academicJournals

Vol. 9(2), pp. 27-44, February 2017
DOI: 10.5897/IJBC2016.0999
Article Number: B31F0A662715
ISSN 2141-243X

http://www.academicjournals.org/IJBC

International Journal of Biodiversity and Conservation

Full Length Research Paper

Diversity of ectomycorrhizal fungal fruit bodies in Comoé National Park, a Biosphere Reserve and World Heritage in Côte d'Ivoire (West Africa)

Linda Patricia Louyounan Vanié-Léabo[1,2]*, Nourou Soulemane Yorou[3], N´Golo Abdoulaye Koné[4], François N'Guessan Kouamé[1,5], André De Kesel[6] and Daouda Koné[1,2]

[1]WASCAL Graduate Study Program (GSP) Climate Change and Biodiversity, University Félix Houphouët-Boigny, B.P. 582 Abidjan 22, Côte d'Ivoire.
[2]Laboratoire de Physiologie Végétale, U.F.R. Biosciences, Université Félix Houphouët-Boigny, Côte d'Ivoire.
[3]Faculty of Agronomy, University of Parakou, BP 123 Parakou, Bénin.
[4] Station de Recherche en Ecologie du Parc National de la Comoé, U.F.R. des Sciences de la Nature, Université Nangui Abrogoua, 28 BP 847 Abidjan 28, Côte d'Ivoire.
[5]Laboratoire de Botanique, U.F.R. Biosciences, Université Félix Houphouët-Boigny, Abidjan, Côte
[6]Botanic Garden Meise, Nieuwelaan 38, B-1860 Meise, Belgium.

Received 1 June, 2016; Accepted 21 December, 2016

The key role of ectomycorrhizal (EcM) fungi in ecosystems functioning has been demonstrated worldwide. However, their diversity, spatial distribution, fruiting phenology and production as influenced by climatic parameters variability remain poorly understood in tropical African forests. Weekly surveys were conducted from April to early October 2014 at the Comoé National Park (CNP), Côte d'Ivoire (West Africa) in 09 permanent plots established in *Isoberlinia doka* (IW), *Uapaca togoensis* (UW) and Mixed (MW) woodlands. Non metric multidimensional scaling (NMDS) of EcM fungi abundance was run to assess the influence of environment tal parameters on fungi distribution using the package VEGAN. Hierarchical clustering based on dissimilarity and indicator species analysis were run to characterize fungi communities. Analyses were computed with the statistical program R. A total of 123 EcM fungi species belonging to 23 genera and 09 families were collected at CNP. Simpson diversity (1-D) and evenness were 0.97 and 0.54, 0.97 and 0.61, 0.96 and 0.52 for IW, MW and UW respectively. Yet, weekly-based species accumulation curves did not reach an asymptote. Stem density of *U. togoensis* Pax (UTDen) and *I. doka* Craib & Stapf were the most important tree parameters influencing EcM fungi distribution (respectively r^2 = 0.92 / p-value = 0.002 and r^2 = 0.83 / p-value = 0.018). Two sites groups were distinguished and four indicators species were identified.

Key words: EcM fungi, fruit bodies, diversity, indicator species.

INTRODUCTION

Productivity, diversity and composition of plant communities have been demonstrated indirectly and directly influenced by belowground micro-organisms from which plant symbionts play a key role (Van Der Heijden

et al., 2008; Van Der Heijden and Horton, 2009). Globally, over 90% of terrestrial plants depend upon an ecological relationship with soil fungi for their growth and regeneration (Smith and Read, 2008; Singh et al., 2011; Dickie et al., 2014). This relationship termed mycorrhiza is the most prevalent symbiosis on Earth, including cultivated plants, herbaceous species and forest trees. Generally, autotrophic plants provide carbohydrates to their fungi partners, which in turn improve host performance by enhancing mineral nutrient uptake from soil, especially nitrogen (N) and phosphorus (P). Symbiotic fungi enhance plant tolerance to environmental stress caused by low soil water potential, toxic heavy metals, salinity, herbivores and root pathogens (Smith and Read, 2008; Singh et al., 2011; Dickie et al., 2014). Among mycorrhizas types, ectomycorrhiza (EcM) is the most advanced one (Moore et al., 2011) involving mostly higher plants and fungi (Piepenbring, 2015). Thus, EcM fungi have an important position in the plant-soil interface (Ceulemans et al., 1999) worldwide, playing a key role in the growth and regeneration of forest trees, and in ecosystems functioning.

However, the global biodiversity is under decline since the 19th century due to serious climate, environmental and ecological changes through human activities around the globe. The global climate system is actually modified by increased greenhouse gases (GHG) in the atmosphere subsequently to unrestrained deforestation, fossil fuel combustion and other anthropogenic activities (WMO, 2007). Few key parameters of global change are among other trend towards warming (increasing temperature), increase of atmospheric CO_2 and disturbance in the distribution, seasonality and amount of rainfalls. It is predicted that Earth surface temperature will increase from 0.3°C to 1.7°C under scenario RCP2.6 by the end of the 21st century (2081–2100) whilst the atmospheric carbon level is continuously increasing (IPCC, 2014). Though the impact of global change on ecosystems is not yet adequately addressed, it is expected that many changes in global biodiversity and ecosystem functions will occur. High temperature is expected to alter tree phenology, plant growth and distribution toward migration and adaptation ecozones (Montoya and Raffaelli, 2010) but also to increase the length of the growing season (Walther et al., 2002; Morin et al., 2007), and the aboveground growth and reproductive effort of plants (Hollister et al., 2005). At the other side, elevated atmospheric CO_2 and nitrogen will likely increase the rate of net photosynthesis by 40 to 80% (Körner et al., 2005), the allocation of carbon to the plant roots (Janssens et al., 2005) and the production of leaves, wood and coarse roots (Hyvönen et al., 2007). It is actually difficult to predict the exact response of plant diversity to climate change as many investigations are still needed to understand the resilience, adaptation and/or migration following fluctuation of climatic parameters.

