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Table of Contents: Volume 10 Number 8, October 2018

ARTICLES

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Full Length Research Paper

Vulnerability assessment of *Gnidia glauca* (Thymelaeaceae) exploitation, traditional uses and domestication potential in the community forest of Kilum-Ijim, North Western Cameroon

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A study was conducted in the western highland region of Cameroon with the aim to assess sustainability of *Gnidia glauca* exploitation in its natural habitat. In 33 plots of 40 x 40 m, the unexploited, exploited and dead trees were evaluated for vitality using a multi-criteria vulnerability assessment method. An ethnobotanical survey was conducted with 60 respondents in six villages around Mount Oku area. Data were submitted to ANOVA and means separated using Duncan test. The results revealed that 95 % of G. glauca trees were unexploited and only 3.92% showed signs of exploitation, among which 1.08% were dead. Among the exploited stems, 18% showed a completely dead crown, whereas 73% were described to be regular and healthy. Wood (29%) and bark (28%) were the main products being exploited. However, the species' bark was the most frequently harvested product (64%). *G. glauca* was shown to be more vulnerable in forests (2.6) than in savanna (2.4). The motivating factors for the species' domestication were the fragility of its habitat, the potential high future demand for its products and the unsustainable exploitation techniques being applied. It is therefore recommended to promote the species uses, conservation and cultivation within its national distribution range for local livelihood improvement.

Key words: Ethnobotany, *Gnidia glauca*, sustainable management, vulnerability, Cameroon.

INTRODUCTION

Mountain forest ecosystems of the Bamenda Highlands in Cameroon were considered as zones of high biodiversity concentration in the Africa continent in 2007 (Bergl et al., 2007; Burgess et al., 2007) and globally in

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2000 (Myers et al., 2000). In fact, species richness, range-size rarity, and threatened species scores are all significantly higher in Bamenda highlands along with Eastern Arc and Albertine Rift than in other sub-Saharan Africa land use type (Burgess et al., 2007). Mount Oku is one of the highest peaks in the Bamenda Highlands, and is among the sites with the highest endemism rates in the region, including 14 plants and 10 animals species as assessed in early 2000 (Cheek et al., 2000; Asanga, 2002; Forboseh et al., 2003). The Oku mountain forest provides diverse ecological functions as it plays a vital role for local human populations, providing them with drinking water, firewood and wood for construction, honey, medicine and food plants. This forest is also part of the spiritual and cultural heritage at Cameroon level (Gardner et al., 2001). Among the exploited products of this mountain forests are non-timber forest products, mostly collected from their natural environment. This mount Oku forest, already naturally isolated from other forested areas within the country due to its mountainous characteristics, is also highly fragmented by the progression of farm lands, repeated fires, increasing wood harvesting (Gardner et al., 2001) and unregulated exploitation of forest products (Stewart, 2009).

Since 1994, the Kilum-Ijim Forest Project has been working with 44 communities with the aim of establishing legally recognized community forests, which will cover the entire forest highland within the area. The main goal of this action was to insure the sustainable management of the Kilum-Ijim Forest resources. In actual fact, the communities around the forest have a strong interest in the forest, depending on it for a wide range of products, the most important being fuelwood, medicines (*Prunus africana*), honey, building materials and pulp for paper. For this last use, the bark of *Gnidia glauca* (Thymelaeaceae) is used for the local manufacture of wrapping papers (Ferrari, 2002).

The Thymelaeaceae comprise 46 to 50 genera and 890 to 900 species, mostly confined to Africa, Australia, and Asia and found in lowland to montane environments (Klitgård and Baracat, 2014). Many species of the family are reported to have diverse traditional uses (Ferrari, 2002).

G. glauca is one of the most important species of the Thymelaeaceae family. It is a small tree of 6 to 25 meter in height, with a hard fibrous bark. The species is largely widespread in tropical Africa, from Nigeria in the west towards Sudan at the east, and from Ethiopia in the North towards Malawi and Zambia in the south. Almost all parts of *G. glauca* plants are reported to have several medicinal uses and it provides many households services throughout its natural distribution range. In traditional phytomedicine, leaves, roots, and barks are documented for the treatment of throat ache, abdominal pains, sores, burns, snake bites, contusions, swellings, back and joint pains, indigestion, rabies and blisters in East Africa (Amarajeewa et al., 2007; Kareru et al., 2007). Moreover, the species potential in nanomedicine have been positively tested (Mittal et al., 2013). As a household service, fiber from the bark is made into rope and thread. The plant is also known to have toxic properties and is used as an insecticide, piscicide, poison for fish and arrow (Brink, 2009).

Although *G. glauca* is reported in many vegetation studies (Asanga, 2002; Assi-kaudjhis et al., 2010) from central African highlands, its uses, management and ecological status within the region is poorly documented; hence offsetting the elaboration of a strategy for its sustainable management. A previous study reported that *G. glauca* was among the most vulnerable medicinal tree species exploited in Chilimo forest of Ethiopia, showing lack of regeneration and an erratic stand structure (Soromessa and Kelbessa, 2015). In order to promote the species valorization in Cameroon, there is a need to document the actual products and uses of the species, as well as the exploitation practices and vulnerability status of exploited stands. Therefore, the present work was designed to determine optimal practices for the exploitation of the bark of the plant. The participation of the local populations in the various processes of evaluation and follow-up in order to define a viable operating system which is socially suitable, economically viable and ecologically durable was taken into account (Guedje et al., 2017). The aim of the study is to characterize the sustainability of exploited populations of *G. glauca*, in relation to local uses in the Oku area within the Kilum Ijim Mountain Forest of Cameroon.

MATERIALS AND METHODS

Description of study area

Mount Oku does not form a clear mountain as it occurs on the Bamenda Plateau. The Kilum-Ijim forest, which covers Mount Oku, is the largest of the remaining patches and is the most important remnant of Afro-montane forest in West Africa. It is located on Mount Kilum (3011 m a.s.l.) and the adjoining Ijim Ridge (2000 to 2500 m a.s.l.). It was recognised in 2001 as a globally important centre for endemism (Gardner et al., 2001). Habitats on Mt Oku consist of montane forest with high altitude *Podocarpus* forest, *Gnidia glauca* and *Maesa lanceolata* woodlands, mature bamboo forest, *Erica mannii* scrubland, montane grassland, and subsistence agriculture. The national Gross Domestic Product per capita is considered to be the lowest for the Central African region with the national monthly revenue per inhabitant estimated at 117US $ in 2016 (World Bank, 2017).

The population is constituted mainly by small scale farmers cultivating *Coffea arabica* as cash crop associated with staple food crops such as maize, potatoes, yams and beans among others in farmlands of less than 2 ha. Therefore, they strongly depend on NTFPs exploitation for their daily health care, food, and income.

In the Kilum-Ijim montane forest area, there is significant relationship between the exploitation of forest resources and the well-being of communities adjacent to forest landscape. This implies that the exploitation of forest resources greatly helps in generating income that is used by the communities in purchasing their basic needs. The exploitation of resources such as fuel wood and building materials directly help to sustain the daily needs of

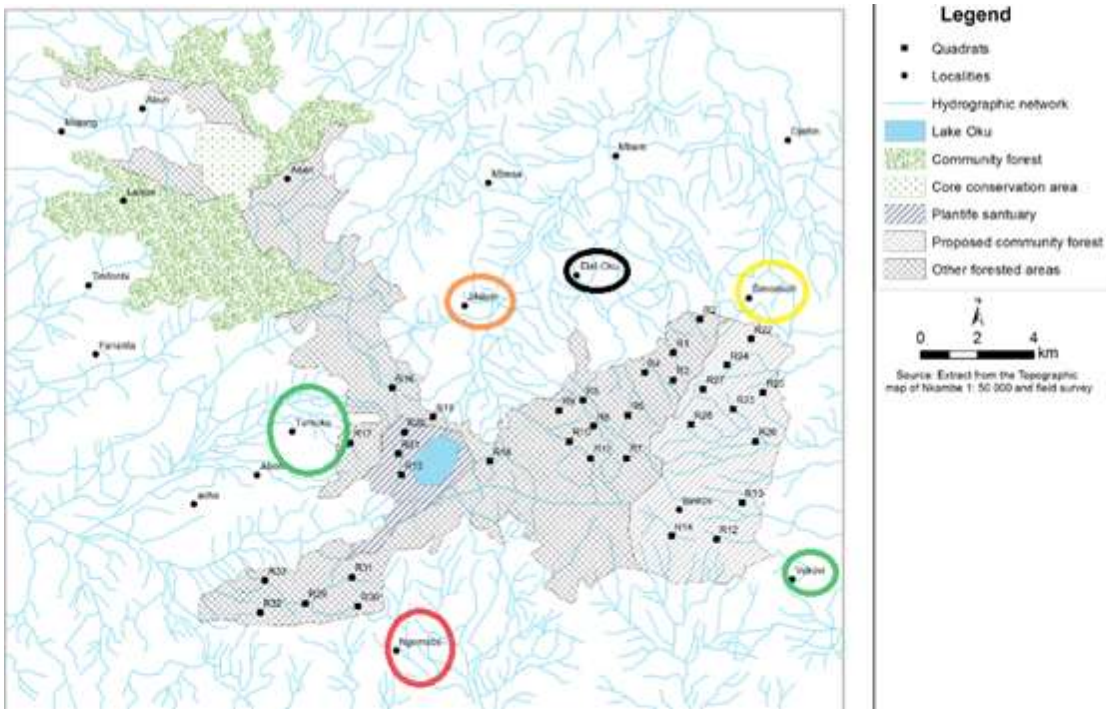

Figure 1. Distribution of sampling villages and sites around the Mount Oku area.

households around this forest area (Kimengsi and Ngala, 2018).

Selection of study site

Montane forests around Mount Oku were sampled at various altitudes. The sampling criteria were based on the occurrence of *G. glauca* in the nearest forest to selected villages, communities' knowledge of the species and its uses, as well as the willingness of villagers to freely participate in the study. The selected villages were: Elak (2474 to 2785 m above sea level), Vekovi (2283 to 2348 m a.s.l.), Simonkoh (2185 to 2391 m a.s.l.), Jikijem (2326 to 2401 m a.s.l.), Ngemsiba (1963 to 2198 m a.s.l.) and Lake (2185 to 2459 m a.s.l.). The sampled sites are represented on the Mount Oku Map illustrated in Figure 1.

Ethnobotanical survey

Interviews were conducted from September to October 2012 with resourceful persons, using previously established questionnaires. Sixty respondents, selected using snowball method and consisting of 36 men and 24 women, divided into 3 age classes, 38 people (≥40 years), 14 people (25 to 40 years) and 8 people (17 to 25 years) were sampled for the study. The number of respondents per village was determined by the availability of the species' knowledgeable persons and varied from a minimum of 8 respondents (Vekoki, Ngemsiba and Lake village) to 10, 12 and 14 people at Jikijem, Simonkoh and Elak Oku respectively. The respondents were first informed on the objectives of the study and their free and verbal consent requested before starting the interview. The discussion themes focused on knowledge about products, uses, harvesting methods, plant parts collected, frequency and season of collection of *G. glauca* in Kilum-Ijim Forest.

Vulnerability assessment

The method of quadrat (total: 1600 m^2) was used to assess the sustainability of exploitation method being applied on *G. glauca*. In 2007, the surface area of mount Oku forest was 9544 ha (Momo et al., 2012). Thus, 5.28 ha of the Kilum-Ijim Forest was sampled representing approximately 0.05% of the above mentioned forest area. The thirty three plots of 40 x 40 m were set from 1963 to 2785 m a.s.l. in the *G. glauca* woodlands. In each plot, all *G. glauca* exploitable stems (dbh≥20 cm) were identified and counted.

The vulnerability parameters (Table 1) used in the assessment constituted of 4 criteria and 3 level scales as described by Betti (2001), Tsabang (2008), and Kemeuze (2010). Such criteria included: gathering method, the life form or morphology, the vegetative organ harvested, as well as the popularity of the species at a given site. The crown health status of the trees was evaluated based on the percentage of drying out (0, 20, 40, 60, 80 and 100% (dead individual).

The values from 1 to 3 are assigned to each of the parameters used for the assessment, which affected the survival of the species within a particular land use system. The overall vulnerability index (VI) was estimated by calculating the average of the values obtained for all the 4 parameters considered in Table 1, with: $1 < VI \leq 2$, meaning that the plant is not vulnerable and the natural potential is still quite appropriate for exploitation; $2 < VI \leq 2.5$ indicates that the plant is becoming vulnerable in the given environment; $VI \geq 2.5$ shows that the plant is highly vulnerable and need sustainable management strategies.

The health status of the tree crown of *G. glauca* was adapted from the methodology developed by Cunningham (2001). The method is based on the possible effect of the bark harvesting on the

Table 1. Parameters assessed for the estimation of the vulnerability index (VI) in the various land use systems considered for the study.

Parameters	Vulnerability scales		
	Weak (Scale 1)	**Medium (Scale 2)**	**High (Scale 3)**
Life form	Herbs	Shrub	Tree
Popularity	Not popular (F<20%)	Less popular (20%<F<60%)	Popular (F>60%)
Part collected	Leaves	Fruits	Bark, roots and wood
Collection methods	Harvesting of the leaves	Harvesting of the seeds	Debarking and felling

Scale 1: low vulnerability (high chance of surviving after harvest), Scale 2: average vulnerability; and 3: highly vulnerable after exploitation (Betti, 2001).

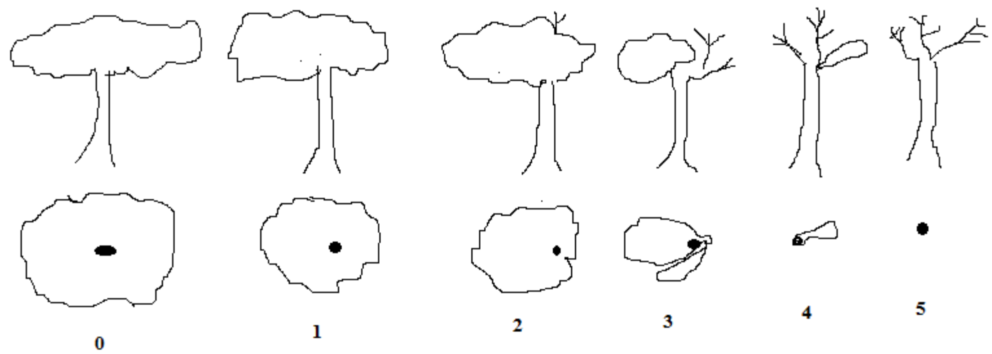

Figure 2. Classification of the health status of the tree crown as a function of the state of their crown (Modified from Cunningham, 2001). The status of the crown is thereafter related to the exploitation intensity of the tree (Cunningham, 2001): (0): Perfect, complete circle; excellent size and development, wide, symmetrical and generally circular in plan; (1): Good irregular circle; slightly asymmetrical with some dead branch tips (silviculturally satisfactory" to forester); (2): Tolerable: half of the crown; markedly asymmetrical, some die-back; (3): Poor: extensive die-back, leaves form less than half of the original crown size; (4): Very poor: few leaves on the branches; badly damaged, unlikely to survive; (5): Dead.

reduction of the tree crown, starting from the entire crown for an unexploited and healthy stem (0) to complete death of the crown for an overexploited and dead tree(5) (Figure 2).

Data analysis

Data recorded for different variables (exploited and dead individuals) were analyzed using the statistical software package SPSS 17.0 for Windows. Collected data were tested for normality using the Shapiro-Wilk test before being submitted to Analysis of Variances (ANOVA) to determine variability among means of exploited, unexploited and dead trees and the DUNCAN test was used to separate significantly (p<0.05) different means.

RESULTS

Current practices of *G. glauca* exploitation in the Mount Oku area

Exploitation of *G. glauca* is carried out both in the dry and rainy seasons. 91.66% of respondents harvests the species bark during both seasons, 5.78% in rainy season while 2.78% of them were harvested in dry season. *G. glauca* products are usually harvested individually for personal use, as none of these products were found to have any commercial value following ethnobotanical survey. The choice of *G. glauca* was driven by the presence and the abundance of exploitable stems, the user's need and site accessibility. The criteria for the selection of the harvestable trees were the thickness of the bark (22 % of respondents), size of the tree (67%) and the color of the bark after notching (11%). Machetes were the only harvesting tool cited by all respondents as needed for the peeling of the bark. The debarking technique applied varied from circular ring removal of the bark on more than 50% on the tree boles starting at the base to the middle of the trunk, to the collection of small patches of bark of irregular sizes taken at different levels of the bole, covering a total of less than 50% of the tree bole surface, and also the tree felling and harvesting of all the bark on its trunk and branches (Figure 3). The tree felling method was practiced only on 1.09% of the

Figure 3. Ring debarked stem of *Gnidia glauca* in the highland savanna of the Mount Oku.

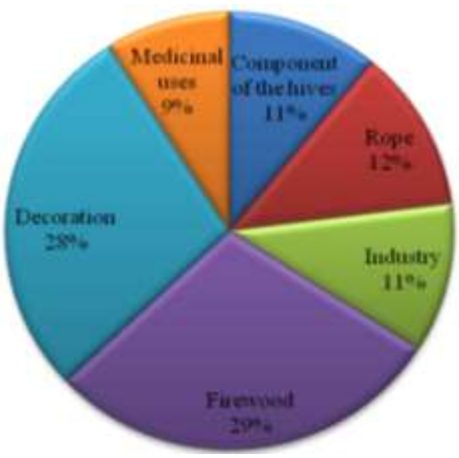

Figure 4. Various uses of *Gnidia glauca* products by the population of the community forest of Kilum-Ijim, North-West Region, Cameroon.

exploited trees in the area of Mount Oku, while ring and patches debarking were applied respectively on 9.28% and 89.63 % of the exploited individuals.

Products and parts of *G. glauca* used in the community forest of Kilum-Ijim

Products exploited from *G. glauca* trees have various uses for local populations of the Oku area (Figure 4). The main products of the species are stem, branches used as firewood (29%), and bark for decorations (28%). The colorful fiber obtained from the bark is locally well appreciated to improve the beauty of various craft instruments such as mats. Bark, leaves and roots were also cited for being used marginally (9%) for medicinal purposes.

Barks were the most frequently used part (64%), followed by stems (19%), leaves (11%), while the roots were the least used (6%).

Potential for exploitation and vulnerability status of *G. glauca* in the community forest of Kilum-Ijim

The largest number of exploitable stems was observed at Simonkoh and Lake villages. The proportion of stems exploited in the sites of Simonkoh, Jikijem and Elak villages are comparable; while Ngemsiba, Vekovi and Lake show the fewer percentage of exploited individuals (P= 0.04). The percentage of dead trees after exploitation was significantly (p =0.003; Table 2) higher in Elak (3.50%) compared to other sites.

Table 3 shows the vulnerability indices calculated for the two main production systems of *G. glauca* in the Mount Oku area. The values were found to be high for parameters such as popularity (3), parts used (3) and harvesting methods (3) in both savanna and forest lands. However, the vulnerability values were average and low for availability parameter in the forest and savanna ecosystem respectively. The morphological parameter showed an average value of vulnerability irrespective of the ecosystem. On the basis of these values for vulnerability parameters, the vulnerability index was estimated at 2.4 in savanna and 2.6 in the forest.

Vitality of the exploited trees

Figure 5 gives indications on the crown health status of the exploited trees, based on the percentage of dead or reduced crown (0, 20, 40, 60, 80 and 100%). It was observed that 18% of the exploited trees had a completely dead crown (100%) (Figure 6); and 73% of them could be described as having healthy and regular crown.

DISCUSSION

Current practices of *G. glauca* exploitation

The result of the present study indicates that *G. glauca* exploitation does not vary with season. Such results indicate that the availability of the exploited products does not depend on weather conditions. It was also shown that bark and wood were the main products exploited. Although both products could be available at all seasons, previous studies on *Prunus africana and Parkia biglobosa* exploitation showed that bark peeling was easier in the rainy season and bark harvesting during the

Table 2. Characteristics of *G. glauca* stands in the sampled villages around the Mount Oku area.

Sites	Number of plots (Total 33)	Number of exploitable stems	Exploited stems (%)	Dead stems (%)
Simonkoh	7	812	8.71±3.96[a]	1.14±0.97[b]
Jikijem	7	394	5.67±4.33[ab]	0.17±0.27[b]
Elak	4	400	5.25±5.25[ab]	3.5±2.5[a]
Ngemsiba	5	242	2.5±1.33[b]	0.83±1.11[b]
Lake	6	824	0.08±0.85[b]	0.86±0.49[b]
Vekovi	4	192	1.33±0.44[b]	0.00±0.00[b]
Mean			3.92±3.20	1.083±1.15
P (ANOVA)			0.04	0.003

In the column, means with same letter(s) are not significantly different at base on the probability level presented.

Table 3. Vulnerability Indices (VI) for forest and savanna stands of *G. glauca* in the Oku Mountain Area, North-west region, Cameroon.

