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Impact of *Triplochiton scleroxylon* K. Schum Exploitation on Fern Richness and Biomass Potential in the Semi-Deciduous Rain Forest of Cameroon

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Abstract

Triplochiton scleroxylon K. Schum is the plant species most affected by logging activities in the East Region of Cameroon due to its market value. This logging has impacted the ecological niche of the fern plant for which limited research has been done. The aim of this study is to contribute towards improving knowledge of fern richness and biomass on *T. scleroxylon* within the Central African sub-region. Fern data collection was done on 20 felled/harvested *T. scleroxylon* where, in addition to fern inventory, fern biomass was collected by the destructive method. The diameter and height of *T. scleroxylon* measured were used as explanatory variables in allometric equations for fern biomass estimation. Fern inventory was characterized using diversity index. Eight fern species were recorded on *T. scleroxylon* (≈5 species/*T. scleroxylon*). The minimum diameter where fern could be found is 59.4 cm. The average fern biomass found was 23.62 kg/*T. scleroxylon*. Pearson correlation coefficient showed a positive correlation ($r>0.55$) between fern biomass and *T. scleroxylon* diameter. For allometric equation, the logarithmic model improved better the adjustment than the non-logarithmic model. However, the quality of the adjustment is improved more when only the diameter is considered as an explanatory variable. Fern biomass is estimated to 90.08 kg/ha^{-1} with 76.02 kg/ha^{-1} being lost due to *T. scleroxylon* exploitation in the study area. This study is a contribution towards increasing knowledge of fern diversity specific to *T. scleroxylon*, and also fern biomass contribution to climate change mitigation and the potential carbon loss due to *T. scleroxylon* exploitation.

Key Words: fern diversity, biomass, sustainable conservation, *Triplochiton scleroxylon*, semi-deciduous forest

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Introduction

Fern are vascular plants with about 12,000 known species (PPG I 2016), including 279 species found in Cameroon (Maréchal et al. 2014). They are terrestrial epiphytes without seeds and which are widely distributed from the tundra to tropical forests (Moran 2008). Approximately 70% of the entire fern species are epiphytic (Watkins and Cordelus 2009). Their presence or absence reflects microhabitat characteristics because they are not randomly distributed in the forest (Zotz and Bader 2011; Patil et al. 2016). In Central Africa, ferns have long been neglected in biodiversity inventory (Maréchal et al. 2013); whereas they represent more than 25% of total epiphytes in the semi-deciduous forest of the Congo basin (Zapfack et al. 1996). In the semi-deciduous tropical forests in Central Africa, most phorophytes species have over 30 epiphytes species including more than 15 fern species (Zapfack et al. 1996; Zapfack and Engwald 2008; Noumi et al. 2010; Nfornkah et al. 2019). Phorophytes represent the habitat of fern epiphytes and their exploitation contribute to fern epiphytes habitat destruction and it is probably the greatest threat to the survival of these plants species (Nfornkah et al. 2019).

Ferns play an important ecological role including bio-indicator of pollution, habitat for species (animals, plant and microorganism), climate change mitigation, source of food for insects and birds, etc. (Gradstein et al. 2003; Wolf et al. 2009; Nfornkah et al. 2018; Della and Falkenberg 2019). For Fay (2013) and Sharma and Pegu (2011), they are used in traditional pharmacopeia and others for agricultural and horticultural purposes. For Barthlott et al. (2001), fern diversity can be used as biological indicator of pollution and the ecological damage. Indeed, the need for water and light are factors limiting the distribution of fern in the natural environments, as their abundance reduces as the climate becomes drier (Kimpouni et al. 2018). Ferns generally grow in habitats which are very shaded, characterized by high relative humidity (Kimpouni et al. 2018). These conditions are present only in habitats less exposed to light. The discontinuity of the forest cover represents a limiting factor to the harmonious growth of species including ferns as well as its diversity and abundance (Chung and Lee 2021).

In spite of the limited interest currently expressed in the study of the epiphytic flora of Africa, it is important to note that this plant group remains relatively unknown, looking at the low publication record observed in comparison to those of tropical America (Sporn et al. 2010). Taking into consideration this situation and threat of disappearance of the species in the tropical zones, it becomes necessary and even urgent to study the flora of Cameroun (where only the flora of Cameroon published in 1964 is available) in all its facets (Tardieu-Blot 1964). With the high level of tropical forest degradation and its continuous disappearance, the issue of species conservation remains primordial. Taking the case of *Triplochiton scleroxylon* K. Schum for example, which is among the most intensively exploited tree species in the Congo basin forest (WWF 2007), there is no guarantee for the preservation of fern which needs *T. scleroxylon* as its host. In Cameroon, the exploitation of *T. scleroxylon* is now subjected to quotas allocated by the Ministry of Forestry and Wildlife according to law N°0021/MINFOF of the 18th February 2018 based on the modification of the classification of forest timber species. It is a native host tree species in the semi-deciduous forest of Africa that hosts an important fern diversity (Zapfack et al. 1996). Its exploitation is at the origin of habitat destruction of many other species which use this species as host; and also the loss of carbon stocks potential (Zapfack et al. 1996; Wolf et al. 2009; Nfornkah et al. 2018, 2019; Cedric et al. 2021). Concerning climate change mitigation, Nfornkah et al. (2018) pointed out the fact that, *T. scleroxylon* is the phorophytes in tropical forest where epiphytes biomass is most represented.