As both partners are living more or less obligatory and intimately, any possible change that affect host plants is also expected to influence the symbiotic fungi. In temperate and boreal zone, rainfall and moisture availability have been demonstrated as critical to EcM fruiting and natural production (O'Dell et al., 2000; Gange et al., 2007; Kauserud et al., 2010). Furthermore, long term observations of fungal phenology in temperate forests reveal that fruit bodies production and temporal changes are strongly influenced by either increasing temperature (Kauserud et al., 2008; Kauserud et al., 2010) and/or rainfalls (Krebs et al., 2008). Due to their vital role in forest ecosystems and the sensitivity of their respiration to high temperature and strong seasonality (Vargas et al., 2010; Bahram et al., 2012), EcM fungi represent best candidates to investigate for a better understanding of ecosystems response to global warming and especially in carbon sequestration capability (Simard and Austin, 2010; Orwin et al., 2011; Büntgen et al., 2012; Büntgen et al., 2013; Boddy et al., 2014). Unfortunately, the response of EcM communities to global warming and environmental changes is scarcely addressed in tropical zones and especially in tropical. In Sudanian woodlands of Africa, a strong variability has been noticed regarding species richness and community structure throughout the fruiting season (Yorou et al., 2001). Nevertheless, the authors failed to link species composition, community structure and productivity patterns of EcM with either the local temperature or soil humidity. To our knowledge, that study is the only one in tropical Africa addressing the impact of climate parameters on wild EcM fungi phenology and productions. Now, knowing temporal change in the phenology and production distribution, and their determinants is essential in the valorisation of natural productions of wild edible EcM fungi that amounts to thousand tons annually and involves many rural women (Yorou et al., 2001, 2014; Boa, 2004). However, a prerequisite to climate impact assessment is the analysis of EcM fungi diversity and the evaluation of possible other natural underlying mechanisms of richness pattern (Tedersoo and Nara, 2010). It has been demonstrated that the impacts of atmospheric carbon dioxide enrichment is more clear on fruit bodies than on below-ground tips (Andrew and Lilleskov, 2009; Pickles et al., 2012). Therefore, this study aims to (1) assess the diversity (species richness and community structure) of

*Corresponding author. E-mail: lindaleabo@hotmail.fr

EcM fungi species through fruit bodies diversity and (2) assess the spatial variability of the community composition following habitat characteristics (plant and soil parameters) at local scale. We hypothesised that (1) African protected areas harbour a great diversity of EcM fungi with many species likely new to sciences, and (2) host plants and soil structural parameters drive the communities of EcM fungi.

MATERIALS AND METHODS

Study site

The Comoé National Park (CNP) is located in the North-East of Côte d'Ivoire (8°32' - 9°32'N, 3°01' - 4°24'W) between the towns of Bouna and Dabakala, and south of the border with Burkina Faso. The CNP covers about 11 500 km² (Hennenberg, 2004) and is presently one of the largest national park in West Africa (Poilecot et al., 1991). Initially erected as a game park since 1926 ('Refuge Nord de la Côte d'Ivoire') and then established as national park in 1968, Comoé was approved in 1983 and declared as Biosphere Reserve and World Nature Heritage by the UNESCO (Hennenberg, 2004).

The park is located on the large granite stand of West Africa and is characterized by a smooth and level relief. Soils are impoverished sandy to loamy ferralsols above Precambrian granites with small areas of lateritic crusts or banks outcrop at some places (Hennenberg et al., 2005). The climate is a Guineo-Congolian/Sudanian transitional type, a sub-humid tropical climate (Chidumayo et al., 2010) with mean annual rainfall of 1 011 mm falling mainly between March and October. The mean annual temperature is 26.5 to 27°C (Koulibaly, 2008). CNP vegetation is transitional ranging from forests to savannas including riparian grasslands (Poilecot et al., 1991; Hennenberg et al., 2005).

Selection of habitat types and establishment of permanent plots

One-week exploratory survey was undertaken within the accessible parts of the park in November 2013 to identify appropriate study sites. Based on available vegetation maps (Poilecot et al., 1991; Lauginie, 2007), three habitat types were selected with regard to; (1) The presence and abundance of known EcM partners trees, members of Caesalpiniaceae and Phyllantaceae (to ensure collection of symbiotic fungi and assess partners influence on fungal species distribution) and (2) the distance to the Ecological Research Station of Comoé, our base camp (for rapid handling of fragile specimens during hot and wet season).

The different habitat types were at least 300 m away from one another and included:

Habitat type 1: *Isoberlinia doka* Craib & Stapf Woodland (IW);
Habitat type 2: Mixed Woodland (MW);
Habitat type 3: *Uapaca togoensis* Pax Woodland (UW).

In each selected habitat type, three permanent plots of 30 m × 30 m each have been established by mean of a hectometer, making a total of nine plots (Figure 1). They have been labelled *FiPi* with *Fi* representing the habitat type and *Pi* the plot. All nine (09) plots have been geo-referenced by recording the coordinates of each corner with a GPS Garmin GPSMAP® 62stc (Garmin International Inc., Olathe, KS, USA). Plots within a habitat type were spaced at least by 10 m one another, according to tree partners' presence and density (Table 1).

EcM fungal fruit bodies collect and handling

EcM fungal fruit bodies (EFFB) were collected in each plot following parallel bands of 2 m large. To avoid missing short living species, each plot was visited once a week from April to early October 2014 as implemented by Yorou et al. (2001). We recorded the nearest EcM partner trees to each sampled fruit body and geographic coordinates using GPS Garmin GPSMAP® 62stc (Garmin International Inc., Olathe, KS, USA). To facilitate future comparison and morphological identification of species, technical photographs of most representative fruit bodies per species (at different development stage, when applicable) were taken on field and at the base camp using a Canon EOS 1000D digital cameras. Fresh macroscopic features were then recorded from specimens, using standardized descriptions sheets (size, shape; colour and any change with time; presence/absence of ephemeral structures; type of hymenophore, its colour and organization; etc.) developed for tropical African fungi (De Kesel et al., 2002; Eyi Ndong et al., 2011). Afterwards, Fruit bodies per collection were counted, weighted, labelled and representative specimens were dried at 40°C for 24 h. Labelled collections were conserved with basic ecological data (habitat type, substrate, putative nearest partner tree, exposition to sun, etc.) as herbarium materiel at the WASCAL GSP Climate Change and Biodiversity, University Felix Houphouet-Boigny (Côte d'Ivoire).