Ecosystem type	Morphology	Availability	Popularity	Parts collected	Methods of collection	VI
Savanna	2	1	3	3	3	2.4
Forest	2	2	3	3	3	2.6

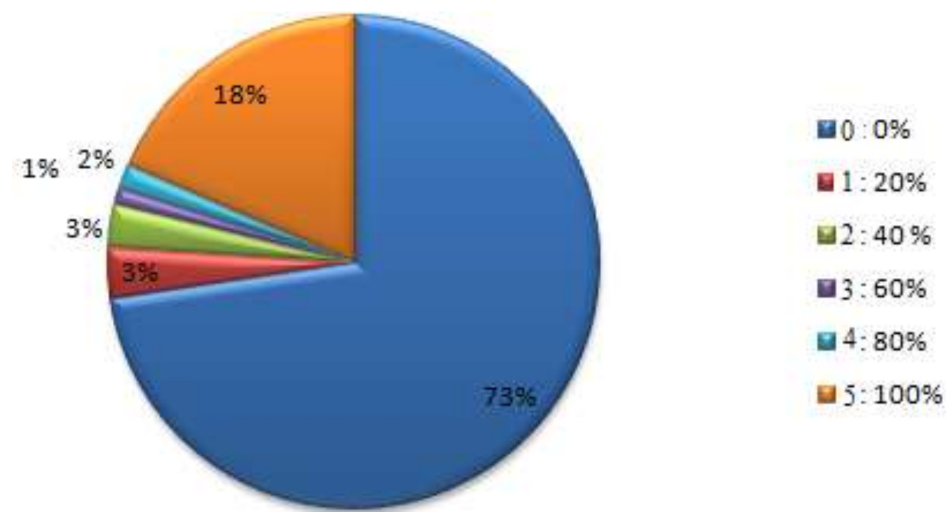

Figure 5. Vitality status of exploited trees of *G. glauca* in the area of Mount Oku as function of their percentage of dryness. The scale from 0 to 5 represents the degree of dryness or reduction of the crown as per the chart described by Cunningham (2001).

dry season, resulted in susceptibility to pests and diseases and poor regrowth (Nkeng et al., 2009; Delvaux et al., 2010).

The selection criteria for exploitable trees mainly depend on the bark thickness and size of the tree. This result is consistent with those obtained for many bark producing species such as *Garcinia lucida* (Guedje et al., 2016; Guedje et al., 2017), *P. africana* (Nkeng et al., 2009) and *Rytigynia* spp. (Kamatenesi et al., 2014). Usually, big size trees (with Diameter at Breast Height (DBH) greater than 30 cm) are preferred due to high yield, bark thickness and concentration of active ingredient. Previous studies had shown that the bark thickness and yield are positively correlated to tree

Figure 6. A completely dead crown of *G. glauca* at Elak village, Kilum-Ijim area, North-west region, Cameroon.

Diameter at breast height (Williams et al., 2007; Delvaux et al., 2010). Moreover, these bigger diameter trees show little damages and better recovery capacity after exploitation than those at younger stages (Nkeng et al., 2009; Delvaux et al., 2010; Kamatenesi et al., 2014; Guedje et al., 2016).

The exploitation techniques applied varied from collection of small bark patches to circular ring debarking and tree felling. The multiplicity of exploitation techniques always reflects the diversity of uses as well as the level of pressure on the species (Cunningham, 2001). It is well known that exploitation for traditional and household uses are always restricted to collection of bark patches, while the huge quantity of barks needed to meet commercial demand implies strip and ring debarking and tree felling to maximize yield (Delvaux et al., 2010; Guedje et al., 2017;Ramana and Raju, 2017). Therefore, the high proportion of trees exploited using small bark patches technique indicate that the exploitation of *G. glauca* bark in the study zone is still restricted to local use with little pressure on the species resources at the ecosystem level. The commercial exploitation of *G. glauca* was suspended in 1997, following the change in raw material of the paper making-company named the "Kilum Forest Craft Paper Cooperative"; as consequence, there is loss of an income generation opportunity to local population (Gardner et al., 2001). Although the species is still locally exploited for household use, the present study also contributes to highlight the untapped industrial potential of the *G. glauca* bark in the Kilum Ijim community forest.

The few trees exploited using ringbarking and felling could have been used to accelerate their dryness for firewood use; rated as first most important use of the species in the study zone.

Apart from the bark, leaves, roots, stem and branches of *G. glauca* are exploited and used in diverse ways by the Kilum Ijim people. However, the numbers of uses reported for this study are few compared to those already documented in Eastern Africa by Amarajeewa et al. (2007) and Kareru et al. (2007). Moreover, the medicinal use highly valued and documented in East Africa is still marginal in this study zone. All these reasons are indications that the species potential is still poorly exploited in the context of the present study. Therefore sensitization and proper documentation of the medicinal properties of the species are highly needed for its valorization in the Kilum Ijim area and in Cameroon.

Exploitation potential and vulnerability status of *G. glauca* in Kilum Ijim community forest

The number of stems varied considerably from one village to another (Table 2). The high number of exploited stems in the sites of Simonkoh, Jikijem and Elak are due to their proximity with a formal paper production company situated at Elak. The closer the sites are to the villages and the easier it is to access the trees, the more they are prone to exploitation of their bark, stem or leave. This result is also reflected in the number of dead trees observed in Elak.

According to the values of Vulnerability indices obtained in this study, *Gnidia glauca* is vulnerable in the study zone. Apart from “availability”, all the vulnerability parameters assessed scored high vulnerability values (scale 3), indicating the multiplicity of plant parts diversely exploited for different uses. A similar result was obtained for *Pterocarpus santaloides* in South Benin which was found vulnerable due to the multiplicity of plant organs exploited and used (Ayena et al., 2016). The forest stand of *G. glauca* is more vulnerable to exploitation than the savanna population. Among the vulnerability parameters assessed, only the value of the “availability parameter” differ between forest (2) and savanna (1) habitats, indicating a higher number of exploitable stems in savanna as compared to the forest ecosystem. This could be explained by the proximity of forest stands to the villages, making them more easily accessible than savanna stands. Open and easy accessibility of resources are known to favor overexploitation; therefore increasing vulnerability if strong regulations are not put in place (Cunningham et al., 2016; Guedje et al., 2016). Recent studies also indicated that open access resources were more prone to overexploitation than individuallyowned plants preserved in farming systems (Cunningham et al., 2016; Guedje et al., 2017).

Health status of the crown and vitality of exploited trees

The high proportion of exploited trees showing "perfect" crown could be related to the appreciable rate of stems exploited using small bark patches technique in the study zone. The result is consistent with those observed by Guedje et al. (2016) on *Garcinia lucida,* Nkeng et al. (2009), Cunningham et al. (2016) on *Prunus africana* and Kamatenesi et al. (2014) on *Rytigynia* spp*.* which revealed that the capacity of these species for bark reconstitution after harvesting and therefore their survival after exploitation depend on the exploitation techniques and debarking intensity. This capacity to resist stress caused by exploitation of bark should however offer a potential for a durable harvest.

Domestication and valorisation potentials of *G. glauca* in the Kilum-Ijim area

Many factors could be used to assess the domestication potential of a species among which are the socio-economic importance that determine its products demand at local, regional and international levels; the species population dynamic and current vulnerability to exploitation which could orientate available exploitable potential and leads to reduction over time; the willingness of the local population to manage the species in their farms is usually assessed through their current planting initiatives (Tchoundjeu et al., 2006; Asaah et al., 2011). From this result, the socioeconomic importance of the species is proven through its multiple uses at local level. However, the inexistence of a structured market could be a constraint for the economic development of the species (Leakey and Van Damme, 2014). Moreover, the low exploitation rate unveils the need for an alternative source of supply, while the current potential is still untapped (Leakey and Asaah, 2013). However, the exploitation history of the species, indicating its use as raw material for a paper-making enterprise has been further confirmed in recent study, assessing its wood characteristics (Gardner et al., 2001; Momo et al., 2017). Moreover, the species documented potential in phytomedecine and nanomedicine poorly valued in the study area need to be further explored.

It is well known that a proper documentation of the use, commercial and industrial potentials of NTFPs is a prerequisite for their valorization (Cunningham, 2001). However, the common weakness of enterprises based on NTFP harvests, by small scale producers, are their inability to get large volumes to meet market demand, the lack of attention to quality, quantity as well as production on time (Cunningham, 2011). Although there is still a high number of exploitable trees yet unexploited in the study area, the usually huge demand needed to sustain industries will require additional supply sources. In the same line, the fact that the specie is already preserved in farmlands indicates farmer's interest for its management on-farm and also its suitability for the existing agroforestry systems in the study site (Gyau et al., 2012). Therefore, the fragility of the species' habitat coupled with its industrial potential and suitability for local agroforestry systems, as well as the unsustainability of the exploitation methods observed could be considered as motivating factors to initiate its domestication. The same approach was applied to include species such as *Prunus africana, Pausinystalia johimbe and Annickia chlorantha* in the list of priority species for domestication in Cameroun (Tchoundjeu et al., 2006; Leakey, 2012). In such case, the domestication process is seen as a conservation-development strategy for the species being threatened by poor exploitation techniques and habitat destruction (Leakey, 2012). *Gnidia glauca* could therefore be considered as a potential candidate for domestication in the Kilum-Ijim area and other highlands landscapes at national level. This domestication initiative will contribute in meeting the expectation for green and niche markets for an improved and locally accessible product (Tchoundjeu et al., 2010; Leakey and Van Damme, 2014). However, further studies on its interaction with associated crops as well as nursery-based propagation and growth requirements are needed to anticipate for the future necessity for quality, uniformity, and regularity of supply implies for a successful domestication process (Leakey and Van Damme, 2014).

Conclusion

In spite of the unsustainable exploitation technique of *G. glauca* in the Kilum Ijim forest, the area still have a high proportion of living and exploitable individuals that is worth harvesting for community livelihood. *G. glauca* has multiple uses as the population thought its potential as traditional medicine is still to be explored in the study area. It could therefore be concluded from our study that *G. glauca* population in the Mount Oku area, though vulnerable to unsustainable harvesting technique should be reconsidered for exploitation by population, provided that a more appropriate debarking method is developed, tested and handed on to local harvesters. Moreover, domestication process initiated through tree preservation on-farm should be encouraged to ensure future supply sources.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Amarajeewa BWRC, Mudalige AP, Kumar V (2007). Chemistry and mosquito larvicidal activity of Gnidia Glauca. Proceedings of the Peradeniya University. Research Sessions Sri Lanka 12(1):101-102.

Asaah EK, Tchoundjeu Z, Leakey RRB, Takoutsing B, Njong J, Edang I. (2011). Trees, agroforestry and multifunctional agriculture in Cameroon. International Journal Agricultural Sustainability 9:110-119.

Asanga C (2002). Case study of exemplary forest management in Central Africa: community forest management at the Kilum-Ijim mountain forest region, Cameroon. Forest Management. Working Papers, FM/11, Forest Resources Development Service, Forest Resources Division, FAO, Rome, 43 p.

Assi-Kaudjhis C, Digbehi BZ, Roche E, Lezine A-M (2010). Synthèse sur l'évolution des paléoenvironnements de l'Afrique occidentale atlantique depuis la fin de la dernière période glaciaire. Influences climatiques et anthropiques. Revue Internationale de Géologie, de Géographie et d'Ecologie 34:1-28.

Ayena AC, Agassounon DTM, Assogbadjo A, Adoukonou-Sagbadja H, Mensah GA, Agbangla C, Ahanhanzo C (2016). Usages et vulnerabilité de Pterocarpus santalinoides L'her. Ex De (Papillionoidae), une plante Utilisée dans le traitement des Gastro-Enterites dans le Sud du Benin. European Scientific Journal 12(6):218 -231.

Betti JL (2001). Usages traditionnels et vulnérabilités des plantes médicinales dans la réserve de Dja et dans le marché de Yaoundé, Cameroun. Thèse de Doctorat Université Libre de Bruxelles, Belgique.

Bergl RA, Oates JF, Fotso R (2007). Distribution and protected area coverage of endemic taxa in West Africa's Biafran forests and highlands. Biological Conservation 134:125-208.

Brink M (2009). Gnidia glauca (Fresen.) Gilg. [Internet] Record from Protabase. Brink M, Achigan-Dako, EG (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. < http://database.prota.org/search.htm>. Accessed 9 July 2012

Burgess ND, Balmford A, Cordeiro NJ, Fjeldså J, Küper W, Rahbek C Sanderson EW Scharlemann JPW Sommer JH,Williams PH (2007). Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa. Biological Conservation 134:164-177.

Cheek M, Onana JM, Pollard BJ (2000). The Plants of Mount Oku and the Ijim Ridge, Cameroon, A Conservation Checklist. Royal Botanic Garden, Kew, 211 p.

Cunningham AB (2001). Applied ethnobotany. People wild plant use and conservation. WWF, UNESCO, KEW, Earthscan, condon and streling, 450P.

Cunningham A, Anoncho VF, Sunderland T (2016). Power, policy and the Prunus africana bark trade, 1972–2015. Journal of Ethnopharmacology 178:323-333.

Delvaux C, Sinsin B, Van Damme P (2010). Impact of season, stem diameter and intensity of debarking on survival and bark re-growth pattern of medicinal tree species, Benin, West Africa. Biological Conservation 143:2664-2671.

Ferrari J (2002). Contribution à la connaissance du métabolisme secondaire des Thymelaeaceae et investigation phytochimique de l'une d'elles: Gnidia involucrata Steud. ex A. Rich. Thèse de Doctorat, Université de Lausanne, Suisse, 242 p.

Forboseh PF, Keming EC, Toh CL, Wutlof IN (2003). Monitoring of Kilum-Ijim forest bird communities: initial findings. Bird Conservation International 13:255-271.

Gardner AA, Demarco J, Asanga CA (2001). A conservation partnership community forestry at Kilum-Ijim, Cameroon. Rural Development Forestry Network 25:9-16.

Guedje NM, Tchamou N, Lejoly J (2016). Tree response to bark harvest: the case of a medicinal species, Garcinia lucida, as source of raw materials for plant-based drug development. Journal of Applied Biosciences 99:9476-9471.

Guedje NM, Tadjouteu F, Tchamou N, Ndoye O (2017).The use of traditional ecological knowledge in sustainable use and management of plant resource through a community-based and participatory assessment. International Journal of Biological and Chemical Sciences 11(4):1611-1626.

Gyau A, Chiatoh M, Franzel S, Asaah E, Donovan J (2012). Determinants of farmers' tree planting behaviour in the North West region of Cameroon: the case of Prunus africana. International Forestry Review 14:265-274.

Kamatenesi MM, Hoft M, Hoft R, Cunningham AB, Ziraba RB (2014). Sustainable harvesting of medicinal barks (*Rytigynia* spp., Rubiaceae) in multipleuse zones around Bwindi impenetrable National Park, Uganda. Cunningham AB, Campbell BM, Luckert MK. Advances in Economic Botany 17:211-226.

Kareru PG, Kenji GM, Gachanja AN, KerikoJM, Mungai G (2007). Traditional medicines among the Embu and Mbeere peoples of Kenya," African Journal of Traditional, Complementary and Alternative Medicines, 4(1):75-86.

Kemeuzé VA (2010). Diversité et Ethnoecologie du genre Combretum dans les régions semi-Arides du Cameroun. Thèse Master, Université de Dschang, Cameroun 70 p.

Kimengsi NJ, Ngala PM (2018). Revisiting participatory forest management and community livelihoods in the Kilum-Ijim Montane Forest Landscape of Cameroon. International Journal of Global Sustainability 2(1):39-55.

Klitgård BB, Baracat A (2014). Neotropical Thymelaeaceae. In: Milliken, W., Klitgård B & Baracat A (2009 onwards), Neotropikey - Interactive key and information resources for flowering plants of the Neotropics. http://www.kew.org/science/tropamerica/neotropikey/families/Thymelaeaceae.htm.

Leakey RRB (2012). Living with trees of life: towards transformation of tropical agriculture. CABI ISBN978-1-78064-099-0 200P.

Leakey RRB, Asaah EK (2013). Underutilised species as the backbone of multifunctional agriculture: the next wave of crop domestication. Acta Horticulturae 979:293-310.

Leakey RRB, van Damme P (2014). The role of tree domestication in green market product value chain development. Forests, Trees and Livelihoods 23(1-2):116-126.

Mittal AK, Chisti Y, Banerjee UC (2013). Synthesis of metallic nanoparticles using plant extracts. Biotechnology Advances 31(2):346-356.

Momo SMC, Chabrerie O, Gallet-Moron E, Nkongmeneck BA, Leumbe Leumbe ON et Decocq G (2012). Analyse de la dynamique de déforestation par télédétection couplée aux modèles d'équations structurales: exemple de la forêt néphéliphile du mont Oku (Cameroun). Acta Botanica Gallica 159(4):451-466.

Momo SMC, Avana ML, Ngueguim JR, Kemeuze VA (2017). Wood characterization of Gnidia glauca (Fresen.) gilg (Thymelaeaceae) and its possible utilization as material for pulp production in Northwest Cameroon. Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo 8:36-44.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent (2000). Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Nkeng PF, Ingram V, Awono A, Tientcheu MLA (2009). Assessment of Prunus africana bark exploitation methods and sustainable exploitation in the South west, North-West and Adamaoua regions of Cameroon, in Project GCP/RAF/408/EC « Mobilisation et Renforcement des Capacités des Petites et Moyennes Entreprises impliquées dans les Filières des Produits Forestiers Non Ligneux en Afrique Centrale », CIFOR, Editor. FAO-CIFOR-SNV-World Agroforestry Center-COMIFAC: Yaounde 57 p.

Ramana KV, Raju AJS (2017). Traditional and commercial uses of *Litsea glutinosa* (Lour.) C.B. Robinson (Lauraceae). Journal of Medicinal Plants studies 5(3):89-91.

Stewart K (2009). Effects of bark harvest and other human activity on populations of the African cherry (Prunus africana) on Mount Oku, Cameroon. Forest Ecology and Management 258(7):1121-1128.

Soromessa T, Kelbessa E (2015). Interplay of regeneration, structure and uses of some woody species in Chilimo Forest, Central Ethiopia. Science Technology and Arts Research Journal 3(1):90-100.

Tchoundjeu Z, Asaah EK, Anegbeh P, Degrande A, Mbile P, Facheux C, Tsobeng A, Atangana AR, Ngo Mpeck ML, Simons AJ (2006). Putting participatory domestication into practice in West and Central Africa. Forest Trees Livelihoods 16(1):53-69.

Tchoundjeu Z, Degrande A, Leakey RRB, Nimino G, Kemajou E, Asaah E, Facheux C, Mbile P, Mbosso C, Sado T, Tsobeng A (2010). Impacts of participatory tree domestication on farmer livelihoods in West and Central Africa. Forest Trees Livelihoods 19(3):217-234.

Tsabang N (2008). Etude ethnobotanique des plantes à vertus anti-diabétique et/ou antihypertensives au Cameroun. Thèse Doctorat/PhD, Université de Yaoundé I, 300 p.

Williams VL, Witkowski ETF, Balkwill K (2007). Relationship between bark thickness and diameter at breast height for six tree species used medicinally in South Africa. South Africa Journal of Botany 73:449-465.

World Bank (2017). Annual report 2016 on Gross Domestic Products per Capita for African Countries.

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Understorey birds' nests predation in afrotropical forest ecosystem: A case study of Korup area, Cameroon

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Worldwide understorey nesting bird species such as bulbuls can also be highly vulnerable to nest predation in disturbed landscapes because they breed mainly on the lower stage of the forest. We test the following hypotheses: the transformation of forests into alternative land use systems and the vegetation's variables at the nesting sites will affect the understorey nest predation rates. The nests of 12 understorey bird species were surveyed and vegetation variables were measured within five types of habitats along a gradient of increasing forest destruction in the north-eastern peripheral zone of the Korup National Park in Cameroon. Only the open-cup nest type suffers from predation, mostly egg predation. The general linear mixed model analysis suggests that the types of habitat do not affect nest daily predation rate which decreases with increasing trees and understorey plant density. The most deleterious impact of deforestation in this study area is the reduction of nesting sites whose characteristics remain unchanged across the landscape. These results underscore the need to give understorey nesting species, as well as other particularly sensitive groups, special consideration within conservation strategies such as the reduced-impact logging techniques.

Key words: Cameroon, deforestation, land-use system, nest predation, understorey birds.

INTRODUCTION

Tropical forests have been destroying in at an alarming rate (Sodhi et al., 2004). Yet, the mechanisms of how forest modification affects the biodiversity destruction of African tropical rainforest regions are less well known (Norris et al., 2010; Newmark and Stanley, 2011; Newbold et al., 2015). These regions with high wildlife species richness and abundance have severe extinction rates because of habitat loss and overexploitation (Bradshaw et al., 2009; Cordeiro et al., 2015). There is evidence that habitat loss and alterations of species interaction are the major impacts of land use changes on bird populations (Cordeiro et al., 2015). Accordingly,

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extinctions of some forest birds resulting from direct or indirect consequences of deforestation have been recorded from various tropical regions (Castelletta et al., 2000; Sodhi et al., 2004). Understorey birds are within the most vulnerable of the forest bird communities because their nests are the most exposed to diverse predators species (Bellamy et al., 2018) as compared to canopy nesters in some study areas (Martin, 1993a). Furthermore, some evidence in tropical forests showed that off-ground nests are generally less predated than ground nests (Pangau-Adam et al., 2006; Bobo, 2007).

Nest survival within a tropical understorey bird community in a fragmented landscape is affected by many environmental factors (Newmark and Stanley, 2011; Aldinger et al., 2015). Nest predation seems to be the primary cause of nest failure among birds. Many studies have registered increased rates of nest predation in fragmented habitats (Githiru et al., 2005; Newmark and Stanley, 2011) due to higher densities of predators and reduced food availability in that landscapes (Chalfoun et al., 2002). Predation is also an important and ubiquitous selective force that can determine habitat preferences of prey species (Chalfoun and Martin, 2009) and it has been considered as an influential force in the evolution of an avian life-history trait (Bradley and Marzluff, 2003).