Despite the contribution of epiphytes to biodiversity in tropical forest, its contribution to forest biomass remains low. Although Nfornkah et al. (2018) and Cedric et al. (2021) have equally shown that its contribution is low, it is necessary to consider it in the policies concerning climate change mitigation. In fact, the monitoring of plant biodiversity is a fundamental step to influence the management and conservation of biodiversity and habitats (Maréchal et al. 2014) because in most cases, management practices in forest ecosystems ignore epiphytes. However, information on fern biomass in semi-deciduous rain forest of Cameroon remain weak and this study wanted to complete the gap concerning methodological approach of these fern biomass estimation for a specific host intensively exploited tree species. Then, our goal in this study is to show how the exploitation of *T. scleroxylon* in the semi-deciduous forest of

Cameroon affects fern epiphyte diversity and possible biomass loss. The objectives were: i) to do an inventory of fern species on *T. scleroxylon* ii) to estimate the biomass potential of fern found on *T. scleroxylon* and finally iii) the potential fern biomass loss due to *T. scleroxylon* exploitation in the semi-deciduous forest of Cameroon.

Materials and Methods

Study area

This study was carried out in the semi-deciduous rain forest of Cameroon especially the area located between the geographical coordinates 14°48'38.73" and 3°56'40.17" North; 3°53'58.76" and 14°51'43.80" East. The climate is typically Guinean equatorial characterized by four seasons: including two dry seasons (a long dry season from December to February and a short dry season from July to August) and two rainy seasons (a short rainy season from September to November and a long rainy season from March to June). The mean temperature, rainfall and relative annual humidity in the study area are respectively 25°C, 1,600 mm/year 75%. The relief in the study area is relatively gentle and varies between 600 and 900 m. The soil is essentially lateritic and hydromorphic in wetlands and along river courses (Laclavère. 1979). Ecologically, this area which constitutes the semi-deciduous forest belongs to the Guineo-Congolese domain type (Latouzey 1985). This area is rich and has varied plant species (Chimi et al. 2018; Kabelong et al. 2020) and especially in exploitable trees such as *T. scleroxylon*, *Entandrophragma cylindricum* (Sprague) Sprague, *Terminalia superba* Engl. & Diels, *Mansonia altissima* (A. Chev) A. Chev., *Petersianthus macrocarpus* (P. Beauv.) Liben, *Milicia excelsa* (Welw.) C .C .B erg, *Pterocarpus soyauxii* Taub. which are timber species most exploited by the company in the study area.

Data collection

During the data collection process, logging activities were active and *T. scleroxylon* was the species more exploited by the Forest Company in the study area. Then, fern data collection was done on 20 stems of *T. scleroxylon*. These *T. scleroxylon* trees were those exploited by a logging company in the study area and/or trees pulled down during logging activities especially those with a diameter less than the minimum exploitable diameter. This was done in order to limit the negative impact of our study on the ecosystem. Firstly, for each felled *T. scleroxylon* identified, a prospection of the entire tree was done; when fern was present and easily accessible, we considered it as a host tree which can be sampled. Secondly, for the selected host trees, inventory data of fern species distribution along the host trees were recorded based on the sampling method defined by Zapfack (1993). In this case, the updated methodology proposed by Johansson (1974) and adapted by Nfornkah et al. (2019), for the vertical stratification which consist of subdividing each phorophyte into five zones ((I) basal compartment of trunk (0-3 m); (II) trunk from the 3rd meter to the first ramifications; (III) from the first ramification to the second ramification; (IV) from the second ramifications to ramifications with diameters ≥10 m and (V) branch ramifications of diameter <10 m) was applied. Then, on each tree sampled and for each subdivided zone, the method used consisted of collecting abundance of each fern species present on the minimum area of 2 m established. Each minimum area depended on the presence of at least two different species. Identification of these species was done using the fern Flora (Tardieu-Blot 1964) and the confirmation of their identity was done at the National Herbarium of Yaounde. In addition, for each felled *T. scleroxylon* sampled, diameter and total height were measured. Diameter was measured at 30 cm above the buttress and total height was measured directly on felled trees (Cedric et al. 2021).

Concerning fern biomass data collection, the protocol recommend by Nfornkah et al. (2018) for epiphytes biomass was applied. According to this protocol, the destructive method was applied for fern biomass collection on each *T. scleroxylon* sample which consisted of collecting all fern present on each *T. scleroxylon* and weighing with the help of suspension electronic scales (max: 300 kg). Seeing that it is difficult to dry all these samples, a sub-sample of fern biomass (500-800 g) was collected and sealed in appropriate bag for each tree and weighed with laboratory electronic scale (max: 2,000 g; precision: 0.05 g). The sub-samples were then taken to the laboratory of Botany and Systematics of the University of Yaounde I, where they were oven dried at 80°C. The weighing of dry samples was done after 48 h, 24 h, 12 h, 6 h, 6 h, 6 h, etc. until a constant mass was obtained. Then, the following formulae was used for total mass of fern per individual *T. scleroxylon*. Total mass (kg)=total fresh mass×sub-sampled dry mass/sub-sampled fresh mass. Fern biomass was expressed in kg/*T. scleroxylon*.