The identification of collected fungal species was performed based on morphological features at Botanic Garden of Munich in Germany and Botanic Garden Meise in Belgium by experts (De Kesel and Yorou, personal communications). Appropriate keys and numerous illustrated monographs on fungi of Central and Western Africa (series of "Flore Iconographique des Champignons du Congo" and "Flore illustrée des Champignons d'Afrique Centrale") were used. These series include monographs on *Amanita* spp. (Beeli, 1935), *Boletineae* and *Cantharellus* spp. (Heinemann, 1954, 1959, 1966), *Scleroderma* spp.(Dissing and Lange, 1963) and *Russula* spp. (Buyck, 1993, 1994, 1997) and Lactarius spp. (Heim, 1955). An additional monograph on *Lactarius* spp. (Verbeken and Walleyn, 2010) was also used. Species names and nomenclatural aspects were checked in index fungorium (http://www.indexfungorum.org/Names/Names.asp). Moreover, molecular-based identification of representative specimens per species was performed (Gardes and Bruns, 1993; Maba et al., 2013) at both abovementioned research institutes. Results of molecular analysis along with metabarcoding analyses of composite soil samples (for belowground fungi diversity assessment) will be presented in a manuscript in preparation.

Habitat types characterisation

Biotic and abiotic variables were collected to assess their possible influence on EFFB occurrence and spatial distribution.

First, systematic inventory of plant species and total canopy cover estimation within plots were performed in April 2014 according to the phytosociological method (Braun-Blanquet, 1932). Primary identification of plants specimens were done with field guide (Arbonnier, 2004) and completed with collected herbarium materials by experts from the Laboratoire de Botanique of the University Felix Houphouet-Boigny in Abidjan, Côte d'Ivoire. However, for statistical analyses, only woody species with diameter at breast height (dbh) equal or above (≥) 10 cm were considered. Therefore, in addition to plant species richness, structural parameters (number of stems and dbh per species and per plot) were recorded.

Second, soil cores were collected with a 10 cm × 10 cm - 10 cm depth auger at each corner and the center of each plot at mid-rainy season (late July). All five cores were mixed to make a composite soil which was air-dried and passed through a 2-mm sieve. Three

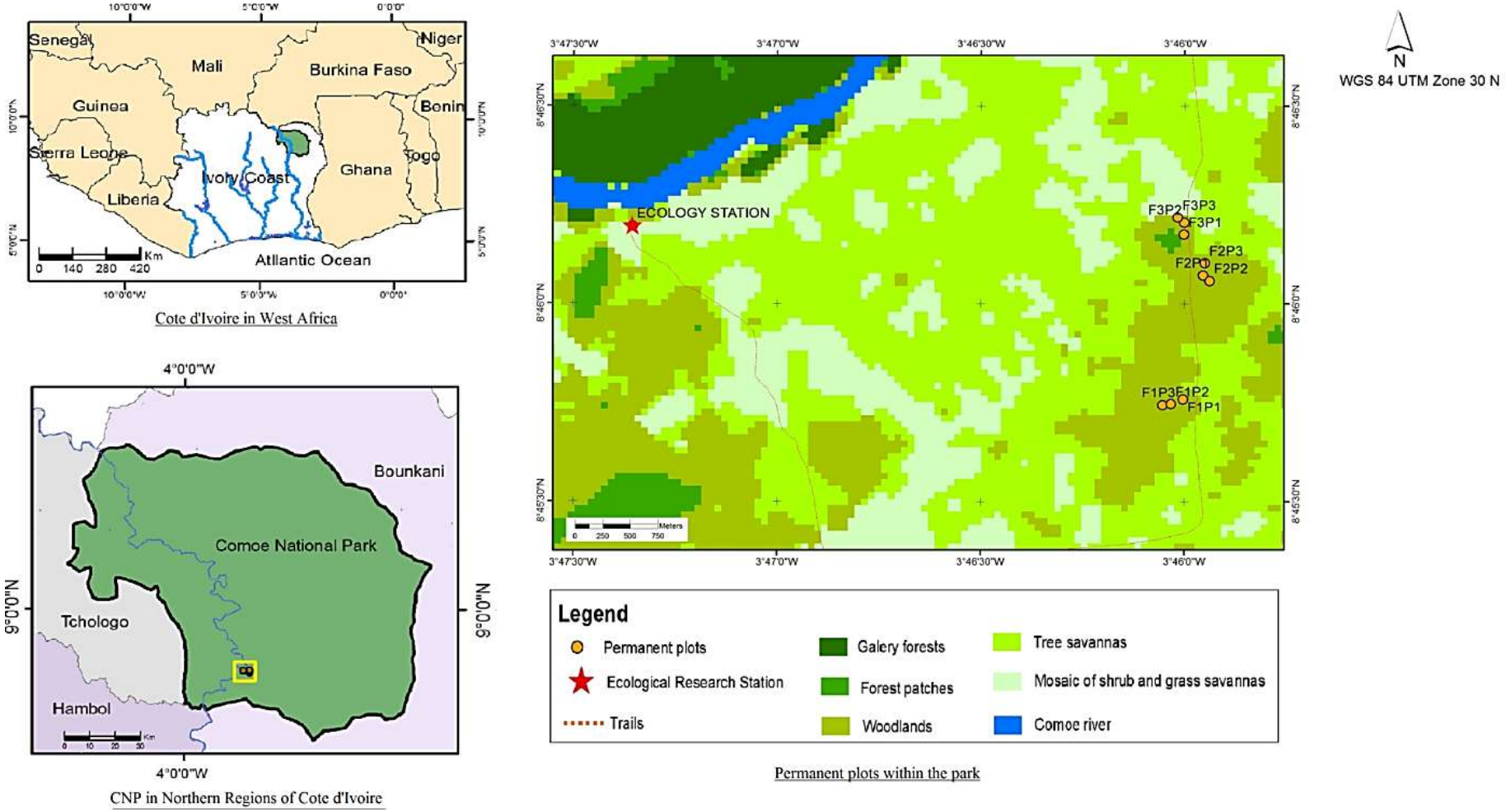

Figure 1. Location of Comoé National Park (north east of Côte d'Ivoire) and established permanent plots within it (south west of the reserve).

composite soils were thus made per habitat and 200 g per sample were used to assess soil granulometry, pH and minerals contents. Chemical parameters assessed were pH (H_2O), Carbon (C), Nitrogen (N), soil organic carbon (SOC), ratio C/N, Total Phosphorus (TotalP), Available Phosphorus (AvailP), Calcium (Ca) and Potassium (K). Physical parameters referred to soil texture: Clay, fine and coarse Silt, fine and coarse Sand. They were determined as follows:

1. pH (H_2O) measurement was performed with a soil solution at a ratio 2/5 (Duchaufour and Blum, 1997).