Evaluating the theory of the negative roles of tropical forests fragmentation on avian nesting success has always been a complex task because nests are concealed in tropical forests and are very difficult to localize (Tewksbury et al., 2006; Newmark and Stanley, 2011). From this, artificial nest experiments have often been used (Posa et al. 2007; Vergara and Simonetti 2004). These studies compare disturbed and non-disturbed habitats. They do not look at the effect of a gradient of increasing habitat destruction on predation. Also, they do not evaluate the negative or positive influences of vegetation variables on predation. Although, many studies on the bird nest predation have been carried out in Americas (Bradley and Marzluff, 2003; Vergara and Simonetti, 2004; Debus, 2006; Tewksbury et al., 2006), only a few of them are devoted in Africa (Djomo et al., 2014; Githiru et al., 2005; Newmark and Stanley, 2011). To the best of our knowledge, only two studies have been carried out in the “Guineo Congolese” area (Djomo et al., 2014) which considered predation on artificial nests. So, the real effects of forest destruction on natural nests remains less clear. The purpose of our research is to examine the effects of types of habitats on understorey avian nest predation within an Afrotropical understorey bird community. In this analysis, we compare the number of active nests found and the predation rates of open-cup nests between natural forests (near primary forest and old secondary forest) and modified habitats (disturbed forest, cocoa/coffee plantations and annual crop food fields) in one hand and between breeding phases (which are egg laying, incubation and nestling phases) in another hand. Additionally, the study investigates the influences of the vegetation parameters on daily predation rate. Based on other studies in similar ecosystems in Africa (Githiru et al., 2005) and South America (Vergara and Simonetti, 2003; Brawn et al., 2011), our hypothesis is that nest predation rates will increase with the gradient of increasing forest destruction and nest loss will be greatest in the nestling stage. In accordance with other studies (Dion et al., 2000; Estrada et al., 2002; Debus, 2006), we also hypothesize that in our study area, some nest sites features such as the density of trees, the canopy cover, etc. will significantly affect the depredation levels with more concealed nest sites being less predated (Vergara and Simonetti, 2004).

MATERIALS AND METHODS

Study area

The study sites (Mgbegati, Abat and Basu), found between 5°21’18”-5°25’38” N and 9°06’29”-9°15’07” E, are in the Northeastern peripheral zone of Korup National Park (KNP) Southwest Region of Cameroon and are a legal entity in the management of KNP (Figure 1). It is the only extensive forest of western central Africa that originally spread from the Niger delta eastwards to Cameroon and South through Equatorial Guinea and Gabon. Located in the centre of the Guinea Congolese forest refugium, Korup is made up of four different forests (Atlantic Biafran Forest, Swamp Forest, Piedmont Forest and Sub-montane Forest) (Thomas, 1995). Our study sites are in the Piedmont Forest. Shifting cultivation is practised on farming areas which are associated with different forest types. Both food crops and cash crops are produced.

The study area encompasses the following broadly defined types of habitat: (1) primary forest (PFO), which is the natural forest with about 570 trees/ha (Waltert et al., 2005) and very little or no anthropogenic activities; the dominant tree species are *Oubanguia alata, Gilbertiodendron demonstrans* and *Dichostema glaucescens*; (2) old secondary forest (OSF), with about 530 trees/ha (Waltert et al. 2005) and where anthropogenic impacts are present but more than in PFO; *Elaeis guineensis, Rauvolfia vomitoria, Pycnanthus angolensis* and *Barteria fistulosa* constitute the main tree species; (3) disturbed forests (DFO), where logging was executed within 5 years prior to the study period; (4) cocoa/coffee plantations (CCP), with about 377,8 trees/ha (cocoa/coffee trees excluded) (Waltert et al., 2005) and where the land has been used for cocoa/coffee production, with few natural trees remaining; the dominant tree species are *Coffea/Theobroma, Elaeis guineensis, Dacryodes edulis, Rauvolfia vomitoria* and *Funtumia elastic;* (5) annual crops fields (ACF), where the land has been used for subsistence crops production (cassava, yams, maize, groundnut, etc.), with about 107,8 trees/ha (Waltert et al., 2005); *E. guineensis, Ricinodendron heudelotii* and *Rauvolfia vomitoria* are the main tree species. Each of the above habitats constitutes a stratum (Figure 1). The avifauna is a typical lowland rainforest, with more than 184 species restricted to this biome (Fishpool and Evans, 2001) and 420 species recorded (Rodewald et al., 1994). Particularly diverse groups are flycatchers (Muscicapidae), Old World Warblers (Sylviidae), Bulbuls (Pycnotidae), Sunbirds (Nectariniidae), and Weavers (Ploceidae).

Study design and data collection

The study was based on a total of 30 200 m x 200 m plots, six plots in each of five pre-classified habitats, primary forest, secondary

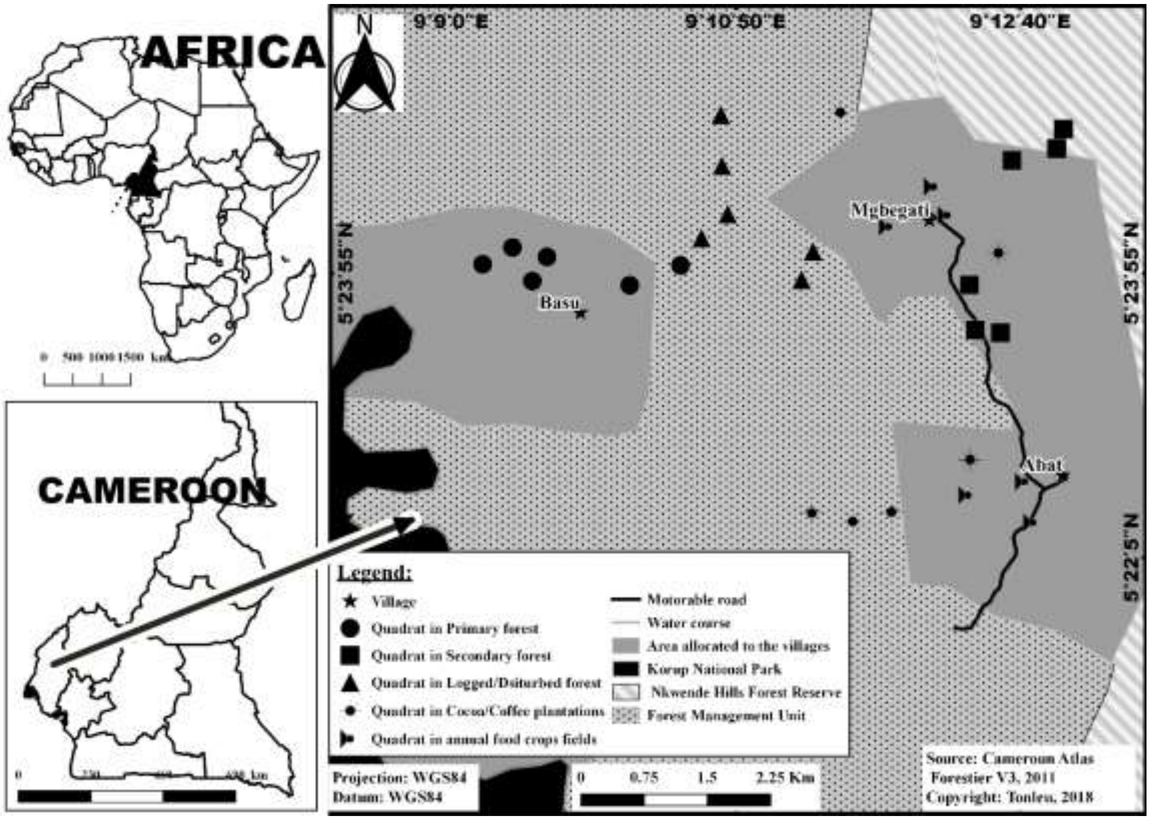

Figure 1. The study area.

forest, disturbed forest, cocoa/coffee plantations and annual culture fields (Figure 1). The plots were demarcated randomly within each habitat with at least 0.5 km between plots (Bobo, 2004). The period from April to August 2013 (within the wet season) corresponds to the nesting season of understorey nesting bird of this region (Serle, 1981). Nests between 0 and 2 m height were localized using direct searching in the shrub and lianas in accordance with the observed behaviour of adult birds. Each nest was monitored until the nesting attempt failed or the young fledged successfully. Nests searching had been carried out for five days per week. Each located nest was marked with flags at least 5 m from the nest (Dion et al., 2000) and visited every three days (Buler and Hamilton, 2000). At each visit, nests were examined for signs of predation, including missing, dead, or partially consumed young, broken eggs and disturbed nest bowls. Predation was presumed to be the cause of nest failure when the nest had disappeared, was torn apart or when the entire contents of the nest were absent (Newmark and Stanley, 2011). It is assumed that the young would have fledged if signs of predation were absent and if nestlings were close to fledging during the previous visit (Dion et al., 2000). We specially named as "Egg + chick predation" a case of predation in which we could not determine which stage it happened. Bird species were identified with a reference field guide to African birds (Borrow and Demey, 2008).

To test the hypothesis that the vegetation parameters would influence the daily predation rate of the understorey bird nests, nest habitat features over two scales were measured. One scale consisted of the plants that supported the nests, the nest's position inside the plants and the immediate surroundings of the nesting site (microhabitat). The second scale covered the vegetation patch surrounding the nest (mesohabitat) (Mezquida, 2004). At the level of the microhabitat, information was collected based on the modification of the method of (Dion et al., 2000) and the method of Wray and Whitmore (1979) so as to note three indicators of nest-site vegetation since only shrub nests were found. At each nest depredated or fledged young, four 1 m bamboo poles serving as sample sticks were positioned horizontally on the ground around the nest. These bamboo poles formed a square plot with a nest at its centre. The first indicator was the percentage of vegetation cover around the nests which was visually estimated at the nearest 5%. The second was the maximum height of the vegetation above the nest which was estimated by observing the last contact of the plant with a one-metre pole placed on the nest and the third was the horizontal density of the trees based on the number of stems in the above-defined square. The following set of variables were also measured for all nests. These include the type of the supporting plant (liana or shrub), the height (estimated with the metre) of the nest on the supporting plant and the total visibility of the nest or concealment category (subjective score ranked from 0 = low to 3 = high). The latter was obtained as a sum of horizontal and vertical concealment (each scored as 0 = nest well visible from most directions; 1 = intermediate; 2 = nest not visible in any direction from a distance of c. 1 m) (Weidinger, 2002; Remeš, 2005). Finally, nest concealment scores (that is after the sum) were up to 10 (the highest score) for some nests

At the mesohabitat scale, the methods of Bobo et al. (2006) were adapted to sample the plant's parameters such as density and the basal area. Firstly, each of the above plots was divided into 400 (10 m x 10 m) subplots for overstorey plants data recorded. Then, 20 study plots were chosen systematically from the previous subplots so that, the distance between two subplots of the same line is 30 m and the distance between two lines containing the study subplots is 50 m (Additional File Figure S1). This resulted in a total of 600 subplots covering a sampling area of 60 000 m². Overstorey plants are defined as all trees of more than 10 cm in diameter at 1.3 m height (DBH) and understorey plants being all vascular plants of less than 1.3 m height as well as grasses etc. One m² (1 m × 1 m) quadrat was demarcated at the centre of each study subplot to collect understorey plants data. In agroforestry sites, cocoa/coffee trees were not measured, but their numbers (based on 3 m × 3 m as space for a cocoa/coffee tree) and size classes were estimated for each plot. All plants species were counted and identified at the morpho-species level. Only the most common trees and understorey plants were identified at the species level.

The classes of canopy cover were described as Clark and Clark (1992). Therefore, crown illumination indexes (or classes) were recorded for all trees placed at the corners (four) and the centre of each study subplot and the most encountered index were then adopted for the entire subplot. This index scores the source and relative amount of crown lighting. They are broadly equivalent to the estimation of canopy closure and are measured on an ordinal scale (Jennings et al., 1999) that is: Class 1, Class 1.5, Class 2, Class 2.5, Class 3, Class 4 and Class 5 where Class 1 is highest canopy cover and Class 5 is no canopy cover (Jennings et al., 1999) (Additional file Explanation Notes).

Statistical analyses

During the analyses, a nest was considered as an individual and only the predation of open nests types was considered because the sample size of enclosed nests was very small (only 4). Although these are built by different species, these nests were generally cup-shaped and were constructed on either shrubs or lianas so they would likely experience similar predation rates (Auer et al., 2007). Also, there were not significant differences between the clutch sizes of these understorey-nesting birds' species (Kruskal-Wallis χ^2= 17.261, *df* = 10, p = 0.068).

The daily predation rates (DPR) in different types of habitat were estimated using the adaptation of the logistic exposure model (Shaffer, 2004). The latter was implemented in R using a *complementary log-log link* with the package MASS (Venables and Ripley, 2002). The predation rates were also performed using the adaptation of the nesting success formula (Mayfield, 1975) as the predation of nests being the result of exposure events.

The Kruskal-Wallis rank sum test was performed to compare the mean number of nests between habitat types (Hollander et al., 2014). This test was also used to compare the mean DPR between types of habitat as well as to verify the dependence between types of predation (eggs and nestlings) and the types of habitat (Hollander et al., 2014). The Chi-Squared Test of equality of proportions with Yates' correction (Yates, 1934) was conducted to compare the proportions of predated nests between different types of habitats and breeding stages (Wilson, 1927).

The effects of habitats and features of habitats on birds' nests predation were assessed using the generalized linear mixed models (GLMM) in which species had random effects and vegetation variables and habitat types (selected in the best model using the AIC) viewed as fixed effects (Table 1) (McCullagh and Nelder, 1989). Only the vegetation variables that appeared in the best model was included in the GLMM. Vegetation variables included in the models were first transformed using the square root transformation techniques after Kolmogorov test (Conover, 1972). Mixed-effects models were created using package lme4 (Bates et al., 2014), with the explanatory variables incorporated as nested (hierarchical) Fixed effects and types of habitats as random effects (Table 1).

Akaike's information criterion (AIC) Burnham and Anderson, (2003) was used to derive best fit top models in package AICcmodavg (Mazerolle, 2016) that is, models having variables that best explain the variation of the DPR. This calculated an AICc (bias-adjusted AIC for small sample sizes), ΔAICc (AICc of the alternative model – AICc of best models) and Akaike weight (wi) for each candidate model. We, first of all, choose several models by AIC in a Stepwise Algorithm (Venables and Ripley, 2002). Top fit models were chosen where there was enough strength of evidence to reject the alternative models. This was defined as the best model having an Akaike weight greater than that of the alternative models (Symonds and Moussalli, 2011).

Furthermore, to indirectly evaluate the factors stimulating the nesting sites choice of these birds along the gradient of increasing forest destruction, the mean trends of vegetation parameters having significant influences on the DPR were accessed using the Jonckheere-Terpstra test, an ordered non parametric test (Terpstra, 1952; Jonckheere, 1954) with the package "clinfun" version 1.0.14 (Seshan, 2017). All these analyses were performed in the R-Core software version 3.4.1 (R Foundation for Statistical Computing, 2017).

RESULTS

Active nests monitored in different types of habitat

During the 2013 breeding season, we located and monitored 60 active nests of 12 understorey nesting bird species distributed inconsistently across the five habitats under studied (Table 2). All these nests were off the ground and were open-cup (56 nests) or enclosed (4 nests). No ground nests were found. The 56 open-cup nests surveyed belong to 11 different species and did not differ significantly along the gradient of increasing forest destruction (Kruskal-Wallis χ^2 = 8.5195, *df* = 4, p = 0.074) although they seemed to be highest in the secondary forest.

Nest predation rates according to types of habitat and breeding phases

About 241 observations were made on the nests and only the open-cup nests were predated. About 47% of the open-cup nests monitored were predated. The proportions of predated nests did not vary significantly between types of habitats (χ^2 = 4.192; df = *4; p = 0.381*). However, the highest number of predated nests (43%) was found in the old secondary forest and the lowest in Annual culture farms (4%) (Figure 2A). Egg predation (77.78%), chick predation (18.52%), chick and egg predation (3.7%) were recorded in the study area (Figure 2B). There was a significant difference between the main types of predation in the study area (χ^2= 137.051; df = 2; p < 0.0001). Also, variation on predation rates of eggs (χ^2 = 5.556; df = 4; p = 0.234) and chicks (χ^2 = 1.356; df = 4; p = 0.851) did not exist between types of habitats. Moreover, the frequency of predation varied significantly along the nesting phases (χ^2 = 97.915; df = 2; p < 0.0001), with the nests being mostly predated during the incubation phase (71.43%) (Figure 2C).

The average predation rate across the ecosystem varied between < 0.001 and 27.18% but was not influenced significantly by the types of habitats (Kruskal-

Table 1. The explanatory and dependent variables used in the analysis.

Variables	Scales	Sizes of plots	Descriptions
Explanatory variables			
H	Meso	200 m × 200 m	Habitat types were grouped into five land use systems
a	Meso	10 m × 10 m	The classes of canopy cover (Class 1, class 1.5, Class 2, Class 2.5, Class 3, Class 4 and class 5). Also, 1 is complete canopy cover, 5 is no canopy cover.
b	Micro	1 m × 1 m	The understorey plants density (number of individuals/ha)
c	Micro	1 m × 1 m	The microhabitat trees density (number of individuals / m²)
d	-	-	The height of the nest on the supporting plant (m)
e	-	-	The type of the nest supporting plant (liana or shrub)
f	Micro	1 m × 1 m	The percentage of vegetation cover around the nests which was visually estimated at the nearest 5%
g	Meso	1 m × 1 m	The horizontal density of the trees (number of individuals / m²)
h	-	-	The maximum height of the vegetation above the nest (m)
i	-	-	The total visibility of the nest (ordinal variable)
j	Meso	10 m × 10 m	The overstorey plants density (number of individuals/ha)
k	Meso	10 m × 10 m	The overstorey plants basal area (m²/ha).
l	-	200 m × 200 m	Understorey-nesting species evaluated as the random effect
Dependent variable			
Daily Predation Rate (DPR)	-	-	Estimated based on Shafer (2004) method

Table 2. List and number of active nests found.

Species	Type of nest	Number of nests in each habitat					Total
		PFO	OSF	DFO	CCP	ACF	
Criniger chloronatus	Open-cup	1	0	0	0	0	1
Chlorocichla flavicollis soror	Open-cup	3	2	0	0	0	5
Eurillas latirostris	Open-cup	5	2	4	2	0	13
Bleda eximus	Open-cup	0	3	1	0	0	4
Arizelocichla montana	Open-cup	0	0	0	1	2	3
Eurillas ansorgei	Open-cup	0	1	0	0	0	1
Phyllastrephus icterinus	Open-cup	0	1	0	0	0	1
Bleda notata	Open-cup	1	4	1	0	0	6
Eurillas virens	Open-cup	6	9	3	0	1	19
Cinnyris chloropygius	Enclosed	0	1	0	0	3	4
Unknown species I	Open-cup	1	0	0	0	0	1
Unknown species II	Open-cup	0	0	0	2	0	2
Total		17	23	9	5	6	60

Notes: **PFO:** Near Primary Forest; **DFO:** Disturbed Forest; O**SF:** Secondary Forest; **CCP:** Cocoa/Coffee plantations; **ACF:** Annual Culture farms.

Wallis χ^2 = 5.955, *df* = 4, *p = 0.203*). Nevertheless, this average predation rate seemd to be highest in primary forest (11.867%) and smallest in the cocoa/coffee plantations (1.539%), compared to other types of habitats (Figure 2 (D)). Also, when pooling the data into two habitats (that is natural forests vs disturbed habitats), the average predation rate did not vary significantly (Kruskal-Wallis χ^2 = 2.188, *df* = 1, *p = 0.139*).