To express the potential fern biomass on *T. scleroxylon*, inventories of *T. scleroxylon* was done in 8 randomized plots of 250 m×20 m. *T. scleroxylon* inventory concerned only those with the required diameter (59.4 cm) where fern was found. Fern biomass at the hectare was estimated using allometric equations established. However, to determine the fern biomass potential which could be loss if this timber was felled, we also estimated the fern biomass for *T. scleroxylon* with minimum diameter of exploitability (MDE) of 80 cm according to the forest law of Cameroon.

Data analysis

Data analysis was done with the help of R (version 3.4.1) software.

Fern biodiversity on *T. scleroxylon* was characterized with the help of "Biodiversity R" package of R software (Kindt and Coe 2005). The Indices taken into account were: (1) Shannon index (ISH) diversity which depend to the following formulae:

$ISH = -\Sigma \frac{Ni}{N} \times \log \frac{Ni}{N}$ where Ni=number of species i;

N=number of species. This index is the most recommended in the standard comparative study because it is independent of the size of the population studied and gives more importance to rare species. (2) The Evenness (EQ) EQ $EQ = \frac{ISH}{\log(N)}$ is between 0 and 1. A low equitability represents a great importance of some dominant species. (3) Sorensen's similarity index (S), S=(2c/a+b)×100; with c=the number of epiphytes species common to two zones, a=the number of epiphytes species recorded in zone "a" and b=number of epiphytes species recorded in zone "b" was calculated between zones. This index expresses the similarity or dissimilarity between fern species with respect to vertical stratification. The value of Sorensen's index less than 50% indicates a weak similarity between the two zones considered. The non-parametric estimators of biodiversity like Chao, Jack1 and Jack2 were used to estimate the precision of fern richness on *T. scleroxylon* in the study area.

The relationship between fern biomass with *T. scleroxylon* measurement was appreciated with the help of the coefficient of correlation of Pearson for linear and exponential model. However, This relationship was also performed using allometric equations where fern biomass were considered like the response variable and *T. scleroxylon* diameter and total height like the explanatory variables. Several models were tested and only five models are presented in this study. These models are: (1) Y=a+b×D, (2) Y=a+b×D+c×D^2, (3) Y=Y=a+b×D+c× H, (4) lnY=a+b×ln (D) and (5) lnY=a+b×ln (D)+c×ln (H). For the comparison of these models two by two to test the reliability of one model in relation to the other, the performance criteria of each model was determined using the following statistical parameters: the Residual Standard Error (RSE), Akaike Information Criterion (AIC) and adjusted coefficient of determination (Adj.R^2). For two models, models with high value of Adj.R^2 and low value of RSE and AIC are better than those where RSE and AIC are high and Adj.R^2 has a low value. Only for the logarithmic models, seeing that this transformations introduce the systematic bias (Xiao et al. 2011), these models were corrected using the correction factor (CF)=RSE2/2 (Djomo and Chimi 2017).

For fern biomass estimation in hectares, the best allometric equation established in the context of this study and which depend to dendrometric parameters of *T.* scleroxylon was used. This equation is defined by the following formulae: $=e^{(-11.138+3{,}029\times\ln(D)}$; where B is the fern biomass in kg and D is *T. scleroxylon* diameter in cm. Then, fern biomass was extrapolated in hectares according to the abundance of *T. scleroxylon* with minimum occurrence diameter.

Results and Discussion

Fern richness of Triplochiton scleroxylon

The richness of fern varied from 2 to 8 species per phorophyte (*T. scleroxylon*). Total richness found on the 20 stems of *T. scleroxylon* was 8 fern species which belong to 3 families and 5 genera. The average richness of fern found was 5 species/*T. scleroxylon*.

The family of Polypodiaceae was the most diverse family in terms of number of fern species with 4 species (*Microsorum punctatum*, *M. scolopendria*, *Platycerium angolense*, and

Table 1. Fern diversity found on 20 *T. scleroxylon* in the semi deciduous rain forest of Cameroon

Family	Genera	Species	Status
Polypodiaceae (50.0%)	*Microsorium*	*Microsorum punctatum* (L.) Copel.	True epiphytes
		Microsorum scolopendria (Burm. F.) Copel.	Hemi epiphytes
	Platycerium	*Platycerium angolense* Welwitsch ex Hooker	True epiphytes
		Platycerium stemaria (P. B.) Desv.	
Oleandraceae (37.5%)	*Oleandra*	*Oleandra distenta* Kunze	True epiphytes
	Arthropteris	*Arthropteris* sp.	Hemi epiphytes
		Arthropteris cameroonensis Alston	Hemi epiphytes
Davalliaceae (12.5%)	*Davallia*	*Davallia chaerophylloides* (Poiret) Steudel	True epiphytes

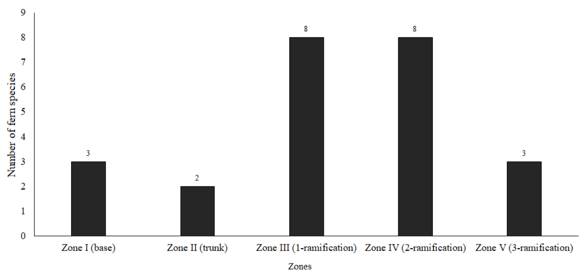

Fig. 1. Vertical stratification of fern richness on the *T. scleroxylon.*

Table 2. Sorensen's similarity according to the vertical distribution of fern richness on *T. scleroxylon*