2. Determination of extractable cations' content was achieved according to standard NFX 31-130 (AFNOR, 1999).

3. Determination of organic and total carbon: The total carbon content in soil is determined after dry combustion. The soil's organic carbon content is calculated

Table 1. Positions of permanent plots within habitat types in Comoé National Park (CNP), Cote d'Ivoire

Habitat type	*Isoberlinia* Woodland			Mixed Woodland			*Uapaca* Woodland		
Plot	F1P1	F1P2	F1P3	F2P1	F2P2	F2P3	F3P1	F3P2	F3P3
Latitude (dd)	8.76264	8.762447	8.762408	8.767876	8.7676	8.768387	8.769594	8.770105	8.7703
Longitude (dd)	-3.7667	-3.76719	-3.76754	-3.76588	-3.766	-3.76581	-3.76668	-3.76665	-3.767
Altitude (m)	235.13	233.17	232.64	230.40	230.79	248.19	216.23	213.81	213.62

dd: decimal degrees; m: meters

according to the method NF ISO 10694 (AFNOR, 1995).
4. Particle size determination by sedimentation - the pipette method following the standard method NF X 31-107 (AFNOR, 2003).

Data analysis

EcM fungal fruiting bodies diversity assessment

Basic estimators and indices were calculated to assess the diversity of fungi species as reflected by EFFB at plot and habitat type level. They included also similarity between plots and habitat types as well as the number of shared species to compare communities.

Observed species richness and diversity assessment

Presence/absence data of EFFB was used to determine (1) the observed species richness (SR: number of species) and composition (SC: list of species) per habitat type; (2) the total observed species richness and composition as cumulative data of all habitat types. Thereby, the frequency of occurrence (percentage of total weeks during which a species was recruited) of fungal species was used to highlight the contribution of each species in the community (Horton and Bruns, 2001). The relative frequency of each species was calculated as the percentage of total frequency.

Assessment of fungi diversity and evenness of frequency of species within habitat types was achieved respectively by computing Simpson's Index of Diversity (1 – D) and Simpson' Evenness with the program Ecological Methodology (Krebs and Kenney, 2002). Simpson's Index of Diversity (1 – D) refers to the probability that two individuals randomly selected from a sample will belong to different species. Its value ranges between 0 and 1, greater value corresponding to high diversity).

Sampling representativeness: Species accumulation curves and similarity assessment

Sample-based species accumulation curves were constructed in EstimateS ver. 9.1.0 (Colwell, 2013) using presence/absence (incidence) data. The sample order was randomized 500 times without replacement for the statistical representation of the EcM fungi community. In this study, "***sample***" referred to frequency of survey, a week-interval, against which Observed and Estimated Chao 2 species accumulation curves were plotted.

The similarity of our sampling to the fungi community was estimated by measuring the autosimilarity (Cao et al., 2002) between plots of each habitat type. This was calculated as mean Jaccard coefficient computed with EstimateS ver. 9.1.0 software. Autosimilarity index varies from 0 (no species common to plots) to 1 (same species composition in plots). Constructed week-based species accumulation curves, Simpson's Index of Diversity (1 – D) and Simpson's evenness along with autosimilarity index served to assess the sampling representativeness of fungal communities of study sites.

Habitat characterisation

Floristic richness and dendometric parameters assessment: Number of stems and dbh per species underwent basic statistical analyses as follows:

1. Plant species density (D_i), the number of stems per species per plot surface in square meters (m^2), converted later in hectares (ha);
2. Individual stem basal area (BA_i). $BA_i = \pi \times 10^{-4} \times (dbh_i/2)^2$, where tree dbh in cm and BA_i in m^2. This formula is simplified as: $BA_i = 0.00007854 \times (dbh)^2$;
3. Species basal area (BA_{sp}) that equals to the sum of all BA_i of stems of the same plant species within a plot, converted later in hectares (ha);
4. Total basal area (TBA), summing up the all calculated BA_{sp} within a plot;
5. Species relative dominance (SRD): $SRD\% = \left(BA_{sp}/TBA\right) \times 100$.

Soil chemical and physical analysis

Soil parameters evaluation was performed according to standard method as follows:

1. Determination of pH (H_20) and content of extractable cations (Ca^{2+}, K^+ , NH_4^+) was performed by reading directly the digital display of the pHmeter or spectrophotometer;
2. Determination of organic and total carbon: $M.org = 1.724 \times C.org$. with M.org = organic matter (mg / kg); C.org = organic carbon (mg/kg)
3. Particle size determination by sedimentation using the pipette method. Content of different fractions was determined as follows:

$$C + St\% = [(Pc + s) - (p1) - (Pb)] \times 5000 \times k/Pe \times Fh \quad (1)$$

$$C\% = [(Pa) - (P1) - (Pb)] \times 5000 \times k/Pe \times Fh \quad (2)$$

$$FSt\% = (C + St)\% - C\% \quad (3)$$

$$TSd\% = (Tt - P1) \times 100/Pe \times Fh \quad (4)$$

$$CSd\% = (Tc - P1) \times 100/Pe \times Fh \quad (5)$$

$$FSd\% = (Tf - P1) \times (100/Pe) \times Fh \quad (6)$$

$$CSt\% = TSd \times (CSd + FSd) \times Fh \quad (7)$$

With C = clay; P_{C+St} = T are weight + clay + silt; St = silt; P1 = weight of empty tare (capsule); FSt = fine silt;P2 = Weight of empty tare + white; TSd = total sand; $Pb = P2 - P1$; CSd = coarse sand; $k = 20N/V$; FSd = fine sand; V = volume of the pipette; CSt = coarse silt; Pe = aliquot intake; Tt = cap weight + the total sand;

Table 2. Richness of EcM fungi within selected habitat types

Fungi parameters	*Isoberlinia* Woodland (IW)	Mixed Woodland (MW)	*Uapaca* Woodland (UW)	Total
Numbers of fruit bodies	1565	513	736	2814
Numbers of species	75	65	56	123
Numbers of genus	21	15	16	23
Numbers of family	9	6	6	9

Fh = humidity factor; Tc = cap weight + coarse sand; Pc = cap weight + clay; Tf = cap weight + fine sand.

The texture of each soil was determined using TRIANGLE, A Program For Soil Textural Classification (Gerakis and Baer, 1999). That texture determination followed percentage of particles within studied soils.

Gradients effectiveness

Analysis of variance (Anova) test at $\alpha < 0.05$ was performed to assess the effectiveness of gradient among soil and plant data. It was performed at habitat type level for both variables using package lawstat of R software (Hui et al., 2008). When requirement of distribution and homogeneity of variance were not met, Kruskal-Wallis test (Kruskal and Wallis, 1952) was performed in R software. Afterward, significant gradient (s) underwent a preliminary analysis to check collinearity between them and clarify the ordination. One variable among all highly collinear ones was conserved in the subset of the ordination. That preliminary analysis has been performed with software Statistica 7.1 (StatSoft France, 2006).