Influences of habitat features on the daily predation rate

The daily predation rate (DPR) of these understorey nesting birds varied between 0.019 and 0.964 but did not vary significantly amongst types of habitats (Kruskal-Wallis χ^2 = 5.955, *df* = 4, *p = 0.203*). This daily predation rate did not vary significantly between natural forests

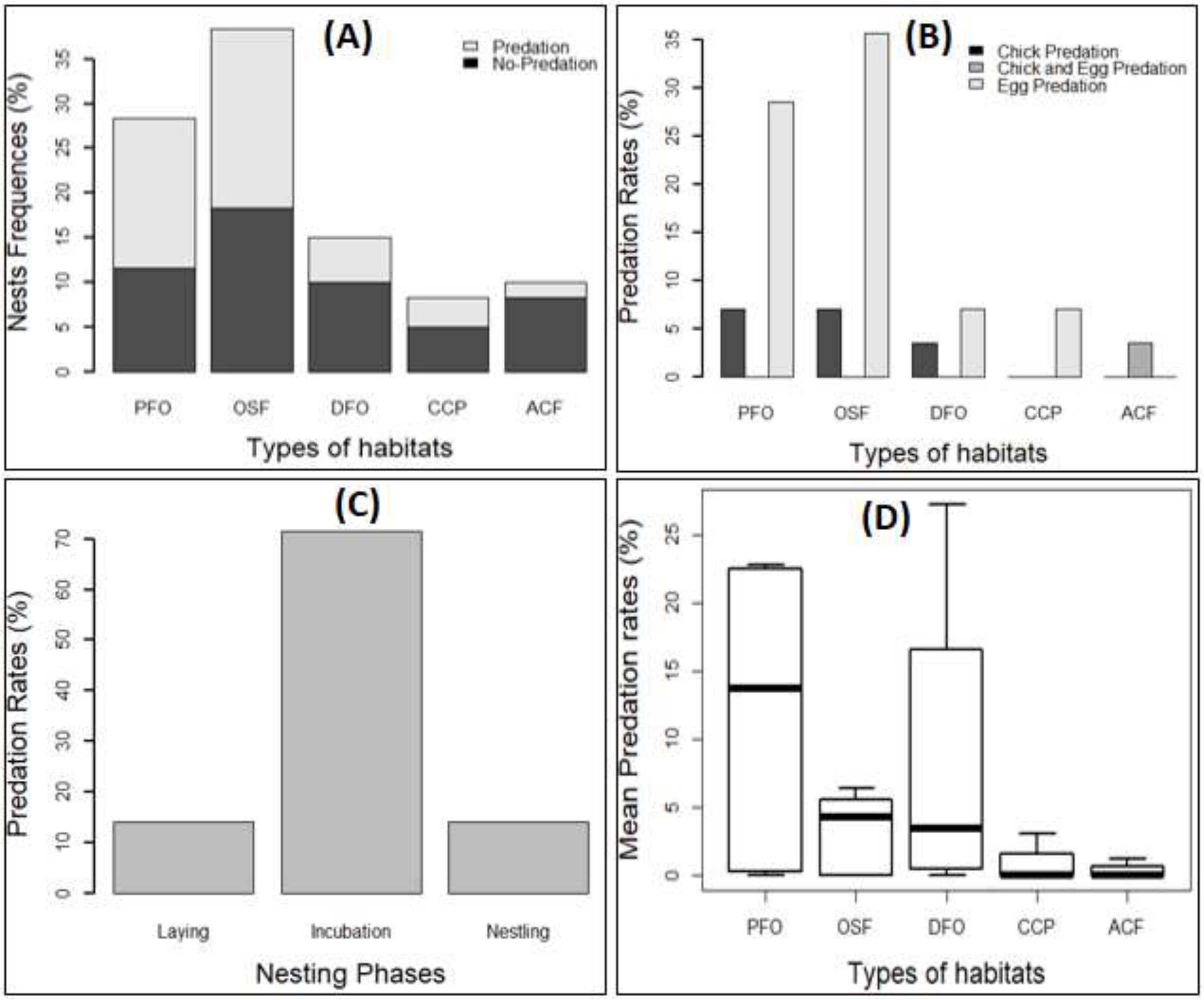

Figure 2. Distribution of predation phenomenon in different types of habitats (A and B); Proportions of predation rates among the nesting phases (C); and Mean daily predation rates (D). Notes: **PFO:** Primary Forest; **DFO:** Disturbed Forest; O**SF:** Secondary Forest; **CCP:** Cocoa/Coffee plantations; **ACF:** Annual Culture farms.

and modified habitats (Kruskal-Wallis χ^2 = 2.188, *df* = 1, *p = 0.139*). Table 2 shows top models according to changes in delta AIC as described by (Burnham and Anderson 2003). The best fit model, which is the one having the smallest value of the Aikake Information Criterion (AIC = 207.23) was chosen (Additional file Table S1). This model included quantitative variables (understorey plant density, microhabitat trees density) and a qualitative variable (classes of canopy cover) were then introduced as fixed effects in the generalized mixed effects model with the understorey-nesting species evaluated as the random effect (Table 3).

The density of trees in the microhabitat and the density of understorey plants had significant negative effects at the 95% significant level. To this effect, when the density of trees (n/m²) in the microhabitat and the density of the understorey plants (n/ha) increased, probabilities of the open-cup nest to be predated decreased for about 3.912e-01 and 8.749e-05 respectively (Figure 3A – B). Furthermore, the influences of the canopy cover classes and the types of nests support (shrub or liana) on the daily predation rate at 95% confidence interval were not significant, although the canopy cover classes 1.5 and 5 had negative effects. However, the canopy cover class 1 and the support had positive influences on the daily predation rate (Table 3). Moreover, very low correlations existed between most of the Fixed effects parameters on the daily predation rate (Additional file Table S2).

Furthermore, the trend in the average density of the trees in the microhabitat did not differ significantly along the gradient of increasing forest destruction (*JT* = 492.5, *p* = 0.301) whereas the average density of the understorey plants increased significantly (*JT* = 249.5, *p* = 0.011) along this gradient (Table 4). This indicates that the choice of the nesting sites depended on the presence of these vegetation parameters.

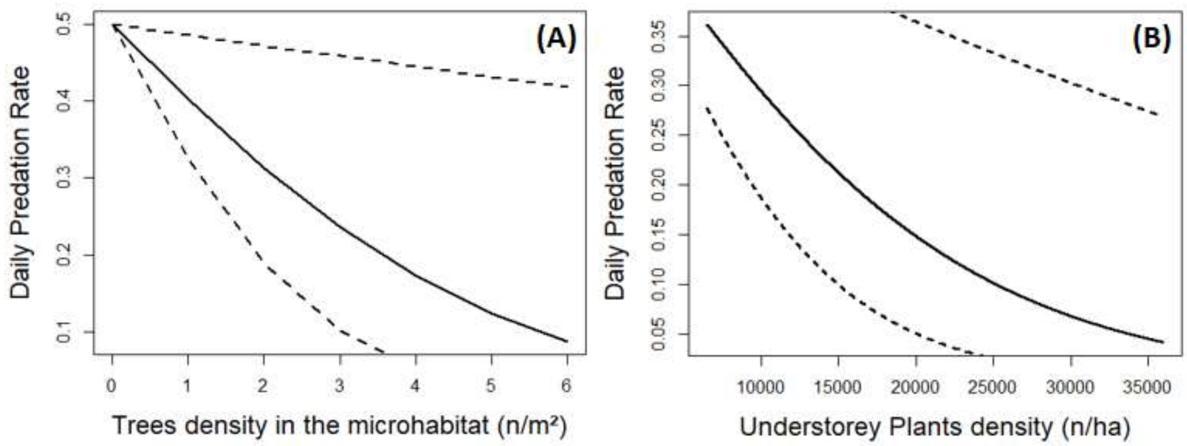

Figure 3. Relation between daily predation rate (DPR) of nests and quantitative parameters of the structure of the vegetation around the nests of understorey bird species. Solid lines represent the estimated DPR obtained from a logit-linear model with significant covariates of the estimated best model. Dashed lines represent upper and lower 95% confidence intervals.

Table 3. The generalized linear mixed model of DPR in relation to vegetation variables and the five habitat types.

Random effects:				
Groups	**Variance**		**Standard Deviation**	
Species (Intercept)	**0**		**0**	
Fixed effects				
Parameter	**Regression coefficients**		**Z value**	**P-value (>|z|)**
	Estimate	**Standard error**		
Canopy cover Class 1 (Intercept)	7.815e-01	7.318e-01	1.068	0.285
Canopy cover Class 1.5	-1.580e-01	5.983e-01	-0.264	0.792
Canopy cover Class 5	-1.333e+00	1.129e+00	-1.181	0.238
Density of the understorey plants	-8.749e-05	3.043e-05	-2.875	0.004 **
Density of trees in the Microhabitat	-3.912e-01	1.715e-01	-2.281	0.023*

Significance level: * p < 0.05; ** p < 0.01; *** p < 0.001. Notes: For Canopy cover classes, 1 is complete canopy cover, 5 is no canopy cover.

DISCUSSION

Number of active bird nests found across the types of habitat

The average number of open-cup nests varies significantly according to the types of habitats with the most degraded having the smallest number of nests. Similar results are found by numerous studies elsewhere in the world (Canaday, 1996; Castelletta et al., 2000). Even if derived forest habitats like cocoa plantations are not a habitat substitute for the forest, they provide habitat for many species, which depend to some degree on forests (Reitsma et al., 2001). Similarly, Van Bael et al. (2007) find that shaded cocoa farms can provide habitat for a wide variety of resident and migratory bird species. However, in the present study, it is not the case for nesting birds, because the less the habitat is disturbed, the more nests are present. This implies that the human activities reduce the probability of understorey nesting bird species of having available nesting sites. Finally, the absence (or rarity) of ground nests in our study area may be due to the presence of highly specialized ground nest predators or to the absence of ground-nesting bird species during sampling time. It could also be due to ground nests being difficult to find.

Predation rates across types of habitat and nesting phases

Predation is the main cause of nest failure in this study.

Table 4. Values of the variables of the vegetation.

Variables of the vegetation		Mean values of some vegetation parameters in each habitat				
		PFO	OSF	DFO	CCP	ACF
Density of overstorey plants (individuals/ m^2)		0.05 ± 0.002	0.04 ± 0.002	0.03 ± 0.003	0.02 ± 0.005	0.01 ± 0.002
Basal area (m^2/ha)		71.81 ± 14.93	51.91 ± 21.63	35.17 ± 14.93	27.19 ± 11.70	7.80 ± 3.40
Understorey plants (individuals/ m^2)		1.71 ± 0.78	2.13 ± 0.23	2.95 ± 0.37	2.14 ± 0.63	2.97 ± 0.72
Density of trees in the microhabitat (individuals/ m^2)		2.11 ±1.13	2.39 ±1.6	2.33 ±1.15	1.6 ±1.2	0.33 ± 0.47
	Class 1	100%	83.33%	83.33%	33.33%	0%
Classes of canopy cover	Class 1.5	0%	16.67%	16.67%	66.67%	0%
	Class 5	0%	0.00%	0.00%	0.00%	100%

Notes: **PFO:** Near Primary Forest; **DFO:** Disturbed Forest; O**SF:** Secondary Forest; **CCP:** Cocoa/Coffee plantations; **ACF:** Annual Culture farms. For Canopy cover classes, 1 is complete canopy cover, 5 is no canopy cover.

Similar results have been found in temperate (Debus, 2006; Tewksbury et al., 2006) and tropical regions (Githiru et al., 2005; Newmark and Stanley, 2011). In this study area, less than half of the nests are predated. This proportion is less than the one found outside the tropics (Mitchell et al., 1996; Tewksbury et al., 1998; Braden, 1999; Mezquida, 2004). These results, however, corroborate those of (Tewksbury et al., 2006) in temperate zones. Several reasons may explain this fact as the diversity of predators, because predation models depend on the response of different predator species, on the composition of the landscape and on the relative effects of these predators on bird species (Tewksbury et al., 2006).

The proportions of predated nests and the daily predation rate do not also vary significantly among types of habitat in our study area. Although the proportion of nests predated in the secondary forest seem to be highest while the proportion found in the annual crop fields was the smallest. This result can be associated with the higher number of active nests found in secondary forest. Moreover, the primary forest seems to have the highest daily predation rate while the secondary forest had the third-highest predation rate. This supports the results of Tewksbury et al. (1998) in temperate forests and contradicts those of Morse and Robinson (1999) in the neotropical forests in which rates of nest predation were significantly lower in the older forest than within even-aged clear-cuts. Moreover, when using artificial nests placed in the forest interior, at the edge and at the clear-cuts in the temperate ecosystem, (Rudnicky and Hunter Jr, 1993) have reported a similar trend. However, this predation model seems to contradict the general assumption that nest predation rate increases with ecosystem disruption due to the influx of predators from neighbouring habitats owing to the best conditions created by ecosystem degradation, as the birds will be more in danger in the heavily modified habitats than in the less degraded ones (Githiru et al., 2005; Pangau-Adam et al., 2006; Tewksbury et al., 2006). Furthermore, predation can be a problem in human-modified habitats if food supplies or nesting sites are reduced but can cope with high predation rates in natural systems (Martin and Clobert, 1996; Wesolowski and Tomialojc, 2005). However, the landscape of Korup National Park (the present study area) is different from other study sites (Githiru et al., 2005; Pangau-Adam et al., 2006; Tewksbury et al., 2006) because the dominant habitats are forests (primary and secondary forests) in terms of area and distribution and are less (or not) disturbed. So, the results obtained here could be completely different due to this landscape structure. This implies that predators arrive rather from modified areas, thus creating a surplus in abundance and diversity of these predators in the natural areas.

Over the course of the nesting cycle, we have found the greatest rate of nest loss in the incubation stage and least in the egg laying and nestling stages. Similar results were obtained in the forest understorey in South America (Ryder et al., 2008). But some studies recorded increasing rate of predation as nesting proceeded (Ryder et al., 2008; Brawn et al., 2011; Fu et al., 2016; Jiang et al., 2017). Increased proportion of predation (DPR) in the incubation phase suggests that nest losses can be ascribed to visually oriented predators as the eggs and chick predation type was recorded over the course of the study.

It can be also explained by lower nest attentiveness and by nesting birds in the early incubation phase. Moreover, decreased proportions of the predation in the laying and nestling stages suggest that, although the number of female trips increases during the nestling phase, nestlings are completely silent even during feeding bouts (Ryder et al., 2008).

Influences of habitat features on predation rates

Generally, habitat quality appears to affect breeding success (Debus, 2006) and birds are mostly scrupulous in their choice of nesting sites (Martin, 1993b). It seems that anthropogenic land management disturbs habitat quality by removing key elements for nesting individuals (Debus, 2006). Many studies have shown that several characteristics (grass cover, height of the nest, percentage of sky visible, detectability index, forb cover, vegetation height around the nest, etc.) of nesting sites have no effect on nest predation rates (Braden 1999; Dion et al., 2000; Githiru et al., 2005; Posa et al., 2007). However, Fu et al. (2016) report that the nest-site-selection variables (tree cover, bamboo cover, liana abundance, etc.) are positively associated with predation. In our study area, only the density of the microhabitat trees and the density of the understorey plants have a significant negative correlation with the daily predation rate.

Moreover, the density of the microhabitat trees does not vary significantly according to the gradient of the increase of forest destruction whereas the density of the understorey plants increases sharply according to this gradient. This explains why annual crop fields, despite their very high level of degradation, might have some secured nesting sites as well. This implies that birds always choose the best nesting site regardless of the degree of disturbance (Martin, 1993b). These results also suggest that bird nest predators in the understorey are more active in relatively stable habitats such as primary forest and secondary forest. These can also be due to the fact that nests might be easier to be found in the natural forests as compared to modified habitats.

Conclusion

In conclusion, our findings support the prediction that well-hidden bird nests are less subjected to predation (Vergara and Simonetti, 2004) and nest-site selection is non-random. As opposed to other findings (Dion et al., 2000; Estrada et al., 2002; Debus, 2006), the predation of understorey bird nests in our study area seems not to be affected by the gradient of increasing habitat destruction. Only the density of trees in the microhabitat and the density of the understorey trees have significant negative effects on the daily predation rates of the open-cup nests. These observations also suggest that this support zone adjacent to the Korup National Park is an important additional breeding habitat for the understorey bird species. Furthermore, in order to consider understorey nesting birds conservation in Korup, sets of timber harvesting guidelines designed to mitigate the deleterious environmental impacts of tree felling, yarding, and hauling known as “reduced-impact logging” techniques (Sist et al., 2003; Putz et al., 2008) must be applied for future trees harvesting practices. Although the effectiveness of reduced-impact logging in reducing tree destruction is limited under high felling intensity (>8 trees/ha) these techniques are better than the conventional techniques (Sist et al., 2003).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Aldinger K, Terhune II, Wood P, Buehler D, Bakermans M, Confer J, Flaspohler D, Larkin J, Loegering J, Percy K (2015). Variables associated with nest survival of Golden-winged Warblers (*Vermivora chrysoptera*) among vegetation communities commonly used for nesting. Avian Conservation and Ecology 10:6.

Auer SK, Bassar RD, Fontaine JJ, Martin TE (2007). Breeding biology of passerines in a subtropical montane forest in northwestern Argentina. The Condor 109:321-333.

Bates D, Mächler M, Bolker B, Walker S (2014). Fitting linear mixed-effects models using lme4. arXiv preprint arXiv:1406.5823.

Bellamy PE, Burgess MD, Mallord JW, Cristinacce A, Orsman CJ, Davis T, Grice PV, Charman EC (2018). Nest predation and the influence of habitat structure on nest predation of Wood Warbler *Phylloscopus sibilatrix*, a ground-nesting forest passerine. Journal of Ornithology 159:493-506.

Bobo KS (2004). Birds as indicators of biodiversity change in tropical landscapes. A case study from the Korup Region, Western Cameroon. Master thesis, The University of Gottingen.

Bobo SK (2007). From forest to farmland: Effects of land use on understorey birds of Afrotropical rainforests. PhD thesis, The University of Gottingen.

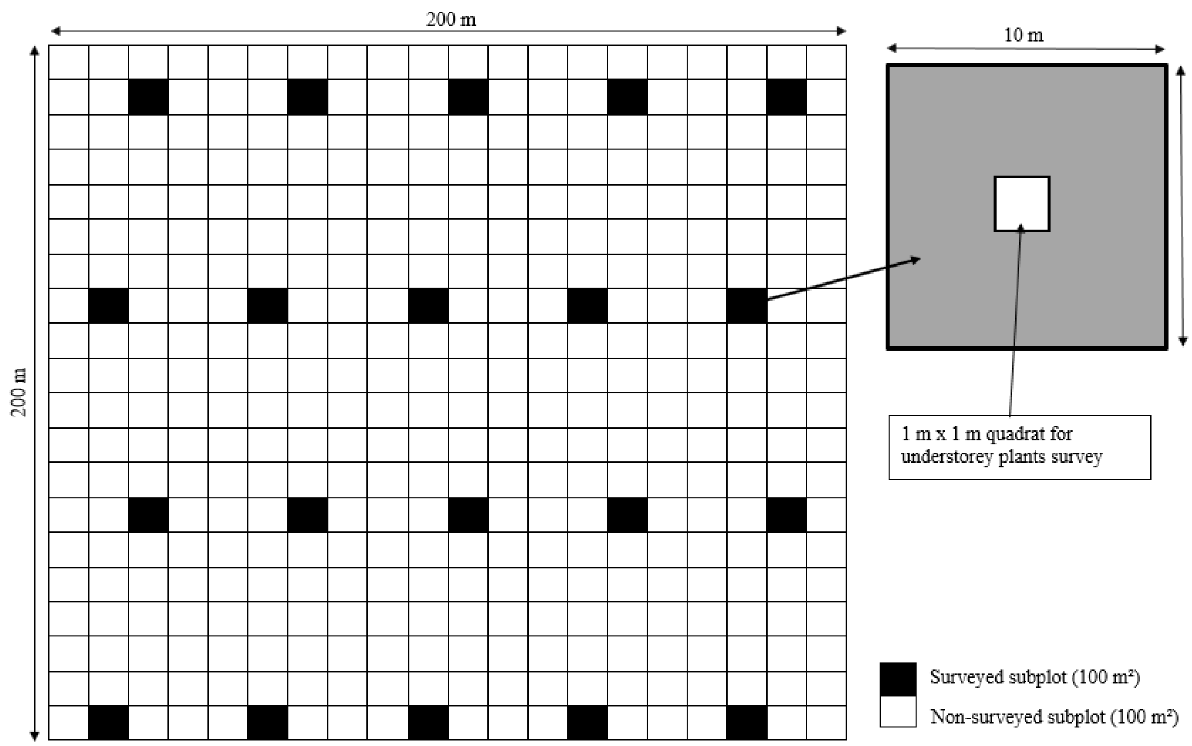
Bobo KS, Waltert M, Sainge NM, Njokagbor J, Fermon H, Mühlenberg M (2006). From forest to farmland: species richness patterns of trees and understorey plants along a gradient of forest conversion in Southwestern Cameroon. Biodiversity and Conservation 15:4097-4117.

Borrow N, Demey R (2008). Guide des oiseaux de l’Afrique de l’Ouest. Delachaux et Niestlé.

