pionner plants.

5. Conclusion

Human activities in the forests of Duekoué and Scio have presented various kinds of impacts on the regeneration in the vegetation types. The highest density of individuals with 10 cm > DBH ≥ 1 cm was found in the coffee farms of both sites while the lowest density was obtained in the rubber plantation; all the other vegetation types had medium density value. But for the individuals with DBH < 1 cm, the lowest density was found in the cocoa farms of both sites and in the teak plantation; all the other vegetation types presented the same higher density. Then the density experienced an exponential rise in all the vegetation types during the transition from the category of 10 cm> DBH ≥1 cm to that of DHB <1 cm. The regeneration showed sometimes higher density in young plantations, sometimes lower or similar in older plantations.

The coffee farms showed the same densities of juvenile plants and, of seeddlings and herbaceous plants at both sites; the cocoa farms experienced also the same densities of juvenile plants and, of seeddlings and herbaceous plants at both sites as well. The other vegetation types experienced various densities according the DBH categories. These results confirm the hypothesis to find a similar regeneration density in the cash crop farms and different regeneration densities in the other vegetation types.

6. Conflict of interest

The authors of this manuscript declare that they have no conflict of interest.

7. Acknowledgements

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