Ectomycorrhizal fungi fruit bodies spatial distribution

To visualize the spatial distribution of EFFB, non-metric multidimensional scaling NMDS ordination was performed based on a matrix of fungi species relative frequency per plot using function *metaMDS* of package Vegan (Oksanen et al., 2015) of R software version 3.3.0 (2016-05-03). Fungi relative frequencies were first transformed by Wisconsin double standardization using function *Wisconsin* to improve ordination. A distance matrix generated by Bray-Curtis dissimilarity index with function *vegdist* was used as input for the NMDS whilst function *metaMDS* used Jaccard index.

Then, main environment variables (host communities and soil parameters) influencing the fungi communities structure were evidenced by fitting them the ordination plot using function *envfit* of the Vegan package. Statistical significance was based on 999 random permutations and plotting was limited to most significant variables with argument *p.max* set at 0.1.

To better visualize the similarity of habitat types, a hierarchical clustering based on Bray-Curtis dissimilarity index was conducted in R software version 3.3.0 (2016-05-03) using function *hclust* and average-linkage. Subsequently, each fungi community was characterized by conducting indicator species analysis using the MULTIPATT function in the R package Indicspecies (De Cáceres and Legendre, 2009; De Cáceres and Jansen, 2015). Indicator Value (IndVal) index (Dufrêne and Legendre, 1997) was computed to measure the association between a species and a site group. Statistical significance of association was tested by running 999 random permutations. In addition, the specificity (the so-called IndVal Component A) and the fidelity (second component B of IndVal) of a species as indicator of a target site group were inspected. Component A or specificity refers to "the probability that the surveyed site belongs to the target site group given the fact that the species has been found" whilst component B refers to "the probability of finding the species in sites belonging to the site group" according to Dufrêne and Legendre (1997) and De Cáceres and Legendre (2009). Final, ecological distance between generated site groups was calculated by Jaccard index using the R package Fossil (Vavrek, 2011).

RESULTS

EcM fungi diversity

Observed species richness and diversity indices

EcM fungal fruiting started in mid-May and was still continuing in early October making a cumulative total of 21 weeks of occurrence. In total 2814 fruit bodies have been collected and were sorted into 123 species belonging to 23 genera and 09 families (Table 2). The most frequently recorded family was Russulaceae with 53 species composed of 36 *Russula* species, 11 *Lactifluus* species and 6 *Lactarius* species. The second frequently observed family was Boletaceae represented by 13 genera with a total of 32 species. The Amanitaceae ranked third most important recorded family with a total of 26 species. The less recorded other families included Cantharellaceae, Cortinariaceae, Gyroporaceae, Inocybaceae, Sclerodermataceae and Clavulinaceae. These families were represented each by only one genus with respectively 1, 3, 1, 1, 5 and 1 species (Figure 2). From the total species richness, 57 taxa (46.34% of the total) were identified up to species level with 19 of them being related to known species from temperate and tropical zones. The remaining 66 species (53.66% of the total) were identified only at the genus level with some of them suspected new to science (Supplementary Table 1).

The most frequent species per habitat type included *Russula congoana* Pat. (13 weeks corresponding to the relative frequency of 2.53%), *Amanita aff. craseoderma* (11 weeks, relative frequency = 2.14%) and *Lactarius tenellus* Verbeken & Walleyn (10 weeks, relative frequency = 1.95%) in IW; *Amanita annulatovaginata sensu lato* Beeli and *Lactarius tenellus* (both with 8 weeks, relative frequency = 1.56%) in MW; *Cantharellus addaiensis* Henn. and *Amanita aff. subviscosa* Beeli (both with 11 weeks, relative frequency = 2.14%), *Amanita aff virosa* and *Amanita strobilaceovolvata sensu lato* Beeli (both in 10 weeks, relative frequency = 1.95%) in UW.

22 species were found common to the three habitat

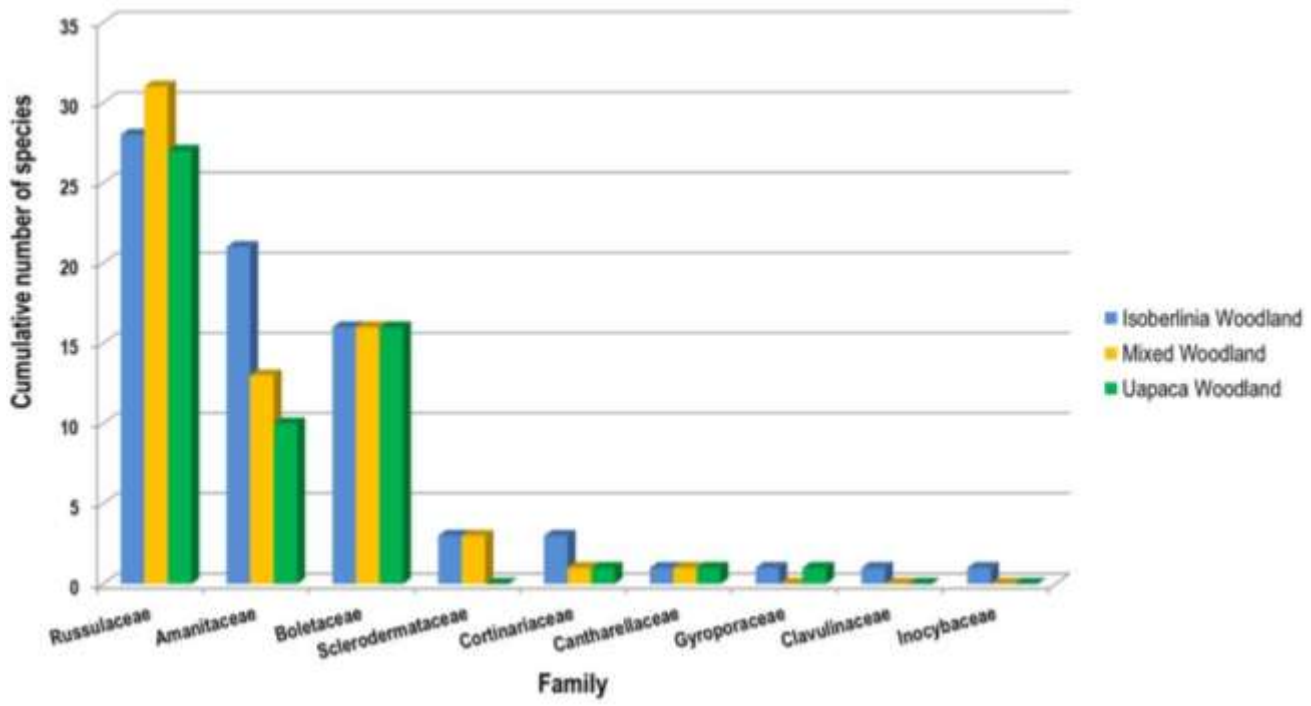

Figure 2. Families representativeness per habitat type.