	Zone I	Zone II	Zone III	Zone IV	Zone V
Zone I	100				
Zone II	40	100			
Zone III	54	40	100		
Zone IV	36	40	88	100	
Zone V	33	33	54	54	100

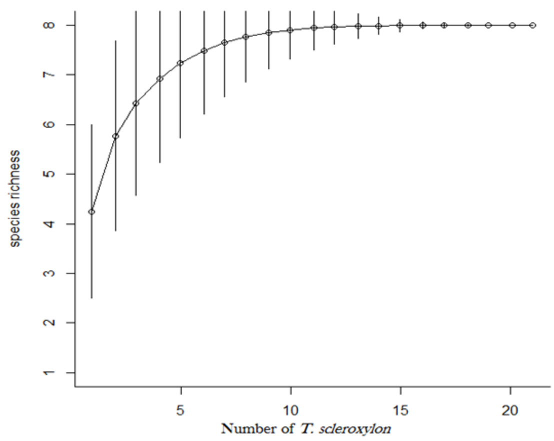

Fig. 2. Accumulation curve using rarefaction method for fern richness on *T. scleroxylon.*

Platycerium stemaria) on *T. scleroxylon* (50%), followed by Oleandraceae (*Oleandra distenta*, *Arthropteris cameroonensis* and *Arthropteris* sp.) with 3 fern species; and then Davalliaceae (*Davallia chaerophylloides*) and with 1 species (12.5%) (Table 1).

According to the vertical stratification of fern on *T. scleroxylon*, they are more diversified in zone III and IV where the maximum diversity (8 fern species) was found. However, the trunk appears to be the compartment characterized by the least diversity in terms of fern richness (Fig. 1).

Testing for fern richness similarity with respect to zones, Sorenson's test showed that fern diversity was similar (more than 50%) with respect to zone 1 and III; zone III and Zone IV and finally for zone IV and Zone V. For other combinations two by two having a Sorensen's index less than 50%, we conclude that a weak similarity exist with respect to fern diversity (Table 2).

Accumulation curves for fern richness showed that the inventory reflects the total species richness of *T. scleroxylon* in the semi-deciduous forest of Eastern Cameroon (Fig. 2). This result was confirmed by the non-parametric estimators of biodiversity (Chao, Jack1 and Jack2) who estimated a total fern richness of 8 species.

The Shannon index was 1.81 which shows a low richness of fern on *T. scleroxylon*. However, this species richness showed a dominance of some species in terms of abundance. These species were: *Platycerium angolense* (26.3%), *Platycerium stemaria* (19.9%), *Microsorum scolopendria* (19.2%), and *Arthropteris* sp. (18.6%). The proportion of other species was less than 5.2%.

Descriptive and inferential statistics for fern biomass on Triplochiton scleroxylon

The minimum diameter where fern biomass was found is 59.4 cm. Fern biomass was correlated positively to the diameter of *T. scleroxylon* with a Pearson correlation coefficient of r>0.5. Fern biomass increases with increasing diameter of *T. scleroxylon* and follows the linear model with logarithmic transformation rather than the linear and exponential model of the Pearson correlation coefficient (Fig. 3). For the 20 *T. scleroxylon* sampled, fern biomass varied between 0.16 to 92.84 kg/tree^{-1}. The average fern biomass was 23.62 kg/tree^{-1}. The total fern biomass found for the 20 stems of *T. scleroxylon* sampled was 496.10 kg. For dendrometric variables, diameter and total height of *T. scleroxylon* sample were 68.60-153.30 cm and 24.10-56.20 m respectively.

Allometric equation for fern biomass estimation on Triplochiton scleroxylon

Based on Adj.R^2, Table 3 showed a weak correlation between fern biomass and explanatory variables like diameter and height of *T. scleroxylon* (Adj.R^2<0.47). According to AIC and RSE, logarithmic models improve the quality of the adjustment more than non-logarithmic models. However, for logarithmic and non-logarithmic models, the quality of the adjustment is improved more when only the diameter is considered like an explanatory variable. In fact, the integration of height into the model did not improve the quality of the prediction.

Thus, the best model found based on AIC (71) and RSE (1.22) was: $B = e^{(-11.138+3,029\times\ln(D))}$ where B is fern biomass and D is the diameter of *T. scleroxylon*.