Braden GT (1999). Does nest placement affect the fate or productivity of California Gnatcatcher nests? The auk 116:984-993.
Bradley JE, Marzluff JM (2003). Rodents as nest predators: influences on predatory behavior and consequences to nesting birds. The Auk 120:1180-1187.
Bradshaw CJ, Sodhi NS, Brook BW (2009). Tropical turmoil: a biodiversity tragedy in progress. Frontiers in Ecology and the Environment 7:79-87.
Brawn JD, Angehr G, Davros N, Robinson WD, Styrsky JN, Tarwater CE (2011). Sources of variation in the nesting success of understory tropical birds. Journal of Avian Biology 42:61-68.
Buler JJ, Hamilton RB (2000). Predation of natural and artificial nests in a southern pine forest. The Auk 117:739-747.
Burnham KP, Anderson DR (2003). Model selection and multimodel inference: a practical information-theoretic approach. Springer Science and Business Media.
Canaday C (1996). Loss of insectivorous birds along a gradient of human impact in Amazonia. Biological Conservation 77:63-77.
Castelletta M, Sodhi NS, Subaraj R (2000). Heavy extinctions of forest avifauna in Singapore: lessons for biodiversity conservation in Southeast Asia. Conservation Biology 14:1870-1880.
Chalfoun AD, Martin TE (2009). Habitat structure mediates predation risk for sedentary prey: experimental tests of alternative hypotheses. Journal of Animal Ecology 78:497-503.
Chalfoun AD, Thompson FR, Ratnaswamy MJ (2002). Nest predators and fragmentation: a review and meta-analysis. Conservation biology 16:306-318.
Clark DA, Clark DB (1992). Life history diversity of canopy and emergent trees in a neotropical rain forest. Ecological monographs 62:315-344.
Conover WJ (1972). A Kolmogorov goodness-of-fit test for discontinuous distributions. Journal of the American Statistical Association 67:591-596.
Cordeiro NJ, Borghesio L, Joho MP, Monoski TJ, Mkongewa VJ, Dampf CJ (2015). Forest fragmentation in an African biodiversity hotspot impacts mixed-species bird flocks. Biological Conservation 188:61-71.
Debus SJS (2006). Breeding-habitat and nest-site characteristics of Scarlet Robins and Eastern Yellow Robins near Armidale, New South Wales. Pacific Conservation Biology 12:261-271.
Dion N, Hobson KA, Larivière S (2000). Interactive effects of vegetation and predators on the success of natural and simulated nests of grassland songbirds. The Condor 102:629-634.
Djomo Nana E, Sedláček O, Vokurková J, Hořák D (2014). Nest position and type affect predation rates of artificial avian nests in the tropical lowland forest on Mount Cameroon. Ostrich 85:93-96.
Estrada A, Rivera A, Coates-Estrada R (2002). Predation of artificial nests in a fragmented landscape in the tropical region of Los Tuxtlas, Mexico. Biological Conservation 106:199-209.
Fishpool LD, Evans MI (2001). Important Bird Areas in Africa and associated islands: Priority sites for conservation. BirdLife International Cambridge, UK, Cambridge, UK.
Fu Y, Chen B, Dowell SD, Zhang Z (2016). Nest predators, nest-site selection and nest success of the Emei Shan Liocichla (*Liocichla omeiensis*), a vulnerable babbler endemic to southwestern China. Avian Research 7:18.
Githiru M, Lens L, Cresswell W (2005). Nest predation in a fragmented Afrotropical forest: evidence from natural and artificial nests. Biological Conservation 123:189-196.
Hollander M, Wolfe DA, Chicken E (2014). Nonparametric Statistical Methods, 3rd Edn. John Wiley and Sons.
Jennings SB, Brown ND, Sheil D (1999). Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. Forestry: An International Journal of Forest Research 72:59-74.
Jiang A, Jiang D, Zhou F, Goodale E (2017). Nest-site selection and breeding ecology of Streaked Wren-Babbler (*Napothera brevicaudata*) in a tropical limestone forest of southern China. Avian Research 8 p.
Jonckheere AR (1954). A distribution-free k-sample test against ordered alternatives. Biometrika 41:133-145.
Martin TE (1993a). Nest predation among vegetation layers and habitat types: revising the dogmas. The American Naturalist 141:897-913.
Martin TE (1993b). Nest predation and nest sites. BioScience 43:523-532.
Martin TE, Clobert J (1996). Nest predation and avian life-history evolution in Europe versus North America: a possible role of humans? The American Naturalist 147:1028-1046.
Mayfield HF (1975). Suggestions for calculating nest success. The Wilson Bulletin 87:456-466.
Mazerolle MJ (2016). AICcmodavg: Model selection and multimodel inference based on (Q) AIC (c)[Software].
McCullagh P, Nelder AJ (1989). Generalized Linear Models, Second Edition (Chapman and Hall/CRC Monographs on Statistics and Applied Probability). Chapman. and Hall, London., London.
Mezquida ET (2004). Nest site selection and nesting success of five species of passerines in a South American open Prosopis woodland. Journal of Ornithology 145:16-22.
Mitchell MC, Best LB, Gionfriddo JP (1996). Avian nest-site selection and nesting success in two Florida citrus groves. The Wilson Bulletin pp. 573-583.
Morse SF, Robinson SK (1999). Nesting success of a neotropical migrant in a multiple-use, forested landscape. Conservation Biology 13:327-337.
Newbold T, Hudson LN, Hill SLL, Contu S, Lysenko I, Senior RA, Börger L, Bennett DJ, Choimes A, Collen B, Day J, De Palma A, Díaz S, Echeverria-Londoño S, Edgar MJ, Feldman A, Garon M, Harrison MLK, Alhusseini T, Ingram DJ, Itescu Y, Kattge J, Kemp V, Kirkpatrick L, Kleyer M, Correia DLP, Martin CD, Meiri S, Novosolov M, Pan Y, Phillips HRP, Purves DW, Robinson A, Simpson J, Tuck SL, Weiher E, White HJ, Ewers RM, Mace GM, Scharlemann JPW, Purvis A (2015). Global effects of land use on local terrestrial biodiversity. Nature 520:45.
Newmark WD, Stanley TR (2011). Habitat fragmentation reduces nest survival in an Afrotropical bird community in a biodiversity hotspot. Proceedings of the National Academy of Sciences 108:11488-11493.
Norris K, Asase A, Collen B, Gockowksi J, Mason J, Phalan B, Wade A (2010). Biodiversity in a forest-agriculture mosaic–The changing face of West African rainforests. Biological conservation 143:2341-2350.
Pangau-Adam MZ, Waltert M, Mühlenberg M (2006). Nest predation risk on ground and shrub nests in forest margin areas of Sulawesi, Indonesia. Biodiversity and Conservation 15:4143-4158.
Posa MRC, Sodhi NS, Koh LP (2007). Predation on artificial nests and caterpillar models across a disturbance gradient in Subic Bay, Philippines. Journal of Tropical Ecology 23:27-33.
Putz FE, Sist P, Fredericksen T, Dykstra D (2008). Reduced-impact logging: challenges and opportunities. Forest ecology and management 256:1427-1433.
R Foundation for Statistical Computing (2017). R: The R Project for Statistical Computing. https://www.r-project.org/
Reitsma R, Parrish JD, McLarney W (2001). The role of cacao plantations in maintaining forest avian diversity in southeastern Costa Rica. Agroforestry Systems 53:185-193.
Remeš V (2005). Nest concealment and parental behaviour interact in affecting nest survival in the blackcap (*Sylvia atricapilla*): an experimental evaluation of the parental compensation hypothesis. Behavioral Ecology and Sociobiology 58:326-332.
Rodewald PG, Dejaifve P-A, Green AA (1994). The birds of Korup National Park and Korup Project Area, Southwest Province, Cameroon. Bird Conservation International 4:1-68.
Rudnicky TC, Hunter Jr ML (1993). Avian nest predation in clearcuts, forests, and edges in a forest-dominated landscape. The Journal of wildlife management 57:358-364.
Ryder TB, Durães R, Tori WP, Hidalgo JR, Loiselle BA, Blake JG (2008). Nest survival for two species of manakins (*Pipridae*) in lowland Ecuador. Journal of Avian Biology 39:355-358.
Serle W (1981). The breeding season of birds in the lowland rainforest and in the montane forest of West Cameroon. Ibis 123:62-74.
Seshan VE (2017). clinfun: Clinical Trial Design and Data Analysis Functions version 1.0.14 from CRAN.
Shaffer TL (2004). A unified approach to analyzing nest success. The Auk 121:526-540.
Sist P, Sheil D, Kartawinata K, Priyadi H (2003). Reduced-impact logging in Indonesian Borneo: some results confirming the need for

new silvicultural prescriptions. Forest Ecology and Management 179:415-427.
Sodhi NS, Liow LH, Bazzaz FA (2004). Avian extinctions from tropical and subtropical forests. Annual Review of Ecology, Evolution, and Systematics 35:323-345.
Symonds MR, Moussalli A (2011). A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. Behavioral Ecology and Sociobiology 65:13-21.
Terpstra TJ (1952). The asymptotic normality and consistency of Kendall's test against trend, when ties are present in one ranking. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen 55:327-333.
Tewksbury JJ, Hejl SJ, Martin TE (1998). Breeding productivity does not decline with increasing fragmentation in a western landscape. Ecology 79:2890-2903.
Tewksbury JJ, Garner L, Garner S, Lloyd JD, Saab V, Martin TE (2006). Tests of landscape influence: nest predation and brood parasitism in fragmented ecosystems. Ecology 87:759-768.
Thomas D (1995). Botanical Survey of the Rumpi Hills and Nta Ali. Report to Korup Project.
Van Bael SA, Bichier P, Ochoa I, Greenberg R (2007). Bird diversity in cacao farms and forest fragments of western Panama. Biodiversity and Conservation 16:2245-2256.
Venables WN, Ripley BD (2002). Modern Applied Statistics with S, W.N. Venables, Springer. Springer, Oxford OX1 3TG Australia England bill, Oxford OX1 3TG Australia England bill. https://www.springer.com/gp/book/9780387954578
Vergara PM, Simonetti JA (2003). Forest fragmentation and rhinocryptid nest predation in central Chile. Acta Oecologica 24:285-288.
Vergara PM, Simonetti JA (2004). Does nest-site cover reduce nest predation for rhinocryptids? Journal of Field Ornithology 75:188-191.
Weidinger K (2002). Interactive effects of concealment, parental behaviour and predators on the survival of open passerine nests. Journal of Animal Ecology 71:424-437.
Wesolowski T, Tomialojc L (2005). Nest sites, nest depredation, and productivity of avian broods in a primeval temperate forest: do the generalisations hold? Journal of Avian Biology 36:361-367.
Wilson EB (1927). Probable inference, the law of succession, and statistical inference. Journal of the American Statistical Association 22:209-212.
Wray TII, Whitmore RC (1979). Effects of vegetation on nesting success of Vesper Sparrows. The Auk pp. 802-805.
Yates F (1934). Contingency tables involving small numbers and the χ 2 test. Supplement to the Journal of the Royal Statistical Society 1:217-235.

Additional files



Additional file Figure S1. Sampling arrangement of the nested grid

Additional file Explanation Notes: Classes of canopy cover definitions

The classes of canopy cover were defined as followed (Jennings et al., 1999):
- Class 1: No direct light (crown not lit directly either vertically or laterally);
- Class 1.5: Low lateral light;
- Class 2: Medium lateral light;
- Class 2.5: High lateral light;
- Class 3: Some overhead light (10-90% of the vertical projection of the crown exposed to vertical light).
- Class 4: Full overhead light (≥ 90% of the vertical projection of the crown exposed to vertical light; lateral light blocked within some or all the 90° inverted cone encompassing the crown and
- Class 5: Crown completely exposed (to vertical light and to lateral light within the 90° inverted cone encompassing the crown).

Lateral light (< 10% of the vertical projection of the crown exposed to vertical light; crown lit laterally.

Additional file Table S1. Results of model selection using logistic exposure methods to assess sources of variation in the probability of daily predation rate of the understorey nesting birds in the Korup region. Only the top model or those included in the confidence set are shown.

Models	K	AICc	ΔAICc	w_i	$Log_e(L)$
$M_{H+a+b+c}$	5	207.23	0.00	0.44	-98.49
$M_{H+a+b+c+d}$	6	208.47	1.24	0.24	-98.06
M_{H+a+b}	4	209.04	1.81	0.18	-100.44
$M_{H+a+b+c+d+e}$	8	210.39	3.16	0.09	-96.88
M_{H+a}	3	211.84	4.61	0.04	-102.87

Note: K is the number of parameters in the model, Loge(L) is the value of the maximized log-likelihood function, AICc is Akaike's Information Criterion adjusted for small sample bias, ΔAICc is the scaled value of AICc, and w_i is the Akaike weight. Many candidate models involved the effect of the types of habitats (H), the classes of canopy cover (a), the understorey plants density (b), the microhabitat trees density (c), the nest height (d) and the nest's support (e). The remaining candidate models had ΔAICc > 4.61 and w_i < 0.05.

Additional fileTable S2. Correlations between the Fixed effects parameters on the daily predation rate.

Parameter	Intercept (Class 1)	Class 1.5	Class 5	Density of the understorey plants
Class 1.5	-0.046			
Class 5	0.047	0.161		
Density of the understorey plants	-0.831	-0.169	-0.275	
Density of trees in the Microhabitat	-0.525	0.130	0.234	0.080

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Litterfall, litter standing crops and nutrient dynamics as influenced by selective logging in tropical rainforest of Ebom, Southwest Cameroon

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Litterfall, litter standing crops, nutrient dynamics and their turnover were studied in Ebom tropical rainforest of Cameroon six years after selective logging practices. Two sample sites, one in the logging part of the forest (disturbed site) and the other in the part of forest not affected by selective logging (undisturbed site) were used for the study. After two years of field experiment, the mean annual of litterfall varied from 1.95 to 10.93 $t.ha^{-1}.y^{-1}$ in undisturbed site, and from 1.49 to 9.07 $t.ha^{-1}.y^{-1}$ in logging site respectively for wood litter and the total litterfall. The greatest significant of total litterfall were recorded in long dry season in the two sites. The litter standing crops varied from 0.96 for wood to 2.09 $t.ha^{-1}$ for leaf litter in the undisturbed site and from 0.49 for rest litter to 1.58 $t.ha^{-1}$ for leaf litter in the logging site. The turnover (K_L) of litter varied from 0.89 to 3.57 for wood in the logging site and from 0.49 to 2.99 for leaf litter in the undisturbed site. Overall, the nutrient amounts in litter fractions are higher in the undisturbed site than in the logging site, except that of Na. The logging impact, six years after logging, was negligible on the litterfall, but results in much faster release of Mg and Na which were low in the Ebom forest soil. It would take more than six years for the logging effects to cancel out.

Key words: Litterfall, litter standing crops, litter turnover, logging, nutrient dynamics, tropical rainforest, Cameroon.

INTRODUCTION

In South Cameroon, the degradation of tropical forests, mainly due to shifting cultivation and logging (van Gemerden, 2004) is currently one of the major problems for the forest management (Jonkers and Foahom, 2003). Impacts on the reduction of biodiversity, soil depletion and loss of productivity are undeniable (Jonkers and Foahom, 2003). To remedy this, Tropenbos Cameroon Programme (TCP) developed a strategy for the sustainable

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management of these forest ecosystems. According to TCP, one of the alternatives that can lead to the sustainable exploitation of these tropical forests without compromising their existence is to take into account, in forest management, the interests of riparian populations (Jonkers and Foahom, 2003) and the functional aspects of these forests, as litterfall, litter standing crops and nutrient contents.

Litter is a major source of organic matter and nutrients in forest ecosystems (Vitousek and Sanford, 1986; Devi and Singh, 2017). The litterfall contributes to the assessment of net primary production and is also the major pathway for the return of dead organic matter and nutrients from aerial vegetation to forest soil (Vitousek and Sanford, 1986). In the forest ecosystem, litterfall reduce bulk density, increase water holding and the cation exchange capacity of the soil (Seta et al., 2018). In addition, litter on the forest floor plays a significant role in determining the moisture status, runoff pattern and release of nutrients accumulated in the aerial parts of the vegetation (Parsons et al., 2014). The litterfall influences also its decomposition, growth of vegetation and soil fertility through the feedback mechanisms (Brouwer, 1996). Under a fertile soil forest, leaf renewal, litterfall and its decomposition are rapid because of a low energy investment for the synthesis of secondary metabolites. On the other hand, regarding infertile soil, leaf turnover, litterfall and its decomposition are low due to a high investment in metabolites (Berendse, 1994).

However, the litterfall production pattern is directly affected by climate, seasonality, tree species composition, stand structure, soil fertility, elevation and latitude (Vitousek and Sanford, 1986; Parsons et al., 2014; Becker et al., 2015; Das and Mondal, 2016; Devi and Singh, 2017; Seta et al., 2018). Qiu et al. (1998) observed that abiotic factors such as rainfall, temperature and light play an important role in litterfall, flushing among dominant canopy species in the forest. Other workers reported that seasonal patterns of litterfall show unimodal, bimodal or irregular modes, and the litter peaks might occur in several months of the year (Sundarapandian and Swamy, 1999**;** Zhang et al., 2014). Consequently, this phenomenon may affect the dynamics of ecosystem carbon and nutrient cycling (Das and Ramakrishnan, 1985).

Other variables that affect litterfall pattern and litter nutrients dynamics in the tropical rainforests are disturbances (van Dam, 2001). Natural or artificial gaps resulting from logging are considered as a disturbance, which alter the environmental conditions, such as temperature, availability of light, nutrients and moisture to plants (Denslow et al., 1998; Burivalova et al., 2016). These changes affect the flora and fauna composition, influence carbon emissions (Harris et al., 2012), the plant litter decomposition process (Brouwer, 1996; Van Dam, 2001; Ibrahima et al., 2016) and litterfall dynamics (Chandrashekera and Ramakrishnan, 1994; van Dam, 2001).

Despite many studies were conducted in tropical rainforests of Cameroon, little information exists on litterfall and nutrient dynamic (Songwe et al., 1988; Chuyong et al., 2000; Ibrahima et al., 2002), but no study has been carried out to understand the effects of logging activities on litterfall. The purpose of this study was to determine the impact of selective logging on litterfall components (total and fractions), nutrient dynamics and their turnover in the Ebom tropical rainforest of southwestern Cameroon.

MATERIALS AND METHODS

Study sites

The experiment was conducted in Ebom Forest, within the Tropenbos Cameroon Programme (TCP) research area, which is located in the western portion of the Atlantic Biafrean Forest of South Cameroon, lying within the Congo-Guinea refuge. The experimental sites are located at 3º05'N and 10º41'E, with elevation of ~440 m. The bedrock is composed of Precambrian metamorphic as well as old volcanic rocks (Franqueville, 1973). The soil is very clayey (35-70%) and strongly acidic (van Gemerden and Hazeu, 1999). The climate is humid tropical with four seasons: a long dry season (from mid-November to mid-March) and a short one (mid-May to mid-August), as well as a short rainy season (mid-March to mid-May) and a long rainy season (mid-August to mid-November). Mean annual rainfall is about 2100 mm and mean annual temperature is 22.9°C (van Gemerden and Hazeu, 1999). Relevant characteristics of these sites like location, rainfall data and soil physico-chemical characteristics are presented in our previous studies (Ibrahima et al., 2002, 2016). Vegetation consists of evergreen forest rich in Caesalpiniaceae (Letouzey, 1985), characterised by tall trees that reach heights of about 60 m, with four strata and one closed canopy (Bibani and Jonkers, 2001). Tree density was about 521 trees per hectare, basal area of about 29.84 m^2 ha^{-1} and diameter classes ranged from 9.39 to 150 cm, with a mean of 21.34 cm (Ibrahima et al., 2002). At some places in the forest Bantou people practice shifting agriculture with short fallows (Nounamou and Yemefack, 2001), while Banyeli Pygmee live from gathering and hunting. Many non-timber forest products like bushmeat, honey, mushrooms, fruits, leaves, seeds and roots are harvested (van Dijk, 1999).

Two one-ha-plots (100 m × 100 m) in the experimental area in the catchments of Bibo'o Minwo near Ebom were selected: one in an undisturbed and the other in a disturbed part of the forests. The undisturbed forest, at 15 km away in the north of Ebom, is characterized by the absence of recent natural or human disturbance. The vegetation consists of evergreen forest rich in Caesalpiniaceae (Letouzey, 1985), as presented before. The other plot was selected in the logging site with small gaps. The forest has been logged in recent years with the exception of the mountainous parts, by national and international companies, principally the Dutch Company, WIJMA - Douala SARL (GWZ) (van Gemerden and Hazeu, 1999). The selective logging rate was low; averaging 10 m^3 ha^{-1}, say 0.7 tree ha^{-1} the last exploitation (van Gemerden and Hazeu, 1999). Only trees with diameter at breast height (DBH) ≥ 80 cm and straight boles of at least 6 m were felled. Damages caused by this felling and extraction of the logs from the stand affected less than 8% of the forest area (Fines et al., 2001; Jonkers and van Leersum, 2000). The vegetation of this site is dominated by heliophilous (pioneer) species, particularly Musanga (*Musanga cecropioides* R. Brown ex. Tedlie). Tree density, the basal area and the mean DBH are respectively 417 trees per hectare, 28.48 $m^2.ha^{-1}$

and 22.91 cm; the diameter classes ranged from 9.20 to 141.72 cm (Ibrahima et al., 2002). The disturbance occurred six years before starting the experiment with a low intensity of logging. The two sites have the same type of soils (Ultisols / Oxisols) (van Gemerden and Hazeu, 1999).

Litter collection

Small litterfall (including leaf, twigs and small branches (<2.5 cm), flowers, fruits, etc.) in each site was collected in twenty 1 m x 1 m litter traps, 1 m high above the ground. The litter traps were made of wooden frame material with a mesh size of 0.5 mm and randomly distributed in 1-ha-plot. The mesh size was sufficient to allow free drainage while retaining the finer litter fragments. Litter was collected fortnightly, excepted in the large rainy season where litter was collected at weekly. Because of technical difficulties (access to plots, disturbance of litter traps by animals, etc.), experiment was only carried out two years in undisturbed site, from August 1999 to July 2001, and one and half year (from February 2000 to July 2001) in logging site. The litter samples were taken to the laboratory in polythene bags and oven-dried at 60°C to constant mass. The samples of each month were bulked and categorized into leaf (L), wood (including twigs, small-wood fraction, small branches (<2.5 cm in diameter) and bark fragments (W)), and all remaining material so called rest (R) including reproductive parts, flowers, fruits, pods, mousses, lichens, and all other unknown material. Dry mass of each component was determined by drying to a constant mass at 60ºC and the mean monthly value for each site was worked out on a unit area basis ($t.ha^{-1}$).

Coarse litterfall, comprising large wood or branches with bark, was estimated for about one year, from June 2000 to July 2001. The samples were collected every six months in five subplots of 20 m × 20 m, located near 1-ha plot of each site. The subplots were cleaned initially. The samples were transported to laboratory in polythene bags and processed, in accordance with the procedures given above for the small litterfall.

Litter standing crops of forest floor (or litter layer on the soil surface) was estimated in undisturbed and logging sites for one year. Five litter samples were collected every three months from each site, using a 0.25 m^2 (0.5 m × 0.5 m) quadrat frame placed randomly near 1-ha-plot, transported to laboratory in polythene bags and processed, in accordance with the procedures given above for the small litterfall.

Chemical analysis

One monthly small litterfall fraction (leaf, wood, rest), and five coarse litterfall samples and five litter standing crops samples resulting from the sample bulking were taken to chemical analysis. Powder samples obtained after grinding all samples through a *Micro Hammer Mill Culatti* grinder equipped with a 1 mm link filter were analyzed. The samples were first mineralized by passing the powder through a furnace at 550°C for 40 mn. The ashes were recollected with a diluted HNO_3 solution for nutrient analyzing: Calcium and Magnesium were determined through EDTA titrimetric method (Association Française de Normalisation (AFNOR), 1982), while Potassium, Sodium and Phosphorous were determined according to standard methods (Rodier, 1978). The nitrogen analysis was done by the Kjeldhal method and its titration by sulphuric acid at 0.01 N (Devani et al., 1989).