types and represented 17.89% of total observed species richness (Supplementary Table 1). On the other hand, 72 species accounting for 58.53% of the species richness were specific to one habitat type. Many of these specific species were observed and collected only once from May to early October 2014 (Supplementary Table 1) and are uniques species. Specific species such *Inocybe* sp 1 and *Cortinarius* subgenus *telamonia* sp 1 have been picked under *Isoberlinia doka* trees in IW. Meanwhile, *Russula annulata* R. Heim, *R. discopus* R. Heim (a rare species) and *Veloporphyrellus africanus* Watling were collected beneath *Uapaca togoensis.* Final, 29 species (23.58%) were shared by two habitat types. In addition with species common to all habitat types, 38 species were shared by IW and MW (e.g. *Amanita afrospinosa* Pegler & Shah-Smith*, Lactarius saponaceus* Verbeken); 28 species shared by IW and UW (e.g. *Gyroporus castaneus* (Bull.) Quél*., Amanita strobilaceovolvata* sensu lato) and 29 species shared by MW and UW (e.g. *Amanita aff. rubescens* Pers*., Boletus loosii* Heinem).

Similarity and sampling representativeness

Computed Simpson's Index of Diversity 1 – D of IW was 0.97 with an autosimilarity index calculated to 0.40. Therefore, plots in IW were found non-similar likewise for, plots within habitat types MW and UW with respectively0.33 and 0.29. In those latter habitat types, higher diversity indices were respectively 0.97 and 0.96.

Weekly-based species accumulation curves of the different habitat types have almost the same shape in observed and estimated species richness (Figure 3). Accumulation curves of IW were generally above those of the other habitat types through weeks except for the estimated species richness where curve of MW outdid the other curves from the fourteenth week till the end of the survey. Globally, all curves were ascendant and did not reach an asymptote of total richness.

Sample coverage highlighted the percentage of species detected by our study on the overall estimated species richness. Thus, 75.25% of species was detected in IW against 81.88% in MW and 58.78% in UW (Table 3). Furthermore, 38, 32 and 36 unique species have been collected in the different habitat types respectively.

Habitats characterisation

Floristic and dendrometric parameters

A cumulative number of 822 stems belonging to 49 woody species with dbh ≥ 10 cm were detected for all habitat types. Those species belonged at least to 20 families, knowing that 6 species identity was undetermined. 18, 19 and 31 species were inventoried respectively in IW, MW and UW. The total density and basal area of all tree species, and the dendrometric parameters (density and SRD) of cores EcM forest trees in each plots is provided in Table 4.

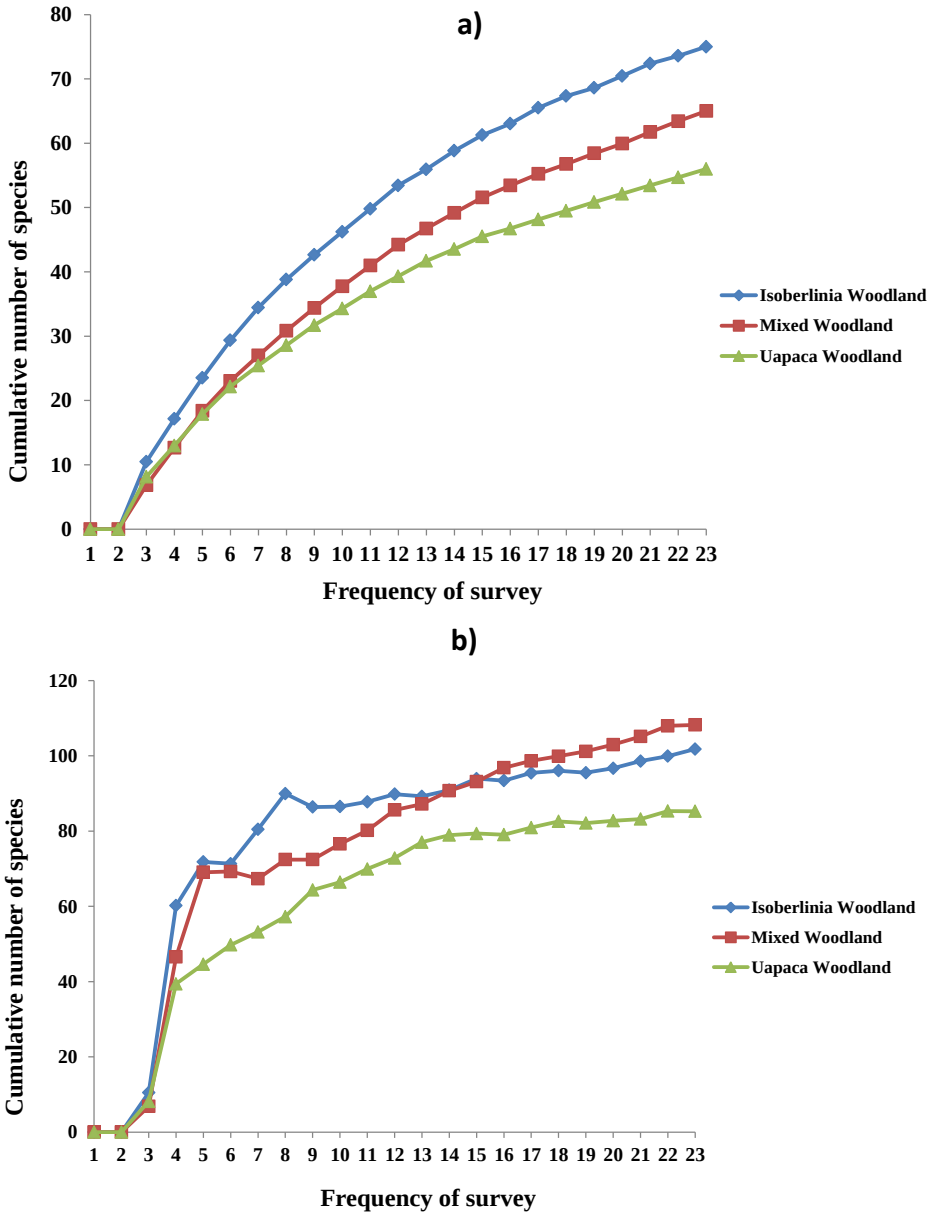

Figure 3. Week-based accumulation curves of observed (a) and estimated (b) species richness of EcM fungi during fruiting season 2014 (mid-May to early-October). Aug. = August, Sept.= September, Oct.= October.