Potential fern biomass loss due to Triplochiton scleroxylon exploitation

Globally, fern biomass in the semi-deciduous rainforest

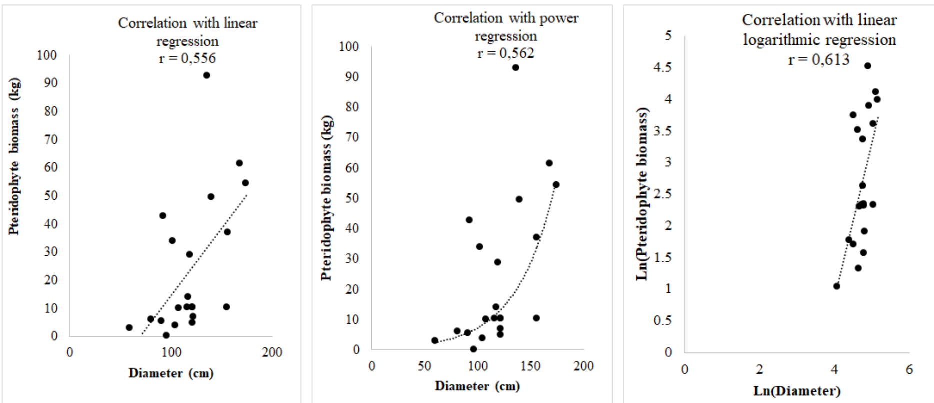

Fig. 3. Relationship between fern biomass and the diameter of *T. scleroxylon*. From left to right we have linear, power and logarithmic models. (r) is the Pearson coefficient of correlation.

Table 3. Allometric equations for estimations of fern biomass (B) on *T. scleroxylon*

Models	a	b	c	RSE	Adj.R2	AIC	CF	p-value
B=a+b×D	-33.022^{ns}	0.476**		21.01	0.373	191	-	<0.01
B=a+b×D+c×H	-95.862^{ns}	0453*	1.354^{ns}	20.79	0.388	192	-	<0.05
B=a+b×D+c×D^2	10.299^{ns}	-0.281^{ns}	0.003^{ns}	21.31	0.352	193	-	<0.05
lnB=a+b×ln(D)	-11.878*	3.029*		1.22	0.463	71	0.74	<0.05
lnB=a+B×ln(D)+c×l n(H)	-5.740^{ns}	3.045*	-1.603^{ns}	1.24	0.431	73	0.77	<0.05

a, b and c are the model's fitted parameters.
D, diameter; H, total height; RSE, residual standard error of the estimate; Adj.R2, is the coefficient of determination; AIC, akaike information criterion; CF, correction factor.

Table 4. Descriptive analysis of fern biomass (kg/ha^{-1}) in *T. scleroxylon* with occurrence diameter and Mean diameter of exploitability of 68.6 and 90 cm respectively

Descriptive statistics	With diameter≥59.4 cm		With MDE≥80 cm	
	N/ha	Fern biomass (kg/ha^{-1})	N/ha	Fern biomass (kg/ha^{-1})
Mean	3	90.08	2	76.02
Min	1	11.29	0	0.00
Max	6	149.77	3	125.98
sd	3	71.19	2	66.91

in East Cameroon is estimated to an average of 90.08 kg/ha^{-1} which varied between a minimum of 11.29 kg/ha^{-1} to a maximum of 149.77 kg/ha^{-1}. This is in the context where we take into account the occurrence diameter where the fern are found. Then considering only *T. scleroxylon* with a minimum diameter of exploitability, a mean fern biomass which could be loss due to the exploitation of *T. scleroxylon* is estimated at 76.02 kg/ha^{-1} (Table 4).

Discussion

This study has shown the potential of fern epiphyte richness and biomass on *T. scleroxylon* in the semi-deciduous rainforest of the East region of Cameroon within the context of plant conservation and climate change mitigation. Seeing that it is not easy to sample fern on standing trees due to the limitation of clumping in this ecosystem and the difficulties to sample fern biomass on standing trees using the destructive method, we were focused in this study only on felled *T. scleroxylon* trees. Even with the felled trees, branches covered fern epiphyte rendering them invisible in most cases, coupled with difficulties accessing all the fern present on felled *T. scleroxylon* after prospection. These were some of the limitations of this study. In this context, sampling one *T. scleroxylon* in this study, involved prospection, presence of fern, accessibility and ease of data collection. With this approach, especially due to the fact that only the Minimum Diameter of exploitability are felled, we considered *T. scleroxylon* with small diameter which were felled during logging activities like the opening of roads and wood parks and also those which were felled during the felling of other trees and unloading. Thus, information about fern occurrence diameter could be at the origin of the discussion.

Fern diversity on Triplochiton scleroxylon

The richness of fern confirms the potential of *T. Scleroxylon* as a fern-rich Phorophyte. *T. scleroxylon* represented the host trees characterized by the most diversity in terms of fern epiphyte (17 species) in the semi-deciduous forest (Zapfack et al. 1996), even if our study has found only 8 fern species. However, we can note that fern diversity varies in terms of the individuals of one specific host species (Nfornkah et al. 2019). It is the case of this study where we found that diversity varied between 2 to 8 fern species on *T. scleroxylon* with an average of 4 per individual tree. Diameter could be seen as one of the main factors that could explain this difference. In fact, an increase in diameter is correlated with increasing epiphyte diversity that includes fern (Nfornkah et al. 2019). Zhao et al. (2015), Nfornkah et al. (2018), Cedric et al. (2021) have also found the same results concerning vascular epiphytes or some vascular epiphyte plant groups like Orchid in the semi-deciduous forest.