Statistical analysis

Before performing any statistical analysis, all variables were tested for normality. The comparison of litter mass and their nutrients among litter fractions, and among seasons was carried out by using ANOVA, followed by *Scheffe*'s test at 5% if ANOVA was significant. A *Student* provided a test of significance of litter mass and their nutrients between undisturbed and logging sites. Turnover rates (K_L) of the forest floor litter or its nutrients were calculated by calculating the ratio between litterfall or its nutrients and litter standing crops or its nutrients for similar fractions. These tests were conducted through SX software (*statistic, version 4.0, Analytical software*, 1992).

RESULTS

Litter

Litterfall and their changes in time

Average mean annual litterfall (1999-2001), its interannual variation and the contribution rate of the different fractions of litterfall in undisturbed and logging sites were presented in Table 1. Contribution of leaf fraction was higher than that of other litter fractions, more than 55% to the total litterfall in both sites, while contribution of coarse litterfall was lower than that of the total litterfall in both sites; it was of 11% in undisturbed site and 17% in logging one. Greater mean annual of the total litterfall was recorded in undisturbed site (12.29 $t.ha^{-1}.year^{-1}$) compared to logging site (10.90 $t.ha^{-1}.year^{-1}$). The mean annual of litterfall and its fraction were higher in the undisturbed site (6.24, 1.95, 2.79 and 10.93 $t.ha^{-1}.year^{-1}$) than in the logging site (5.64, 1.49, 1.94 and 9.07 $t.ha^{-1}.year^{-1}$) respectively for leaf, woods, rest fraction and the total small litterfall, while coarse litterfall was higher in the logging site (1.83 $t.ha^{-1}.year^{-1}$) compared to the undisturbed site (1.36 $t.ha^{-1}.year^{-1}$). The two sites differed significantly from one another only by their rest fraction, the total small litterfall and the annual mean of total litterfall (small + coarse).

Small litterfall varied according to seasons (Table 2). Mean seasonal of total small litterfall and leaf fraction were significantly different according to seasons in both sites, while wood fraction was significant different according to seasons only in the logging site. The greatest significant total small litterfall and leaf fraction were recorded in the long dry season (December, January and February) and the lowest were obtained in the small dry season (June, July and August) in the two sites. According to the season, the two sites were significantly different only during the small dry season and the long rainy season for the total small litterfall, during the small dry season for the leaf and woods fractions, and at last during the long rainy season for the rest fraction.

Dynamics of small litterfall and its fractions showed monthly variation during the two years of litterfall collection in the undisturbed site and the one year and half in the logging site (Figure 1). Peak of small litterfall was recorded in the end of February and that of April,

Table 1. Annual and mean annual litterfall ($t.ha^{-1}.y^{-1}$) in undisturbed and logging sites of tropical rainforest of Ebom, southwest Cameroon.

Litter fractions	Undisturbed site		Logging site		t Student
	Litter mass	%	Litter mass	%	
February 2000 – January 2001					
Leaf	6.09 (1.29)	55	5.92 (1.08)	63	1.24^{ns}
Wood	1.91 (1.38)	17	1.50 (0.90)	16	1.97^{ns}
Rest	3.04 (1.79)	28	1.99 (1.03)	21	2.47*
Total small litterfall	11.04 (3.08)	100	9.41 (2.23)	100	2.72**
August 2000 - July 2001					
Leaf	5.68 (1.02)	54	5.63 (1.08)	62	0.11^{ns}
Wood	1.95 (0.86)	18	1.51 (0.65)	17	1.93^{ns}
Rest	2.95 (1.91)	28	1.93 (1.06)	21	2.03*
Total small litterfall	10.58 (0.65)	100	9.07 (0.40)	100	2.03*
Leaf	6.24 (1.06)	57	5.64 (1.00)	62	1.26^{ns}
Wood	1.95 (1.02)	18	1.49 (0.73)	16	1.61^{ns}
Rest	2.79 (1.55)	26	1.94 (1.02)	21	1.68^{ns}
Total small litterfall	10.93 (2.64)	100	9.07 (1.90)	100	2.05*
Coarse litterfall	1.36 (0.44)	11	1.83 (0.96)	17	0.88^{ns}
Total litterfall	12.29 (2.18)	100	10.90 (1.95)	100	2.31*

Standard error in brackets. ns: no significant; * P < 0.05; ** P< 0.01.

Table 2. Mean seasonal small litterfall ($t.ha^{-1}.season^{-1}$) in undisturbed and logging sites of tropical rainforest of Ebom, southwest Cameroon.

Season	Undisturbed site				Logging site				t Student between sites			
	Leaf	Wood	Rest	Total	Leaf	Wood	Rest	Total	Leaf	Wood	Rest	Total
LDS	2.09^{a}	0.49	0.81	3.39^{a}	2.22^{a}	0.38^{b}	0.59	3.19^{a}	1.20^{ns}	0.50^{ns}	0.60^{ns}	0.60^{ns}
SRS	1.61^{b}	0.71	0.82	3.14^{a}	1.56^{b}	0.53^{a}	0.59	2.68^{a}	0.10^{ns}	1.10^{ns}	1.70^{ns}	1.30^{ns}
SDS	1.12^{c}	0.20	0.45	1.76^{b}	0.73^{d}	0.10^{c}	0.33	1.16^{c}	2.80**	2.10*	0.60^{ns}	2.80**
LRS	1.46^{bc}	0.51	0.76	2.73^{ab}	1.28^{c}	0.45^{ab}	0.53	2.26^{b}	1.10^{ns}	1.10^{ns}	2.30*	2.30*
F *Fischer's*	12.80***	1.00^{ns}	2.00^{ns}	2.90*	30.70***	6.70***	1.00^{ns}	17.90***				

LDS: Long dry season; SRS: short rainy season; SDS: short dry season; LRS: Long rainy season; ns: not significant; * P< 0.05; ** P< 0.01; *** P< 0.001. Different letters indicate that values are different among seasons.

particularly for the total small litterfall and leaf litterfall. The pattern of dynamics was similar in the two sites (Figure 2), excepted in July and August 2000 (short dry season) where the total small litterfall and leaf litterfall were lower in the logging site than in the undisturbed site.

Litter standing crops and turnover

Amount of small litter on the forest floor were presented in Table 3. The dry mass of small litter on the forest floor varied from 0.96 $t.ha^{-1}$ for wood litter to 2.09 $t.ha^{-1}$ for leaf litter in the undisturbed site and from 0.49 $t.ha^{-1}$ for rest litter to 1.58 $t.ha^{-1}$ for leaf litter in the logging site. The highest contribution to the total litter standing crops was recorded for leaf litter fraction in the two sites (more than 45%), while the lowest was found for wood litter fraction in undisturbed site (23%) and for the rest litter fraction in logging site (14%). The dry mass of litter standing crops was higher in the undisturbed site than in the logging one, excepted for the wood litter fraction (Table 3). But the differences between the two sites were only significant (P<0.05) for leaf litter fraction.

Values for turnover (K_L) of total litter and their fractions were presented in Table 4. The values for K_L of leaf litter fraction and total small litter was high, more than 2.5 in the two sites, while these values were lesser than 0 for wood and rest litter fraction in the same sites. The

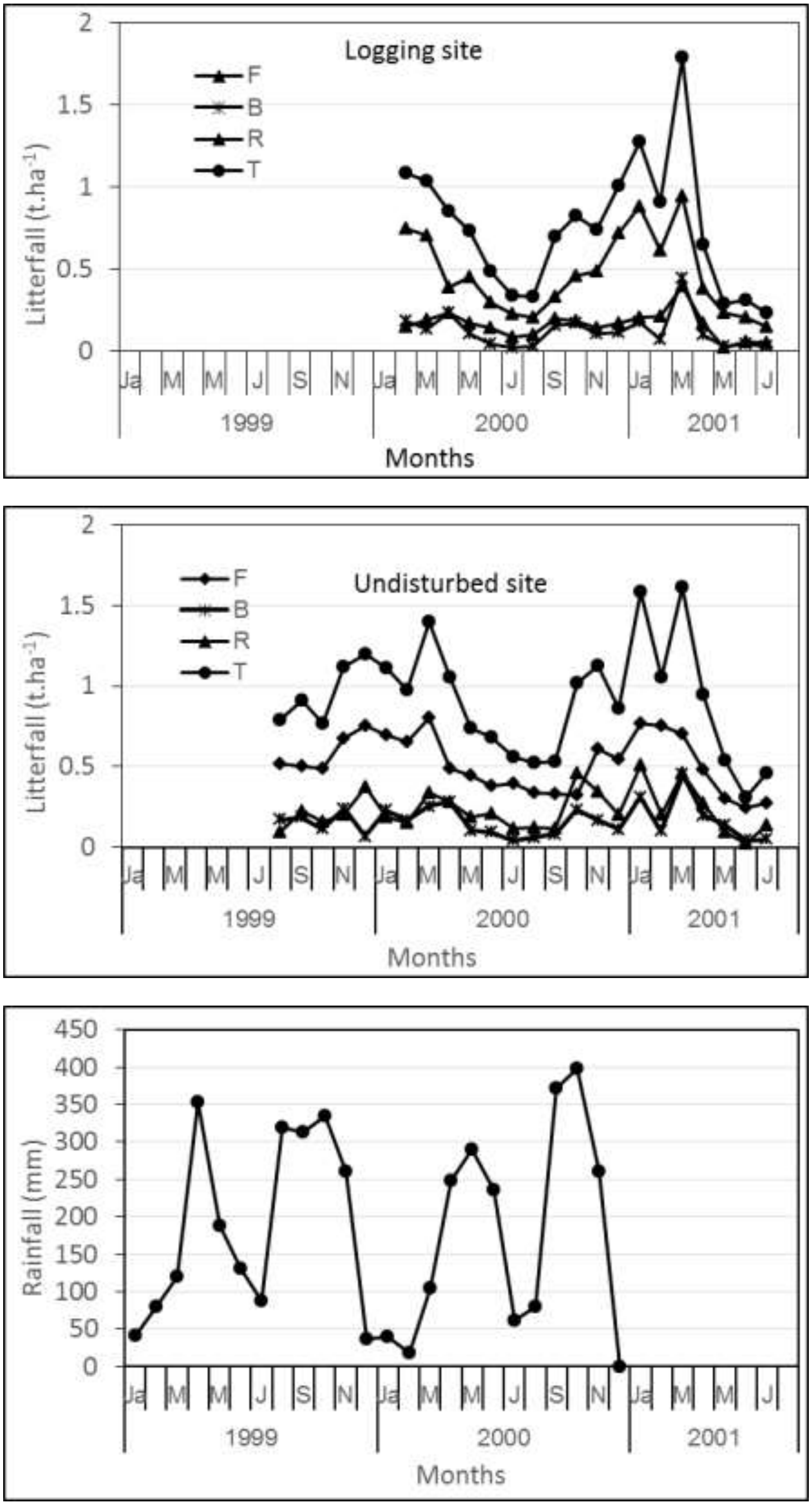

Figure 1. Dynamics of small Litterfall (t.ha^{-1}) and its fractions (F, B and R) in undisturbed and logging sites of Ebom tropical rain forest, southern Cameroon, and monthly rainfall during the experiment period. Leaf litter (F), wood litter (B) and rest litter (R).

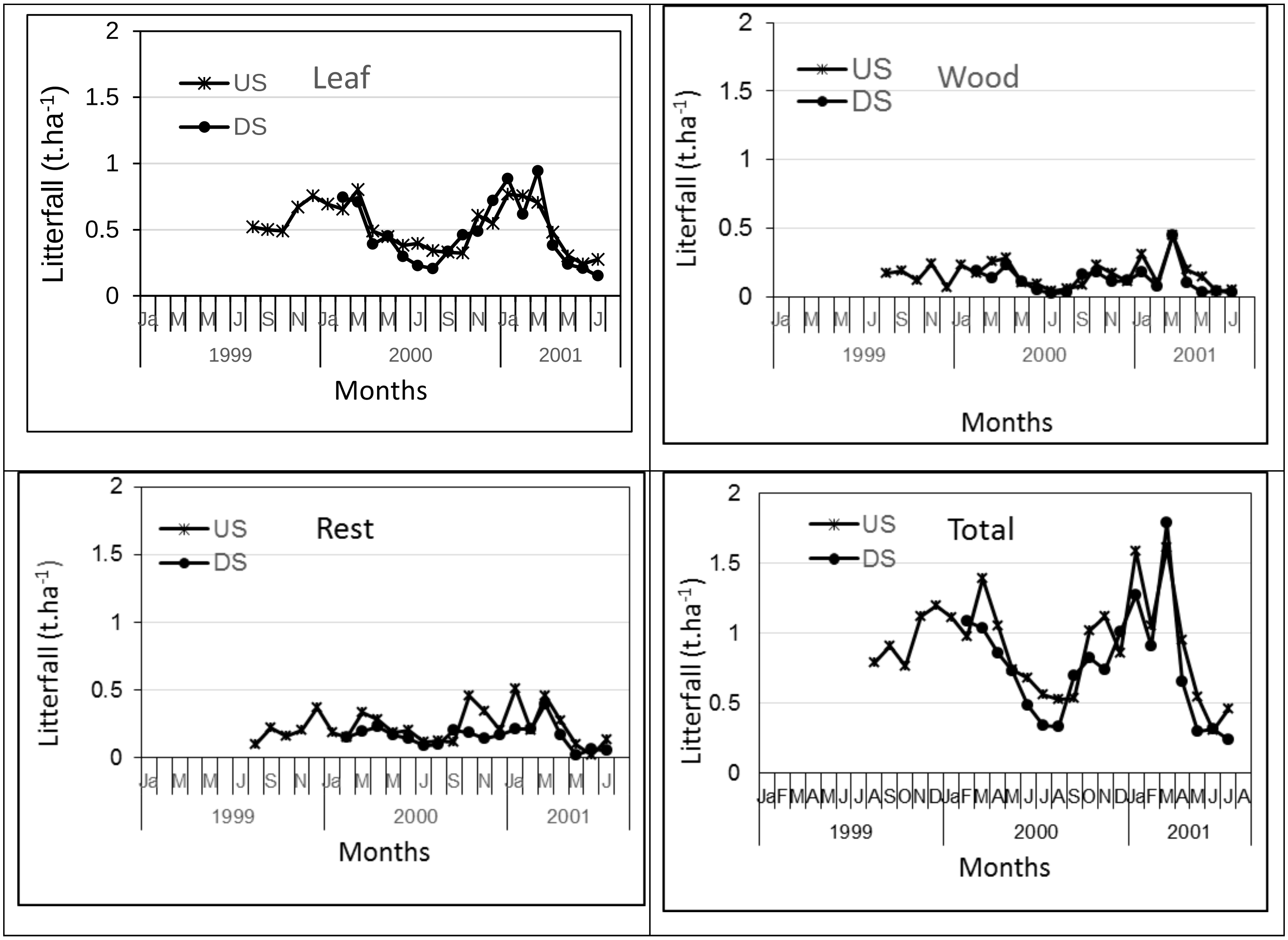

Figure 2. Comparison of dynamics of small litterfall (t.ha^{-1}) fractions (leaf,wood, rest and total litterfall) between undisturbed (US) and logging sites (DS) of Ebom tropical rain forest, southern Cameroon.

Table 3. Mean litter standing crops (t.ha^{-1}) or litter on floor in undisturbed and logging sites of tropical rainforest of Ebom, southwest Cameroon.

Fractions	Undisturbed site		Logging site		t Student
	Dry mass (t/ha)	%	Dry mass (t/ha)	%	
Leaves	2.09 (0.35)	50	1.58 (0.50)	47	2.60*
Wood	0.96 (0.87)	23	1.32 (0.95)	39	0.88^{ns}
Rest	1.11 (1.01)	27	0.49 (0.23)	14	1.87^{ns}
Total	4.16 (1.28)	100	3.39 (1.24)	100	1.32^{ns}

turnover of litter standing crops was higher in the logging site (0.89, 2.68 and 3.57 respectively for wood, total litter and leaf litter) than in the undisturbed site (0.49, 2.63 and 2.99 respectively for the same fractions), except for the rest litter fraction which was higher in the undisturbed site (0.39) than in the logging site (0.25).

Nutrients

Litter nutrient contents

Nutrient contents in litter varied according to litter fractions in undisturbed and logging sites (Table 5).

Table 4. Litter ($kg.ha^{-1}$) and nutrient ($g.kg^{-1}$) turnover (K_L = L/S where L and S respectively litterfall and litter standing crops) in Undisturbed and logging sites of tropical rainforest of Ebom, southwestern Cameroon.

Nutrients	Undisturbed site			Logging site		
	Litter standing crops (kg/ha)	Litterfall (kg/ha)	K_L	Litter standing crops (kg/ha)	Litterfall (kg/ha)	K_L
Small litterfall						
Leaves	2090	6240	2.99	1580	5640	3.57
Wood	960	1950	0.49	1320	1490	0.89
Rest	1110	2790	0.39	490	1940	0.25
Total	4160	10930	2.63	3390	9070	2.68
Nutrients						
In leaf litter						
N	43.93	113.12	2.58	37.95	96.90	2.55
Ca	1.71	42.14	**24.64**	1.91	20.03	**10.49**
Mg	1.13	4.82	4.27	0.93	4.22	4.54
K	1.39	26.82	**19.29**	2.48	12.37	4.99
Na	0.05	0.83	**16.60**	0.05	0.67	**13.40**
P	3.10	7.07	2.28	3.40	5.14	1.51
In total litter						
N	83.84	183.87	2.19	72.29	150.91	2.09
Ca	2.44	73.41	**30.09**	3.02	30.45	**10.08**
Mg	2.38	6.78	2.85	1.69	5.65	3.34
K	3.49	41.42	**11.87**	4.31	21.96	5.10
Na	0.50	0.61	1.22	0.10	1.08	**10.80**
P	6.57	12.19	1.86	6.15	8.77	1.43

K_L = L/S where L and S respectively nutrient in litterfall and in litter standing crops.

Nutrient contents differed significantly between litterfall fractions, excepted K and Na in the undisturbed site, and Ca and P in logging site. In the two sites, N content was significantly lower in the wood litter fraction than in the other litterfall fractions, and that of Mg was higher in leaf litterfall than in the other litterfall fractions. Ca content was significantly the highest in wood litterfall and the lowest in coarse litterfall in the undisturbed site, that of K was significantly higher in the rest litterfall fraction than in the other litterfall fraction in the logging site. At the end, P content was significantly the highest in coarse litterfall and rest fraction, and the lowest in wood fraction in the undisturbed site.

Undisturbed and logging sites differed significantly between them according to some nutrient contents (Table 5). Mg, Na and P contents in the three fractions of small litterfall were not significantly differed between the two sites, while that of Ca in the three small litterfall fractions was significantly higher in the undisturbed site than logging site. N content differed significantly between the sites only in the wood litter fraction, that of K in leaf litterfall and that of Na in coarse litterfall.

Nutrient contents in the litter standing crops were presented in Table 5. In the two sites, N content was the highest and that of Na was the lowest in all litter fractions, except in the rest fraction where Ca content was the lowest in the undisturbed site. All the nutrient contents were generally the highest in leaf litter and the lowest in wood fraction, except N and Ca contents were present in low content in the rest fraction in the logging site. Conversely, in the undisturbed site these patterns were not clear and varied according to a given nutrient.

As for the dynamics of the nutrient content, it was variable over time and according to the nutrient considered (Figure 3). On the whole, nutrient behavior varies very slightly between the logging and undisturbed sites, except that of Na, whose concentration remains constant in 2000 and 2001 in the undisturbed site and decreases at the end of 2000 and 2001 in the logging site. Similarly, P content decreased at the end of 2000 and 2001. On the other hand, those of Ca and K increase from October 2000 onwards. Those of N and Mg remain almost constant over the two years of experience.

Litter nutrient amounts

The quantities of nutrients were significantly different among litter fractions at both sites (Table 6). In general, these quantities are highest in leaf litter and lowest in twigs or large litter in both sites. The nutrient amounts differed between the logging and undisturbed sites according to the nutrient considered (Table 6). Overall, the nutrient amounts in litter fractions are higher in the undisturbed site than in the logging site, except that of Na which was higher in the logging site than in the

Table 5. Nutrient contents (g.kg^{-1}) in litter in undisturbed and logging sites of tropical rainforest of Ebom, Southwest Cameroon.