Table 3. Sampling representativeness estimators. Sample coverage: proportion of observed species richness (S_{obs}) as per cent of estimated species richness (S_{est}); Auto-similarity: mean similarity between plots of the same habitat type; Uniques: number of species collected only once during the whole period

Habitat type	Number of fruit bodies	Observed species richness S_{obs}	Estimated species richness Chao 2 (S_{est})	Sample coverage	Autosimilarity	Simpson's Index of Diversity 1- D	Simpson's Evenness	Uniques
Isoberlinia Woodland	1542	75	99.67	75.25	0.49	0.77	0.06	38
Mixed Woodland	502	65	79.38	81.88	0.41	0.94	0.25	32
Uapaca Woodland	775	56	95.27	58.78	0.36	0.91	0.19	36

Table 4. Mean values of density of woody species, Species relative dominance (SRD) of identified EcM trees and total basal area per habitat.

Plant parameters		*Isoberlinia* Woodland	Mixed Woodland	*Uapaca* Woodland
Cumulative number of stems (three plots)		276	246	300
Forest tree species richness SR		18	19	31
Total tree density TD (stem/ha)		3066.66	2733.33	3333.33
Total basal area TBA (m^2/ha)		179.75	158.43	186.89
Mean canopy cover		66.67	73.33	80
EcM tree partners density(stem/ha)	*Isoberlinia doka*	171.11	5.56	0.00
	Monotes kerstingii	35.56	18.89	23.33
	Uapaca togoensis	10.00	167.78	153.33
EcM tree partners SRD (%)	*Isoberlinia doka*	62.29	3.68	0.00
	Monotes kerstingii	10.28	4.13	6.57
	Uapaca togoensis	0.99	53.48	40.50

Table 5. Soil chemical and physical parameters variations per habitat type.

Soil parameters	Habitat type			F	Chi-square	Df	p-value
	IW	MW	UW				
pH	6.7 ±0.14	6.52±0.4	6.78±0.2		2.0392	2	0.36
Carbon (%)	1.96±0.09	1.85±0.15	1.71±0.13		4.3922	2	0.11
Nitrogen (%)	0.09±0.05	0.09±0.01	0.12±0.02	0.495		2	0.63
Available Phosphorus (ppm)	1.34±0.32	1.63±0.12	1.20±0.12		3.5862	2	0.17
Calcium (cmol/kg)	1.71±0.42	1.45±0.31	1.07±0.17	3.078		2	0.12
Potassium (cmol/kg)	0.06±0.04	0.09±0.03	0.07±0.03	0.936		2	0.44
Clay (%)	8.67±2.08	10±2.64	9.33±0.58		0.85797	2	0.65
FineSilt (%)	9.33±3.51	5±0.00	8.66±3.05		5.7275	2	0.06
CoarSilt (%)	44.33±12.1	42.66±3.05	45.67±5.86		0.29132	2	0.86
FineSand (%)	34.33±8.14	37±2.64	33.67±3.79		1.1954	2	0.55
Type of soil	Silt loam	Silt loam	Silt loam				

Kruskal-Wallis test demonstrated that plant richness and total basal area did not differed significantly from one another habitat type (chi-squared = 1.55, p-value = 0.46 and chi-squared = 0.62, p-value = 0.73, respectively). Considering EcM tree partners, density and SRD of *I. doka* differed significantly between habitat types (chi-squared = 6.72; p-value = 0.03), IW harboring the highest values. Density and SRD of *U. togoensis* were also significant (F = 20.73, p-value = 0.002 and chi-squared = 5.95, p-value = 0.05 respectively), decreasing from MW to UW and finally IW. At the opposite, the density and SRD of *Monotes kerstingii* does not significantly differed from one another habitat type (chi-squared = 0.62, p-value= 0.73 and chi-squared = 2.51; p-value= 0.28 respectively).

Soil chemical and physical parameters

pH (H_2O) measurement indicated that soils in all plots were generally neutral, ranging from 6.52 to 6.78. As for texture analysis, soils in plots were generally silt loamy with regard to soil particles size (Table 5). However, differences among both chemical and physical parameters of the different habitat types were not significant at 0.05, pointing out an absence of soil gradient.

Ectomycorrhizal fungi fruit bodies spatial distribution

In absence of soil gradient between habitat types, soil variables were excluded from initial environmental matrix that was finally reduced to 05 plant variables after multicollinearity test. Those variables were plant species richness (PlantSp), total basal area (TBA), *I. doka* density (IDDen), *M. kerstingii* Density (MKDen) and *U. togoensis* Density (UTDen).

Environment variables fitting into NMDS result indicated that *I. doka* Density (IDDen) and *U. togoensis*