The importance of the substrate deposited could be another important factor which influences fern diversity on the host trees. In fact, the presence of substrate is needed for fern growth (Zapfack 1993; Noumi et al. 2010) because seeds deposited in these substrates mainly adapt to this environment and germinate when the conditions become favorable (Nadège et al. 2017); and also represent their source of hydro-mineral nutrition (Nadkarni et al. 2004). Then, for the big host tree like *T. scleroxylon*, rhytidome configuration are scaly and substrates can be easily deposited in these spaces; that build a microhabitat favorable for fern species growth.

Nevertheless, concerning the same host tree, several authors have shown that in addition to the aforementioned factors, other factors like: level of disturbance of the ecosystem, plant architecture, forest types, level of light, canopy disturbance, etc. could influence fern diversity (Zapfack 1993; Nfornkah et al. 2018; Kimpouni et al. 2018).

We found that zone III and IV constitue the highest fern richness zones on *T. scleroxylon* which is in line with the study of De la Rosa-Manzanoa et al. (2014) in Mexico where they found that epiphyte richness is highest in the middle canopy stratum of the phorophyte due to a favorable combination of micro-environmental factors. According to Watkins and Cardelus (2009), zone I is homogenously dark and humid whereas the middle of the canopy are brighter and drier and exhibit greater environmental heterogeneity, thus favorable for fern richness. According to the level of light in zone V and also the small diameter of branches which does not favour soil deposit, this zone has limited fern richness.

Fern epiphytes biomass in Triplochiton scleroxylon

Specifically from literature review, there are no studies which have shown fern biomass potential in the Congo Basin forest. Concerning epiphytes in this area, most of the studies were generally done on vascular epiphytes (e.g. Wolf et al. 2009; Nfornkah et al. 2018) or in a specific plant family like Orchidaceae (Cedric et al. 2021). Nevertheless, focus for example on the study of Nfornkah et al. (2018) who found a total of 62.34 kg of vascular epiphytes *T. scleroxylon* in the same ecosystem in Cameroon, our study found an average fern biomass estimated at 23.63 kg/*T. scleroxylon*, and concludes that fern biomass on *T. scleroxylon* represents about 38% of total vascular epiphytes on *T. scleroxylon* in the semi-deciduous forest of Cameroon. In this context, with total vascular epiphytes biomass on *T. scleroxylon*, the loss due to *T. scleroxylon* harvest/exploitation is greater (38%) compared to orchid for example which represents only 2% of total vascular epiphytes on *T. scleroxylon*. This observation allows us to confirm that even if fern diversity represents less than 17% of total vascular epiphytes richness (Nfornkah et al. 2019), its contribution in terms of biomass is greater (38%) compared to orchid for example which represents more than 61% of total vascular epiphytes richness but its biomass contribution is only 2%.

Compared to the study of Nfornkah et al. (2018), the consideration of one plant group in the place of total epiphytes provides a good adjustment. This is in accordance with Basuki et al. (2009) who demonstrated that, mono-specific and local allometric equations provides the best adjustment when compared to those who consider a large spectrum of trees. However, we have found globally that in the context of this study, fern biomass have a significant and positive relationship with increasing diameter of *T. scleroxylon*. This result was obtained by several authors concerning epiphytes on their host trees in general; where they have shown an increase in epiphyte biomass with increasing diameter of host trees (Flores-Palacios and García-Franco 2006; Wolf et al. 2009; Nfornkah et al. 2018; Cedric et al. 2021). In fact, for a big tree with a large diameter (and where the largest quantities of fern biomass are found), the architecture of the plant are favorable for fern growth. We can cite for example the rhytidome, canopy architecture which become favorable for substrate deposition. With logarithmic transformation, the integration of total height does not improve the quality of the adjustment. In fact, according to our observation on the field, the quantity of fern is low on the trunk of trees compared to the bottom part of trees (where relative humidity is important) and the canopy where the conditions is favorable for soil deposition and also fern growth. On the trunk, it is only on the rhytidome where the possible substrate deposit of the tree can be favorable for fern growth.

Management of Triplochiton scleroxylon and fern epiphytes conservation strategies

Out of the approximately 10,000 taxa of plants known in central Africa, the IUCN estimates that only 12% are known today (Maréchal et al. 2014). Fern epiphytes species, in spite of the continuous loss of their habitat, remain unknown whereas, it is important to conserve them; because these species are ethno-botanically and ecologically important. In fact, fern species contribute in the improvement of the quality of life for the rural population, because there are used in the traditional pharmacopeia and for agricultural and horticultural purposes (Sharma and Pegu 2011). According to Nfornkah et al. (2018), they contribute to climate change mitigation. There are some aspects that make ferns important to conserve. Nevertheless, taking for example *T. scleroxylon* like it was the case in this study, it is overexploited in Cameroon, and which is the preferred host for some fern like orchid epiphytes species (Cedric et al. 2021). This could represent a basis for the putting in place of conservation strategies in Cameroon's forests (Mey and Gore 2021), especially in forest management units. These epiphyte species are widely distributed (Moran 2008), and logging activities have a direct impact on their natural habitat. It is expected that, in some regions, changing climatic conditions might lead to dramatic changes in the ecosystems, including expansion or reduction in climate-sensitive fern, or worst case scenario, species extinction (Della and Falkenberg 2019).