Nutrients	Undisturbed site					Logging site					*Student*'s t between sites			
	Leaves	Wood	Rest	Coarse litter	F-values	Leaves	Wood	Rest	Coarse litter	F-values	Leaves	wood	Rest	CL
Litterfall														
N	18.02 (3.73)a	11.92 (2.60)b	17.16 (4.10)a	23.10 (0.85)a	19.14***	17.90 (4.25)a	12.46 (1.84)b	18.14 (3.37)a	19.13 (5.63)a	16.98***	0.09ns	0.73*	0.81ns	1.26ns
Ca	7.30 (3.85)ab	9.20 (4.84)a	4.76 (3.21)bc	1.23 (0.65)c	6.74**	3.60 (2.40)	3.68 (2.50)	2.29 (1.94)	2.12 (1.25)	2.09ns	3.55**	4.37***	2.86***	1.13ns
Mg	0.75 (0.26)a	0.44 (0.21)b	0.44 (0.16)b	0.45 (0.24)b	16.00***	0.78 (0.59)a	0.46 (0.21)b	0.44 (0.15)b	0.38 (0.15)b	4.72*	0.18ns	0.32ns	0.08ns	0.59ns
K	4.38 (2.87)	2.92 (2.22)	3.45 (2.62)	2.05 (1.40)	1.78ns	2.14 (1.40)ab	1.88 (1.41)b	3.82 (2.93)a	2.87 (2.60)ab	4.81*	3.01**	1.73ns	0.42ns	0.38ns
Na	0.06 (0.07)	0.05 (0.06)	0.06 (0.07)	0.07 (0.01)	0.11ns	0.17 (0.20)a	0.11 (0.16)a	0.14 (0.19)a	0.03 (0.01)b	4.42*	1.70ns	1.55ns	1.85ns	5.20**
P	1.06 (0.47)ab	0.76 (0.36)b	1.36 (0.54)a	1.76 (0.52)a	9.13***	0.96 (0.47)	0.86 (0.52)	1.25 (0.54)	1.34 (0.56)	2.85ns	0.64ns	0.70ns	0.64ns	1.11ns
Litter standing crops														
N	21.07	22.05	16.80	-	-	24.01	20.83	14.07	-	-	-	-	-	-
Ca	0.82	0.41	0.30	-	-	1.21	0.63	0.56	-	-	-	-	-	-
Mg	0.54	0.45	0.74	-	-	0.59	0.41	0.46	-	-	-	-	-	-
K	0.66	1.11	0.94	-	-	1.57	0.86	1.43	-	-	-	-	-	-
Na	0.02	0.03	0.39	-	-	0.03	0.03	0.03	-	-	-	-	-	-
P	1.49	1.63	1.72	-	-	2.15	1.41	1.84	-	-	-	-	-	-

Coarse litterfall (CL); ns: not significant; * P< 0.05; ** P< 0.01; *** P< 0.001. Different letters indicate that values are different among fractions.

undisturbed site. The amounts of N, Mg and Na were not significantly different between the logging and undisturbed sites, except that of Na in the coarse litter. On the other hand, that of Ca of all litter fractions was significantly higher in the undisturbed site than in the logging site, except that of the coarse litter. The amount of K in the Rest and coarse litter fractions is not significantly different (P> 0.05) between the both sites, while it is for the other fractions (leaves, twigs and total). The amount of P was significantly different (P <0.05) between the two sites only in the rest fraction.

The nutrient amounts of the different litter fractions on the forest floor in the logging and undisturbed sites are presented in Table 6. They are significantly different among the litter fractions in the two sites, except those of K and P in the undisturbed site, which are not different significantly (P>0.05). The nutrient amounts of the leaf litter were significantly higher than those of the other fractions (twigs and rest) in both sites, except for Na in the rest fraction which was greater than those of leaf and twig fractions in the undisturbed site. Between logging and undisturbed sites in the Ebom Forest, there were no significant differences in the nutrient amounts in the twigs (Table 6). Similarly, the N, Ca and P amounts of all litter fractions were not significantly different between logging and undisturbed sites. On the other hand, the Mg and Na amounts in the rest fraction and the total amounts of these nutrients in the undisturbed site are significantly higher than those of the logging site, whereas the K amount in the leaf litter of the logging site was significantly higher than that of undisturbed site.

The turnover (K_L) of nutrients was presented in Table 4. In both sites, the turnover of leaf litter nutrients were generally faster than those of the total litter nutrients, except those of Ca in the undisturbed site (24.64 and 30.09 respectively for the leaf litter and total litter) and that of K in the logging site (4.99 and 5.10 respectively for the leaf litter and total litter). For the two nutrients, their turnovers in the total small litter were faster than those in the leaf litter. In the logging site, the turnover of Na and Ca were the fastest and those of N and P the weakest (Na > Ca > K > Mg > N >

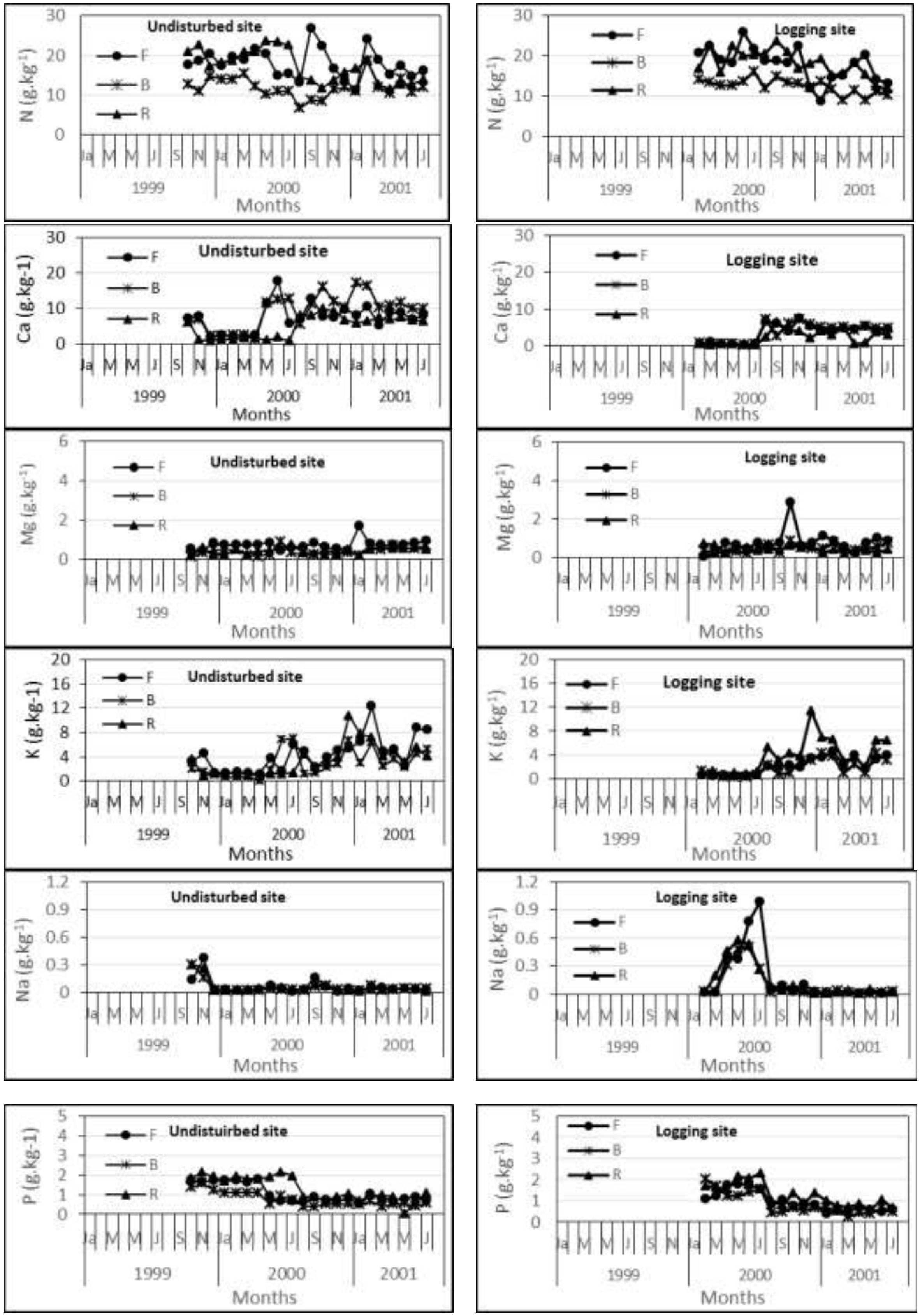

Figure 3. Dynamics of nutrient contents (g.kg[-1]) of small litterfall fractions (F, W and R) in undisturbed and logging sites of Ebom tropical rain forest, southern Cameroon. Leaf litter (F), wood litter (B) and rest litter (R).

Table 6. Nutrient amounts in litter in undisturbed and logging sites of tropical rainforests of Ebom, Southwestern Cameroon.

Nutrients	Undisturbed site						Logging site						*Student's* t between sites				
	Leaves	Wood	Rest	CL	Total	F-values	Leaves	Wood	Rest	CL	Total	F-values	Leaves	Wood	Rest	CL	Total
Litterfall ($kg.ha^{-1}.y^{-1}$)																	
N	113.12^{a} (3.96)	23.28^{b} (1.38)	47.47^{b} (2.04)	32.15^{b} (9.80)	216.02 (40.66)	45.90***	96.90^{a} (3.97)	18.21^{b} (1.09)	35.80^{b} (1.51)	36.91^{b} (16.31)	187.82 (34.38)	33.30***	1.07^{ns}	1.10^{ns}	1.68^{ns}	0.49^{ns}	1.41^{ns}
Ca	42.14^{a} (1.92)	17.29^{b} (1.38)	13.98^{b} (1.25)	1.61^{c} (0.52)	75.02 (16.99)	15.01**	20.03^{a} (1.47)	5.41^{b} (0.55)	5.02^{b} (0.53)	3.88^{b} (2.51)	34.34 (7.66)	10.01***	3.34**	2.81**	2.36*	1.81^{ns}	3.55**
Mg	4.82^{a} (0.25)	0.80^{b} (0.06)	1.15^{b} (0.06)	0.53^{c} (0.15)	7.30 (2.01)	33.52***	4.22^{a} (0.33)	0.59^{b} (0.04)	0.84^{b} (0.04)	0.69^{b} (0.29)	6.34 1.76)	13.48***	0.54^{ns}	1.24^{ns}	1.67^{ns}	0.95^{ns}	0.89^{ns}
K	26.82^{a} (1.95)	4.57^{b} (0.50)	10.03^{b} (0.93)	3.29^{b} (1.86)	44.71 (10.83)	19.96***	12.37^{a} (0.98)	2.41^{b} (0.19)	7.19^{ab} (0.55)	5.73^{ab} (5.80)	27.70 (4.14)	7.15**	2.38*	2.21*	0.95^{ns}	0.62^{ns}	2.15*
Na	0.38^{a} (0.05)	0.09^{b} (0.01)	0.14^{ab} (0.01)	0.10^{b} (0.03)	0.71 (0.14)	3.77*	0.67^{a} (0.08)	0.13^{b} (0.02)	0.28^{ab} (0.03)	0.05^{c} (0.03)	1.13 (0.27)	3.53*	1.15^{ns}	0.79^{ns}	1.42^{ns}	2.24*	1.25^{ns}
P	7.07^{a} (0.40)	1.51^{b} (0.10)	3.61^{b} (0.18)	2.21^{b} (1.05)	14.40 (2.47)	18.08***	5.14^{a} (0.25)	1.23^{b} (010)	2.41^{b}(0.11)	2.39^{b} (1.70)	11.17 (1.66)	18.33***	1.50^{ns}	0.73^{ns}	2.10*	0.18^{ns}	1.67^{ns}
Litter standing crops ($kg.ha^{-1}$)																	
N	43.93^{a} (7.40)	21.19^{b} (19.27)	18.72^{b} (17.03	-	83.84 (0.39)	8.09**	37.95^{a} (12.05)	27.47^{a} (19.78)	6.87^{b} (4.19)	-	72.29 (25.56)	13.54***	1.34^{ns}	0.72^{ns}	2.14^{ns}	-	1.03^{ns}
Ca	1.71^{a} (0.29)	0.39^{b} (0.36)	0.34^{b} (0.31)	-	2.45 (0.44)	59.48***	1.91^{a} (0.61)	0.84^{b} (0.60)	0.27^{b} (0.17)	-	3.02 (0.94)	27.28***	0.91^{ns}	2.01^{ns}	0.60^{ns}	-	1.74^{ns}
Mg	1.13^{a} (0.19)	0.43^{b} (0.39)	0.82^{ab} (0.75)	-	2.38 (0.80)	4.86*	0.93^{a} (0.30)	0.54^{b} (0.39)	0.23^{b} (0.14)	-	1.69 (0.56)	14.50***	1.78^{ns}	0.63^{ns}	2.49*	-	2.22*
K	1.39^{a} (0.23)	1.06^{a} (0.97)	1.04^{a} (0.95)	-	3.49 (1.55)	0.59^{ns}	2.48^{a} (0.79)	1.14^{b} (0.82)	0.70^{b} (0.43)	-	4.31 (1.36)	17.56***	4.21***	0.19^{ns}	1.05^{ns}	-	1.36^{ns}
Na	0.05^{b} (0.01)	0.03^{b} (0.02)	0.43^{a} (0.39)	-	0.50 (0.39)	10.10***	0.05^{a} (0.02)	0.03^{ab} (0.04)	0.02^{b} (0.01)	-	0.10 (0.03)	10.58***	1.24^{ns}	0.62^{ns}	3.35**	-	3.22**
P	3.10^{a} (0.52)	1.56^{a} (1.42)	1.92^{a} (1.74)	-	6.57 (2.17)	3.63^{ns}	3.40^{a} (1.08)	1.86^{b} (1.34)	0.90^{b} (0.55)	-	6.15 (2.02)	14.69***	0.79^{ns}	0.48^{ns}	1.76^{ns}	-	0.45^{ns}

Fischer's values (F); Coarse litterfall (CL); ns: not significant; * $P< 0.05$; ** $P< 0.01$; *** $P< 0.001$. Different letters indicate that values are different among litter fractions.

P), whereas in the undisturbed site, the turnovers of Ca and K were the fastest and the turnovers of N and P the weakest in the leaf litter (Ca > K > Na > Mg > N > P) and those of P and Na in the total litter (Ca > K > Mg > N > P > Na). By comparing the two sites, we see that the nutrient turnovers in leaf litter and total litter of undisturbed site were superior to those of the logging site, except those of Mg of leaf litter and total litter and that of Na in total litter (Table 4). For these two nutrients, their turnovers in the logging site were superior to those in the undisturbed site.

DISCUSSION

Comparison with other tropical rainforests

Litterfall and litter standing crops

The annual average of the small litterfall and its fractions varied among tropical forests (Table 7). The results of this study ranked well among other tropical forests in general and among the highest values of rainforests developed on infertile soils (Oxisols and Ultisols) in particular. Brouwer (1996) showed that the mean (≈ 8.6 ± 1.2 $t.ha^{-1}$) small litterfall of a few South American and Southeast Asian moist tropical forests developed on infertile soils (Oxisols and Ultisols) was less than the values found in our study (10.9 ± 1.9 $t.ha^{-1}$). Leaf litter has generally large contribution to total litterfall than other fractions of litterfall (van Dam, 2001; Zhang et al., 2014) and its rate varies according to forest type and collecting year. Brouwer (1996) found that the contribution of leaf litter varies between 59 and 60% in Guyana Tropical rain forests, values below the average of other tropical forests (70%) and he also showed that in tropical forests developed on Spodosols / Psamments the average leaf litter was about 66%. In the Tropical Peruvian flooded, Nobel et al. (2001) reported that the proportions of small litter fractions were in the order of 60, 16 and 24%, respectively, for leaf litter, the reproductive part and the rest fraction. In this study, the contribution of leaf litter (57%), twig (18%) and rest (26%) were similar to those reported in other tropical moist forests with the same type of soils.

Interannual and seasonal variation of small litter fall

The average annual small litterfall in our study varied according to the year as reported by Songwe et al. (1988) in the rainforests of Bakundu, Cameroon. This variation may be related to the phenology of the vegetation, the interannual variation of climate such as wind or rainfall, etc. The ratio between the maximum and the minimum litterfall between the years in our study (ratio: 1.1), in two years, was similar to that reported by Spain (1984) in Australian rainforests (ratio: 1.1), but lower than that found by Bernhard (1970) in the tropical forests of Ivory Coast (ratio: 1.3).

The seasonality of small litterfall in tropical forests has been demonstrated in the literature (van Dam, 2001; Zhang et al., 2014). The litterfall peaks were observed in or just after the dry season (Brouwer, 1996; Celentano et al., 2011) or in or just after the rainy season (Devi and Singh, 2017). In Cameroon's rainforest in the Bakundu reserve (Songwe et al., 1988) and in most Amazonian and Guyana forests (Brouwer, 1996), the peaks of the maximum small litterfall, especially leaf litterfall, were located in the dry seasons. These two authors have shown that maximum peak of small litterfall were related to the period of water stress, with the maximum in the dry season. Other explanations have been put forward, such as climate, the conjunction of biological and mechanical phenomena, the character of the dry season (Becker et al., 2015; Rozas et al., 2015). In the present study, the monthly analysis of small litterfall clearly showed seasonality effects. The maximum of small litterfall, especially leaf litterfall, occured during the long dry season (December - February) and the minimum in the short dry season (June-August), and was related to rainfall.

Litter nutrients

The nutrients of litterfall and litter standing crops in the Ebom rainforest in the TCP research area were compared with litterfall in other tropical forests (Table 8). The results of nutrient contents of litterfall reported in other Tropical forests were similar to those found in our study, except P was very high and Mg was much lower in our study. Nitrogen (N) and phosphorous (P) have very high amounts, whereas those of Na, Ca, especially Mg were very low compared to values found in tropical rainforests developed on the same type of soil as ours. For N, Vitousek and Sanford (1986) have shown that the availability of N was not a limiting factor in all tropical rainforests. In the TCP research area, comprising Ebom rainforest, van Gemerden and Hazeu (1999) found that N amount was high and could not be a limiting factor, at least in the first year after harvesting.

The P amount returning annually to the soil by the small litterfall was high. However, according to van Gemerden and Hazeu (1999), P available in the soil was low; Al and Fe contents were high in the soils of the TCP research area. The high acidity of the soil facilitates the absorption of P by Fe and Al to form iron and aluminum phosphate and makes available very low P amounts in the soil (Brouwer, 1996; Raaimakers et al., 1995). The cultivation practice can therefore lead to a very rapid decrease of P stock in the soil and after one year, its deficit will be significant (van Gemerden and Hazeu, 1999). The Mg content in litterfall was very low. Similarly, this nutrient contents as an exchangeable base was also low in soil solutions (van Gemerden and Hazeu, 1999). This assumes that Mg would be effectively used or undergoes very easy leaching at plant material level.

Impact of logging

On litterfall and litter standing crops

Impact of selective logging on litterfall is low in the Ebom Forest, six years after selective logging and estimated from a one-ha-plot. However, this impact is still perceptible on the annual average of total small litterfall during the low litterfall season (short dry season and long

Table 7. Small litterfall ($t.ha^{-1}.y^{-1}$) and litter standing crops ($t.ha^{-1}$) of some tropical rainforests in the world.

Location	Rainfall (mm)	Small litterfall				Litter on floor	Source
		L	B	Re	Total		
Oxisols/Ultisols							
Brazil	2600	-	-	-	8.0	-	Dantas and Phillipson (1989)[1]
Brazil	2300	6.3	-	-	9.3	4.6	Scott et al. (1992)[1]
Brazil	-	5.4	-	-	7.8	6.5	Luizão (1995)[1]
Brazil	2300	8.0	-	-	9.9	-	Klinge (1977)[1]
Brazil	1800	6.4	-	-	8.1	-	Sampaio et al. (1993)[1]
Brazil	1800	6.4	-	-	7.9	-	Franken et al. (1979)[1]
Cameroon	2131	6.2	1.9	-	10.9	4.1	This study
Cameroon	1828-2131	5.5-6.5	1.7-2.2	-	8.6-10.9	3.4-4.2	Ibrahima et al. (2002)
Colombia	3100	6.1	-	-	7.4	-	Duivenvoorden and Lips (1995)
Guyana	2700	5.4	-	-	9.1	7.4	Brouwer (1996)
French Guyana	3200	5.7	-	-	7.9	4.2	Puig and Delobelle (1988)[1]
Malaysia	5100	5.4	-	-	8.8	-	Proctor et al. (1983)[1]
Malaysia	2800	6.5	-	-	11.1	-	Burghouts (1993)[C]
Surinam	2200	7.1	-	-	11.7	-	
Trinidad	1800	6.9	-	-	6.8-7	3.9-4.2	Cornforth (1970)[1]
Venezuela	3500	7.6	-	-	10.3	-	Cuevas and Medina (1986)[1]
Other soil types							
Africa							
Cameroon	-	-	-	-	13.5	10.8	Songwé et al. (1995)
Cameroon	-	-	-	-	12.9-14.1	-	Songwé et al. (1998)
Ivory coste	1800	6.3-7.1	1.4-2.3	0.5-1.1	9.1-9.6	-	Bernhard (1970)[2]
Ivory coste	2100	7.6-8.	1.1-2.6	0.7-1.1	9.3-12.4	-	Bernhard (1970)[2]
Gabon	1700	6.5	-	-	13.3	-	Hladik (1978)[2]
Ghana	1650	7.4	1.0	0.4	9.7	-	John (1973)[2]
Ghana	1650	7.0	-	-	10.5	-	Nye (1961)[2]
Nigeria	1321	-	-	-	4.6-7.2	1.8-3	Hopkins (1966)[3]
Nigeria	1200	3.7	-	-	5.6	-	Madge (1965)[2]
DRC (former Zaire)	1828	-	-	-	12.3	-	Laudelout and Meyer (1954)[2]
DRC (former Zaire)	1273-1279	4.5-4.7	1.2-3.0	1.5-0.2	5.1-9.1	-	Malaisse et al. (1975)[2]
America							
Jamaica	2600	4.4-5.5	0.2-1.5	-	5.6-6.6	8-12	Tanner (1981)[2]
Guatemala	3747	6.7-7.3	1.5-2.1	0.4-1.0	9.3-10.0	-	Kunkel-Westphal and Kunkel (1979)[2]
Panama	2725	5.8	2.3	1.2	11.1	-	Haines and Foster (1977)[2]
Peru	2715	4.2	1.7	1.1	7.0	-	Nebel et al. (2001)
Venezuela	1500	3.4	2.3	1.1	7.0	-	Steinhardt (1979)[2]
Colombia	3000	6.6-8.6	2.0-3.1	0.1-0.4	8.7-12.0	-	Foster and de las Salas (1976)[2]
Colombia	2769	-	-	-	10.1	5-17	Jenny et al. (1949)[2]
French Guyana	3373	5.9	1.9	1.0	8.7	-	Puig (1980)[2]
Venezuela	3521	6.1	3.4	-	9.5	-	Jordan and Escalante (1980)[2]
Brazil	1771	4.3	1.1	1.0	6.4	-	Franken et al. (1979)[2]
Asia							
Indonesia	2800	4.3	-	-	5.9	-	Saharjo and Watanabe (2000)[2]
India	1219	3.9	1.3	0.3	5.6	-	Blasco and Tassy (1975)[2]
India	2338	4.1-6.8	0.7-1.6	0.3-0.5	5.6-8.7	3.8-5.5	Sundarapandian and Swamy (1999)[2]

Table 7. Contd.