Potential contribution of fern in REDD+ mechanisms

The contribution of fern in climate change mitigation is limited due to their low quantity of biomass estimated at 90 kg/ha^{-1} only for *T. scleroxylon* host species. This appears negligible when we focus only on fern biomass on one specific host species and estimation at the scale of a hectare without considering firstly the case of the biomass loss also due to *T. scleroxylon* exploitation; direct impact of logging activities (opening of roads, wood parks, etc.); and the total surface area of semi-deciduous forest of Cameroon. Taking for example only the case of total surface area of semi-deciduous forest in Cameroon which is estimated at about 18,640,192 ha (Megevand et al. 2013), the possible potential fern biomass which will be lost at the national scale according to *T. scleroxylon* exploited will be estimated at 1,679,015,294 kg. This biomass could represent more than 20 Million dollars USD in the context of REDD+ if we apply the recommendations of Hamrick and Goldstein (2016) concerning biomass conversion into carbon credits at a rate of 3.3 USD dollars for 1 ton of CO_{2eq} equivalent. It is therefore important to consider fern in REDD+ mechanisms of Cameroon because in addition to its contribution towards conserving *T. scleroxylon*, it will indirectly preserve fern diversity and its habitat and could also permit a gain of approximately 38 million in terms of carbon credits.

Conclusion

Biodiversity conservation and preservation of forest carbon stocks in the context of climate change mitigation is a challenge for logging companies as they could stop logging completely. Little or no control of logging activities will lead to the inevitable disappearance of fern, following the degradation of their habitat. In the context of this study, with the fact that T. sceleroxylon represent a habitat for fern richness, we can conclude that the exploitation of *T. scleroxylon* leads to fern diversity and biomass loss. It is therefore urgent to consider these plants in the management plans of logging companies; not only in the context of biodiversity conservation but also in climate change mitigation seeing that it constitutes a significant carbon pool in the context of REDD+ mechanism, payment of ecosystem services and carbon credit at the local, national, and international scale.

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References

Barthlott W, Schmit-Neuerburg V, Nieder J, Engwald S. 2001. Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. Plant Ecol 152: 145-156.

Basuki TM, Van Laake PE, Skidmore AK, Hussin YA. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. For Ecol Manag 257: 1684-1694.

Cedric CD, Nfornkah BN, Louis-Paul-Roger KB, Jolie Claire N, Alain Christian M, Roger Bruno TM, Walter Forje G, Nadege MT, Amandine Flore NY, Hubert MK, Mireil TV, Louis Z. 2021. Orchid Diversity and Biomass on a Native Host Tree Species in a Semi-deciduous Rain Forest of Cameroon. J Sustain For 40: 142-153.

Chimi CD, Zapfack L, Djomo AN. 2018. Diversity, structure and biomass (above and below) in a semi-deciduous moist forest of East Region of Cameroon. J Bio Environ Sci 12: 60-72.

Chung SH, Lee ST. 2021. Classification of Forest Cover Types in the Baekdudaegan, South Korea. J For Environ Sci 37: 269-279.

De la Rosa-Manzano E, Andrade JL, Zotz G, Reyes-García C. 2014. Epiphytic orchids in tropical dry forests of Yucatan, Mexico-Species occurrence, abundance and correlations with host tree characteristics and environmental conditions. Flora

209: 100-109.
Della AP, Falkenberg DB. 2019. Pteridophytes as ecological indicators: an overview. Hoehnea 46: e522018.
Djomo AN, Chimi CD. 2017. Tree allometric equations for estimation of above, below and total biomass in a tropical moist forest: case study with application to remote sensing. For Ecol Manag 391: 184-193.
Fay MF. 2013. Humans and other animals and the plants they ingest. Bot J Linn Soc 171: 637-639.
Flores-Palacios A, García-Franco JG. 2006. The relationship between tree size and epiphyte species richness: testing four different hypotheses. J Biogeogr 33: 323-330.
Gradstein SR, Nadkarni NM, Krömer T, Holz I, Nöske N. 2003. A Protocol for Rapid and Representative Sampling of Vascular and Non-Vascular Epiphyte Diversity of Tropical Rain Forests. Selbyana 24: 105-111.
Hamrick K, Goldstein A. 2016. Raising Ambition: State of the Voluntary Carbon Markets 2016. Forest Trends' Ecosystem Marketplace, Washington, DC, pp 25.
Johansson D. 1974. Ecology of vascular epiphytes in West African rain forest. Acta Phytogeogr Suec 59: 1-129.
Kabelong Banoho LPR, Zapfack L, Weladji RB, Chimi Djomo C, Nyako MC, Nasang JM, Madountsap Tagnang N, Tabue Mbobda RB. 2020. Biodiversity and carbon sequestration potential in two types of tropical rainforest, Cameroon. Acta Oecol 105: 103562.
Kimpouni V, Lenga-Sacadura MY, Mamboueni JC, Niamba L. 2018. [Study of the floristic diversity of Pteridophytes in Brazzaville, Congo]. VertigO doi: 10.4000/vertigo.23458. French.
Kindt R, Coe R. 2005. Tree Diversity Analysis: A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies. World Agroforestry Centre, Nairobi.
Latouzey R. 1985. [Notice of the phytogeographic map of Cameroon at 1: 500000. International Vegetation Map Institute]. Institut de la carte internationale de la végétation, Toulouse. French.
Maréchal C, Cawoy V, Cocquy C, Dauby G, Dessein S, Hamilton DI, Dupain J, Fischer E, Obang DF, Groom Q, Henschel P, Jeffery KJ, Korte L, Lewis SL, Luhunu S, Maisels F, Melletti M, Ngoufo R, Ntore S, Palla F, Scholte P, Sonké B, Stévart T, Stoffelen P, Van den Broeck D, Walters G, Williamson EA. 2014. [Conservation and management of biodiversity]. In: [State of the forests 2013] (De Wasseige C, Flynn J, Louppe D, Hiol HF, Mayaux P, eds). OFAC, Neufchâteau, pp 67-96. French.
Megevand C, Mosnier A, Hourticq J, Sanders K, Doetinchem N, Streck C. 2013. Deforestation Trends in the Congo Basin: Reconciling Economic Growth and Forest Protection. World Bank, Washington, DC.
Mey CBJ, Gore ML. 2021. Biodiversity Conservation and Carbon Sequestration in Agroforestry Systems of the Mbalmayo Forest Reserve. J For Environ Sci 37: 91-103.
Laclavère G. 1979. [Atlas of the United Republic of Cameroon]. Edition jeune Afrique, Paris. French.
Moran RC. 2008. Neotropical Genera of Ferns and Lycophytes: A Guide for Students. New York Botanical Garden, New York, NY.
Nadège MT, Zapfack L, Valery NN, Cedric CD, Clotèxe TV, Mireil TV, Flore NYA, Funwi FP, Roger TM. 2017. Community of vascular epiphytes on some phorophytes in the Babadjou Subdivision (Western Cameroon): case of Bamelo. J Sustain For 36: 65-75.
Nadkarni NM, Schaefer D, Matelson TJ, Solano R. 2004. Biomass and Nutrient Pools of Canopy and Terrestrial Components in a Primary and a Secondary Montane Cloud Forest, Costa Rica. For Ecol Manage 198: 223-236.
Nfornkah BN, Martin T, Zapfack L, Cedric DC, Frederick MN, Sonke B. 2019. Vascular epiphytes loss in exploited trees of the semi deciduous managed forest of Ndelele, East Cameroon. J Sustain For 38: 670-685.
Nfornkah BN, Zapfack L, Tchamba M, Chimi CD, Sonke B. 2018. A protocol to estimate epiphyte biomass in a forest management unit: case of Cameroon. J Sustain For 37: 619-631.
Noumi VN, Zapfack L, Sonke B, Achoundong G, Kengne OC. 2010. [Distribution and taxonomic richness of epiphytes of some phorophytes in Korup National Park (Cameroon)]. Int J Environ Stud 67: 51-61. French.
Patil S, Lavate R, Rawat V, Dongare M. 2016. Diversity and distribution of Pteridophytes from Satara District, Maharashtra (India). Plant Sci Today 3: 149-156.
PPG I. 2016. A community-derived classification for extant lycophytes and ferns. J Syst Evol 54: 563-603.
Sharma UK, Pegu S. 2011. Ethnobotany of religious and supernatural beliefs of the mising tribes of Assam with special reference to the 'Dobur Uie'. J Ethnobiol Ethnomed 7: 16.
Sporn SG, Bos MM, Kessler M, Robbert Gradstein S. 2010. Vertical distribution of epiphytic bryophytes in an Indonesian rainforest. Biodivers Conserv 19: 745-760.
Tardieu-Blot ML. 1964. [Flora of Cameroon: Pteridophyte]. Muséum National d'Histoire Naturelle, Laboratoire de phanérogamie, Paris. French.
Watkins JE, Cardelús C. 2009. Habitat Differentiation of Ferns in a Lowland Tropical Rain Forest. Am Fern J 99: 162-175.
Wolf J, Gradstein S, Nadkarni N. 2009. A protocol for sampling vascular epiphyte richness and abundance. J Trop Ecol 25: 107-121.
WWF. 2007. [The particular responsibility of France in the exploitation and preservation of the tropical forests of the Congo Basin]. WWF-France, Paris, 16 pp. French.
Xiao X, White EP, Hooten MB, Durham SL. 2011. On the use of log-transformation vs. nonlinear regression for analyzing biological power laws. Ecology 92: 1887-1894.
Zapfack L, Engwald S. 2008. Biodiversity and spatial distribution of vascular epiphytes in two biotopes of the Cameroonian

semi-deciduous rain forest. Plant Ecol 195: 117-130.
Zapfack L, Nkongmeneck AB, Villiers JF, Lowman M. 1996. The importance of Pteridophytes in the epiphytic flora of some phorophytes of the Cameroonian semi-deciduous rain forest. Selbyana 17: 76-81.
Zapfack L. 1993. [Epiphytic flora and vegetation of some phorophytes of the semi-deciduous forest, South Cameroon (Doctorate thesis third cycle)]. thesis. Universite de Yaounde I, Yaounde, Cameroun. (in French)
Zhao M, Geekiyanage N, Xu J, Khin MM, Nurdiana DR, Paudel E, Harrison RD. 2015. Structure of the epiphyte community in a tropical montane forest in SW China. PLoS One 10: e0122210.
Zotz G, Bader MY. 2011. Sampling vascular epiphyte diversity - species richness and community structure. Ecotropica 17: 103-112.