Malaysia	2054	6.5	2.0	0.4	9.2	-	Ogawa and Lim (1978)[1]
Java	3380	4.5	1.0	0.4	6.0	-	Yamada (1976)[2]
Australia							
Papua N. Guinea	3985	6.4	1.1	-	7.6	6.1-7.7	Edwards (1977)[2]
Australia	1626	4.6	0.9	0.6	8.1	6.3	Spain (1984)
Australia	3609	4.9	1.6	1.3	9.7	4.4	Spain (1984)

Sources: [1]Brouwer (1996); [2]Spain (1984); [3]Sundarapandian & Swamy (1999). L: leaves, B: twigs and small litter fall; Re.:rest

Table 8. Nutrient contents (%) of some tropical rain forests of the World.

Location	N	Ca	Mg	K	P	Source
Oxisols/Ultisols						
Cameroon	1.6	0.7	0.05	0.4	0.11	This study
Guyana	1.3	0.4	0.2	0.1	0.02	Brouwer (1996)
Brazil	1.3	0.7	0.3	0.5	0.06	Scott et al. (1992)[1]
Brazil	1.8	0.4	0.2	0.2	0.02	Luizão (1989)[1]
Brazil	1.5	0.2	0.1	0.1	0.03	Luizão (1995)[1]
Colombia	1.5	0.2	0.1	0.2	0.02	Duivenvoorden and Lips (1995)
French Guyana	1.5	0.4	0.1	0.1	-	Puig and Delobelle (1988)[1]
Malaysia	1.0	0.2	0.1	0.5	0.01	Proctor et al. (1983b)[1]
Malaysia	1.4	0.6	0.2	0.5	0.04	Burghouts (1993)[1]
Surinam	1.4	0.6	0.2	0.3	0.04	
Trinidad	0.8	0.8	0.2	0.2	0.03	Cornforth (1970)[1]
Venezuela	1.6	0.2	0.07	0.2	0.03	Cuevas and Medina (1986)[1]
Other soil types						
Guyana	1.2	0.7	0.2	0.2	0.02	Brouwer (1996)
Brazil	1.4	0.8	0.2	0.3	0.03	Luizão (1989)[1]
Brezil	1.1	0.2	0.1	0.1	0.06	Luizão (1995)[1]
Colombia	1.1	0.7	0.2	0.3	0.02	Duivenvoorden and Lips (1995)
Malaysia	0.6	0.9	0.2	0.2	0.01	Proctor et al. (1983b)[1]
Venezuela	0.7	0.8	0.3	0.2	0.05	Cuevas and Medina (1986)[1]
Sarawak	0.8-1.1	0.4-3.5	-	0.1-0.4	0.01-0.04	Anderson et al. (1983)[1]
Average of moderate fertile soils	1.5	1.3	0.03	0.3	0.07	Vitousek and Sanford (1986)
Average of infertile soils (Oxisols/Ultisols)	1.2	0.3	0.08	0.2	0.03	Vitousek and Sanford (1986)
Spodosols/Psamments	0.7	0.8	0.1	0.3	0.03	Vitousek and Sanford (1986)

[1] Source: Brouwer (1996).

rainy season) and on the leaf litter fraction of the litter standing crops. In both logging and undisturbed sites, the leaf litter and total litter turnover were much higher than those of the twigs and rest because the latter two were made up of material whose degradation is very slow (Swift et al., 1979). In both sites, the turnover decrease in the following order: leaf > total > twig > rest. However, these two sites differed from one another by their turnover. The logging site is characterized by a faster turnover than the undisturbed site, with the exception of the rest fraction. These results suggested, by this level of disturbance, that the biological activity was more important or intense in the logging site than the undisturbed site, and explained by effects of climate (Denslow et al., 1998). Devi and Yadava (2010) mentioned that the higher turnover rate may be due to a high temperature and rainfall pattern in gap area, favoring microbial activities. According to Odiwe and Muoghalu (2003), the significant higher litterfall in forest 14 years after the ground fire and the changes in litter fraction contributions to the total litterfall agree with assertion of Chandrashekera and Ramakrishnan (1994). They reported that litter production and nutrient cycling patterns are likely to change during succession and may be affected by gap size, intensity of disturbance and age. Denslow et al. (1998) also found the gap size not only has direct effect on light levels in turn affecting plant growth rate, but also correlated with fine litterfall ($r^2 = 0.88$, $P<0.05$ and $n=6$).

On litter nutrients

The nutrient amounts differed between the undisturbed and logging sites of the Ebom Forest depending on the small litterfall or small litter standing crops. But it is difficult to draw a conclusion by considering only the litterfall and litter standing crops. It would be preferable to consider the turnover rate that informs about the release of these nutrients from litter to the soil and affected by climate condition in the gap (Devi and Yadava, 2010). In the undisturbed site, the order of nutrient release varied according to the litter fractions (decreasing order): Ca > K > Mg > N > P > Na for the small leaf litter and Ca > K > Na > Mg > N > P for the total small litter. In the logging site, the pattern was the same for the total small litter and the leaf litter: Ca > Na > K > Mg > N > P. These results showed that forest logging causes the Na turnover much faster than that of K, which in the absence of disturbance was faster than that of Na. Moreover, the Mg turnover in the total small litter, in the leaf litter and that of Na in the small leaf litter were faster in a logging site than in the undisturbed site.

The soils of the Ebom forests are characterized by high acidity and a very low exchangeable K, Mg and Ca in the soil solutions (van Gemerden and Hazeu, 1999). As in the case of the small litterfall, our results showed that the forest disturbed by the logging differed from the undisturbed forest only by Ca, K and Mg, whose quantities are much higher in the undisturbed forest than in the logging forest. Six years after logging abandoning, the logging forest has not yet reached the equivalent of the undisturbed forest for these three nutrients. Moreover, these nutrients amount in the small litterfall were low. Our results showed that for a logging with an intensity of one tree per hectare, the consequences are such that it would be necessary to wait more than six years to mitigate the effects of this logging for the exchangeable bases.

CONCLUSION

It emerges from this study that the small litterfall and its turnover were among the highest values of the rainforests developed on infertile soils (Oxysols/Ultisols). The contribution of the leaf litter to the total litterfall was higher than that of the other fractions. The maximum small litterfall was during the long dry seasons and it is related to rainfall. This production showed interannual variation, due to the phenology of the vegetation. Among the nutrients, only Ca, K and Mg return annually to the soil in small quantities through small litterfall. The impact of logging six years after selective logging was negligible on the small litterfall, but results in much faster release of Mg and Na which were low in soil solution of the forest of Ebom. It would take more than six years for the effects of logging to cancel out. This study of litter and the effect of selective logging was useful for improving selective logging practices, and silvicultural and environmental approaches for the management of the Ebom Tropical rainforest of Cameroon.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Anderson JM, Proctor J, Vallack HW (1983). Ecological studies in four contrasting lowland rain forests in Gunung mulu national park, Sarawak. Journal of Ecology 71:503-527.

AFNOR (Association française de Normalisation) (1982). Recueil des normes françaises des produits dérivés des fruits et légumes. Jus de fruits. 1ère édition, Paris, France, 27 p.

Becker J, Pabst H, Mnyongaa J, Kuzyakov Y (2015). Annual litterfall dynamics and nutrient deposition depending on elevation and land use at Mt. Kilimanjaro. Biogeosciences 12:5635-5646.

Berendse F (1994). Litter decomposability – a neglected component of plant fitness. Journal of Ecology 82:187-190.

Bernhard F (1970). Etude de la litière et de sa contribution aux cycle des éléments minéraux en forêt ombrophile de Côte-d'Ivoire. Oecologia Plantarum 5:247-266.

Bibani MR, Jonkers WBJ (2001). Silvicultural monitoring in permanent sample plots in Ebom forest, southern Cameroon. In: Jonkers, W.B.J. et al. (eds.). Sustainable management of African rainforest, part II. Tropenbos International, Wageningen, The Netherlands 2001.

Blasco F, Tassy B (1975). Etude d'un écosystème forestier montagnard du sud de l'Inde. Bulletin d'Ecologie 6:525-539.

Brouwer LC (1996). Nitrogen cycling in pristine and logged tropical rainforest. Tropenbos - Guyana Series 1, Tropenbos - Guyana Programme, George-town, Guyana. P 224.

Burghouts TBA (1993). Spatial heterogeneity of nutrient cycling in Bornean rain forest. PhD thesis, Free University Amsterdam.

Burivalova Z, Şekercioğlu ÇH, Koh LP (2016). Thresholds of logging intensity to maintain tropical forest biodiversity. Current Biology. 24(16):1-6.

Celentano D, Zahawi RA, Finegan B, Ostertag R, Cole RJ, Holl KD (2011). Litterfall dynamics under different tropical forest restoration strategies in Costa Rica. Biotropica 43(3):279-287.

Chandrashekera UM, Ramakrishnan PS (1994). Successional patterns and gap phase dynamics of humid tropical forest of the western ghats of Kerala, India: ground vegetation, biomass, productivity and nutrient cycling. Forest Ecology and Management 70:23-40.

Chuyong GB, Newbery DM, Songwe NC (2000). Litter nutrients and retranslocation in a central African rain forest dominated by ectomycorrhizal trees. New Phytologist 148:493-510.

Cornforth IS (1970). Leaf-fall in a tropical rainforest. Journal of Applied Ecology 7:603-608.

Cuevas E, Medina E (1986). Nutrient dynamics with Amazonian forest ecosystems. I. Nutrient flux in fine litter and efficiency of nutrient utilization. Oecologia 68:466-472.

Dantas M, Phillipson J (1989). Litterfall and litter nutrient content in primary and secondary Amazonian terra firme rain forest. Journal of Tropical Ecology 5:27-36.

Das C, Mondal NK (2016). Litterfall, decomposition and nutrient release of Shorea robusta and Tectona grandis in a sub-tropical forest of West Bengal, Eastern India. Journal of forestry research 27(5):1055-1065.

Das K, Ramakrishnan PS (1985). Litter dynamics in Khasi pine (Pinus kesiya Royle ex Gordon) of north-eastern India. Forest Ecology and Management. 10:135-153.

Denslow JS, Ellison AM, Sanford RE (1998). Treefall gap size effects on above and below-ground processes in a tropical wet forest. Journal of Ecology 86:597-609.

Devani MB, Shioshoo JC, Sha SA, Suhagia BN (1989). Spectrophotometrical method for micro-determination of nitrogen in Kjeldahl digest. Journal-Association of official analytical chemists 72(6):953-956.

Devi NB, Yadava PS (2010). Influence of climate and litter quality on litter decomposition and nutrient release in sub-tropical forest of Northeast India. Journal of Forestry Research 21(2):143-150.

Devi NL, Singh EJ (2017). Pattern of litterfall and return of nutrients in five Oak species of mixed Oak forest of Manipur, North-East India. Journal of Applied and Advanced Research 2(1):1-5.

Dijk JFW van (1999). Non-timber forest products in the Bipindi – Akom II region, Cameroon: a socio-economic and ecological assessment. Tropenbos-Cameroon Series 1. The Tropenbos-Cameroon Programme, Kribi, Cameroun 197 p.

Duivenvoorden JF, Lips JM (1995). A land-ecological study of soils, vegetation and plant diversity in Colombian Amazonia. Trobenbos Series 12, The Tropenbos Fondation, Wageningen, The Netherlands.

Edwards PJ (1977). Studies of mineral cycling in a montane rain forest in New Guinea. II The production and disappearance of litter. Journal of Ecology 65:971-992.

Fines JP, Ngibaot F, Ngono G (2001). A conceptual forest management plan for a medium size forest in southern Cameroon. Tropenbos-Cameroon Documents 6, The Tropenbos-Cameroon Programme, Kribi, Cameroun.

Folster H, de las Salas G (1976). Litterfall and mineralization in three tropical forest evergreen forest stands Columbia. Acta Cientifica Venezolana 27:196-2002.

Franken M, Irmler V, Klinge H (1979). Litterfall in inundation, riverine and terra firme forest of central Amazonia. Tropical Ecology 20:225-235.

Franqueville A (1973). Atlas régional Sud-Ouest I, République du Cameroun. ORSTOM, France, Yaoundé, Cameroun. P 380.

Haines B, Foster RB (1977). Energy flow through litter in a Panamanian forest. Journal of Ecology 65:147-155.

Harris NL, Brown S, Hagen SC, Saatchi SS, Petrova S, Salas W, Hansen MC, Potapov PV, Lotsch A (2012). Baseline map of carbon emissions from deforestation in tropical regions. Science 336:1573-1576.

Hladik A (1978). Phenology od leaf production in rain forest of Gabon: in Mongomery GC (ed.). The ecology of Arboreal folivores. Smithsonian Institution Presss, Washington DC, USA.

Hopkins B (1966). Vegetation of the Olokemeji forest Reserve, Nigeria. IV. The litter and soil with special reference to their seasonal changes. Journal of Ecology 54:687-703.

Ibrahima A, Ntonga JC, Mvondo Ze AD (2016). Litter Decomposition and Nutrient Dynamics in Tropical Rainforests of Ebom, Southwestern Cameroon: Effects of LoggingDisturbed. Global Journal of Botanical Science 4:4-36.

Ibrahima A, Schmidt P, Ketner P, Mohren GJM (2002). Phytomasse et cycle des nutriments dans la forêt tropicale dense humide du sud Cameroun. Tropenbos-Cameroon Documents 9:84.

Jenny H, Gessell SO, Bingham FT (1949). Comparative study of decomposition rates of organic matter in temperate and tropical regions. Soil Science 68:419-432.

John DM (1973). Accumulation and decay of litter and net production of forest in tropical west Africa. Oikos 24:430-435.

Jonkers W, Foahom B (2003). Sustainable management of rainforest in Cameroon. Tropenbos-Cameroon Series 9. Tropenbos International, Wageningen, the Netherlands.

Jonkers WBJ, Leersum GJR van (2000). Logging in south Cameroon: current methods and opportunities for improvement. The International Forestry Review 2(1):11-16.

Jordan H (1977). Fine litter production and nutrient return to the soil in three natural forest stands of eastern Amazonia. Geo-Eco-Trop 1: 159-161.

Klinge H (1977) Fine litter production and nutrient return to the soil in three natural forest stands of Eastern Amazonia. Geo-Eco-Trop 1:159-167.

Kunkel-Westphal I, Kunkel P (1979). Litterfall in a Guatemalan primary forest with details of leaf shedding by some common tree species. Journal of Ecology 67:665-686.

Laudelout H, Meyer J (1954). Les cycles d'éléments minéraux et de matière organique en forêt équatoriale congolaise. Fifth International Congress of Soil Science 2:2.

Letouzey R (1985). Notice de la carte phytogéographique du Cameroun au 1: 500,000. Institut de la Carte Internationale de la Végétation, Toulouse, France.

Luizão FJ (1989). Litter production and mineral elements input to the forest floor in a central Amazonian forest. Geojournal 19: 407-417.

Luizão FJ (1995). Ecological studies in contrasting forest types in Central Amazonia. PhD thesis. Stirling University, Royaume-Uni.

Madge DS (1965). Leaf and litter disappearance in tropical forest. Pedologia 5:278-288.

Malaisse F, Freston R, Goffinet G, Malaisse-Moussinet M (1975). Litterfall and litter breakdown in Miombo. In: Golley FB, Medina E (eds). Terrestrial and aquatic research. Springer, New York, USA.

Nobel G, Dragsted J, Salazar Vega A (2001). Litter fall, Biomass and net primary production in flood plain forests in the Peruvian Amazon. Forest. Ecology and Management 150:93-102.

Nounamo L, Yemefack M (2001). Farming systems in the evergreen forest of southern Cameroon: shifting cultivation and soil degradation. Tropenbos-Canmeroon Documents 8, The Tropenbos-Cameroon Programme, Kribi, Cameroon.

Nye PH (1961). Organic matter and nutrient cycling under moist tropical forest. Plant and Soil 13:333-346.

Odiwe AI, Muoghalu JI (2003). Litterfall dynamics and forest floor litter as influenced by fire in a secondary lowland rain forest in Nigeria. Tropical Ecology 44(2):243-251.

Ogawa H (1978). Litter production and carbon cycling in Pasoh forest. Malayan Nature Journal 30:367-373.

Parsons TRH, Brown S, Casarim FM (2014). Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters 9(3):1-11.

Proctor J, Anderson JM, Fogden SCL, Vallack HW (1983). Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak: II. Litterfall, litter stand crop and preliminary observations on herbivory. Journal of Ecology 71:261-283.

Puig H (1980). Production de litière en forêt guyanaise, résultats préliminaires. Bulletin de la société d'Histoire Naturelle de Toulouse 115 :338-346.

Puig H, Delobelle JP (1988). Production de litière, nécrosasse, apports minéraux aux sols par la litière en forêt Guyanaise. Review Ecology

(Terre et Vie) 43:3-22.
Qiu Iu XZ, Xie SC, Liu WY (1998). Studies on the Forest Ecosystem in Ailao Mountains, Yunnan, China. Sciences and Technology Press, Kumming.
Raaimakers D, Boots RGA, Dijkstra P, Pot S, Pons T (1995). Photosynthetic rates in relation to leaf phosphorus contents in pioneer versus climax tropical rain forest trees. Oecologia 102:120-125.
Rodier J (1978). L'analyse de l'eau: Chimie physico-chimie, bactériologie, biologie. Dunod Technique. 6ème édition, Paris (France), 1136 p.
Rozas V, Camarero JJ, Sangüesa-Barreda G, Souto G, García-González I (2015). Summer drought and ENSO-related cloudiness distinctly drive Fagus sylvatica growth near the species rear-edge in northern Spain. Agricultural and forest meteorology 201:153-164.
Saharjo BA, Watanabe H (2000). Estimation of litterfall and seed production of Acacia mangium in a forest plantation in south Sumatra Indonesia. Forest Ecology and Management 130:265-268.
Sampaio EVB, D'all Olio A, Nue Lemos EP (1993). A model of litterfall, litter layer losses and mass transfer in a humid tropical forest at Pernambuco, Brazil. Journal of Tropical Ecology 9:291-301.
Scott DA, Proctor J, Thompson J (1992). Ecological studies on a lowland evergreen rainforest on Maraca Island, Roraima, Brazil. II. Litter and nutrient cycling. Journal of Ecology 80:705-717.
Seta T, Demissew S, Woldu Z (2018). Litterfall dynamics in Boter-Becho Forest: Moist evergreen montane forest of Southwestern Ethiopia. Journal of Ecology and The Natural Environment 10(1):13-21.
Songwe NC, Fasehun FE, Okali DUU (1988). Litterfall and productivity in a tropical rain forest, Southern Bakundu Forest Reserve, Cameroon. Journal of Tropical Ecology 4:25-37.
Songwe NC, Okali DUU, Fasehun FE (1995). Litter decomposition and nutrient release in a tropical rainforest, Southern Bakundu forest reserve, Cameroon. Journal of Tropical Ecology 11:333-350.
Spain AV (1984). Litterfall and the standing crop of litter in three tropical Australian rainforests. Journal of Ecology 72:947-961.
Steinhardt U (1979). Untersuchungen uber den wasser-und-Nahrstaffhaushat eines anddinen wolken waldes in Venezuela. Gottinger Bodenkundliche Berichte 56:1-185.
Sundarapandian SM, Swamy PS (1999). Litter Production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. Forest Ecology and Management 123:231-244.
Swift MJ, Heal OW, Anderson JM (1979). Decomposition in terrestrial ecosystems. Blackwell Scientific Publications, Oxford, United Kingdom.
Tanner EVJ (1980). Litterfall in montane rainforest of Jamaica and its relation to climate. Journal of Ecology 68:833-848.
Van Dam O (2001). Forest filled with gaps: effects of gap size on water and nutrient cycling in tropical rain forest. A study in Guyana. Tropenbos – Guyana Series 10, Tropenbos-Guyana Programme, Georgetown, Guyana 208 p.
van Gemerden BS (2004). Diturbance, diversity and distributions in central African rain forest. PhD thesis. Wageningen University, Wageningen, The Netherlands 199 p.
van Gemerden BS, Hazeu GW (1999). Landscape ecological survey (1:100,000) of the Bipindi-Akom II-Lolodorf region, Southwest Cameroon. TropenbosCameroon Documents 1. The Tropenbos-Cameroon Programme, Kribi, Cameroun P 164.
Vitousek PM, Sanford RL (1986). Nutrient cycling in moist tropical forest. Annual review of Ecology and Systematics 17:137-167.
Yamada I (1976). Effects of gap size on nutrient release from plant litter decomposition in a natural forest ecosystem. Canadian journal of forest research 25:1627-1638.
Zhang H, Yuan W, Dong W, Liu S (2014). Seasonal patterns of litterfall in forest ecosystem worldwide. Ecol. Complex. 20:240-247. Anderson JM, Proctor J, Vallack HW (1983). Ecological studies in four contrasting lowland rain forests in Gunung mulu national park, Sarawak. Journal of Ecology 71:503-527.

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