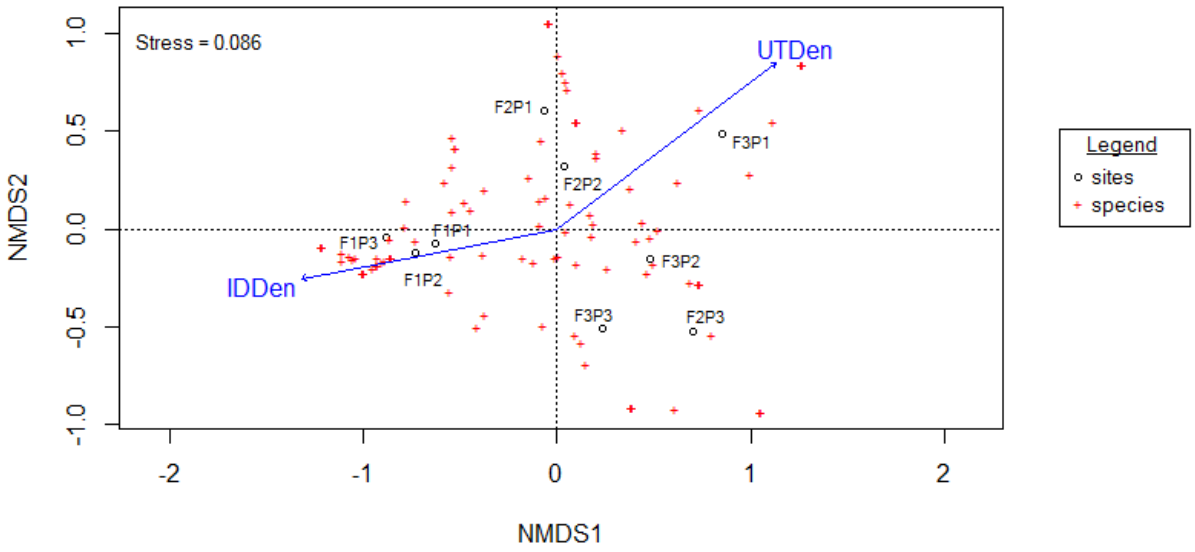

Figure 4. EcM fungi distribution at Comoé National Park according to stem density of *Uapaca togoensis* and *Isoberlinia doka.*

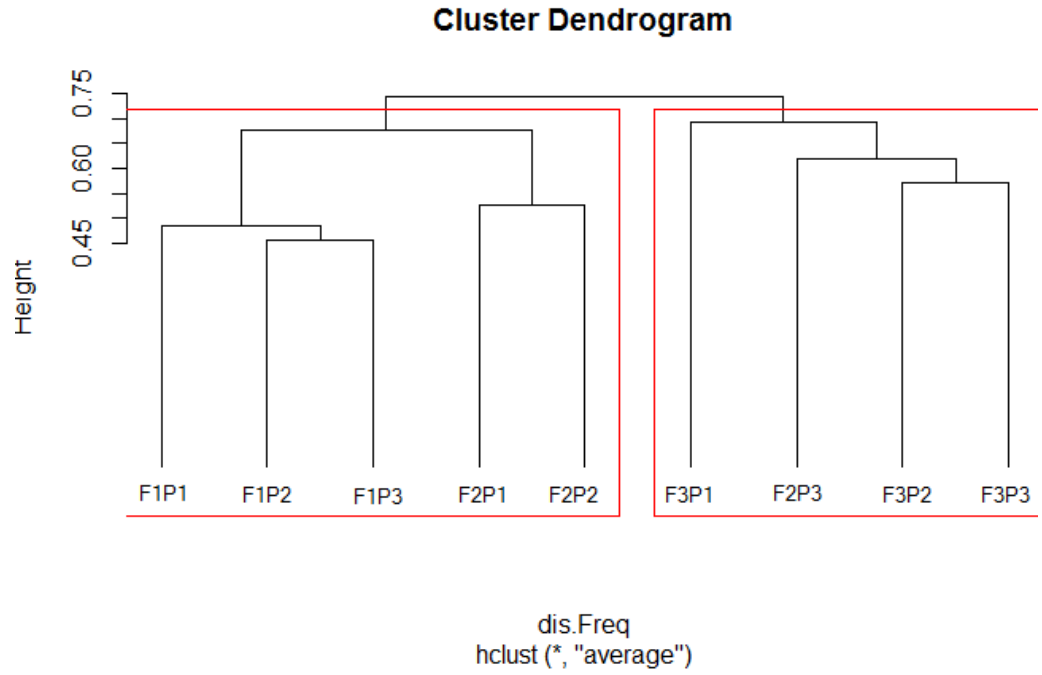

Figure 5. Hierarchical clustering of permanent plots based of dissimilarity.

density (UTDen) are the main statistically significant variables driving the EFFB spatial distribution (Figure 4). UTDen was positively correlated with both axes (r^2 = 0.92; p-value = 0.002) whilst IDDen was negatively correlated to the first axis only (r^2 = 0.83; p-value = 0.018).

Hierarchical analysis of study sites evidenced two sites groups (Figure 5). The first group (G1) encompassed all plots of habitat 1 (Isoberlinia woodland IW) and the two first plots of the second habitat, Mixed woodland (MW). The second group is composed of the remaining plot of habitat 2 (MW) and all plots of the third habitat Uapaca Woodland (UW). The indicator species analysis showed that 04 species were significantly associated to just one group on a total of 123 species. 03 species were associated to G1 and 01 species to G2 (Table 6).

Table 6. List of indicator species associated to each site group.

Site group	Component A	Component B	Stat	p.value
Group 1 #sps. 3				
RusCon	0.9573	1.0000	0.978	0.013 *
Pulve1	0.9057	1.0000	0.952	0.028 *
AmaXa	0.8276	1.0000	0.910	0.040 *
Group 2 #sps. 1				
AcfVir	1	1	1	0.013 *

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 RusCon: *Russula congoana*; Pulve1: *Pulveroboletus* sp 1; AmaXa: *Amanita xanthogala;* AcfVir*: A.* cf *virosa*

DISCUSSION

EFFB richness

Mycological monitoring within Comoé National Park (CNP) shed light on very specious habitats where almost all known EFFB families were represented. As already mentioned in various paleo and neotropical regions (Sanon et al., 1997; Riviere et al., 2007; Bâ et al., 2012; Henkel et al., 2012; Onguene and Kuyper, 2012), dominance of Russulaceae and specifically of genus *Russula* was also observed. Among the other frequently recruited families in tropical regions, Cantharellaceae was represented, in prospected habitats, by only one species member of genus *Cantharellus, C. addaiensis.* In the contrary, four *Cantharellus* species (*C. floridulus* Heinem., *C. platyphyllus* Heinem., *C.* cf*. platyphyllus* Heinem. and *Cantharellus* sp.) were reported in traditional systems of fallows dominated by many confirmed EcM tree partners near the city of Korhogo North western part of Côte d'Ivoire (Ducousso et al., 1999). This difference may be due to higher number of tree partners in that area, namely *Afzelia Africana* Sm. ex Pers*., Anthonotha crassifolia* (Baill.) J. Léonard, *Berlinia grandiflora* (Vahl) Hutch. & Dalziel, *I. doka* and *U. togoensis*. Likewise in genus *Clavulina,* only one species was detected in *Isoberlinia* woodland (IW) suggesting that other species may have been overlooked or mistook for saprotrophic species. Few species belonging to genera *Inocybe* and *Cortinarius* were also found in CNP. This supports the trend observed in other tropical regions (Onguene and Kuyper, 2002; Riviere et al., 2007; Onguene and Kuyper, 2012), and strengthens the idea that those species might be adapted to temperate and boreal zones (Buyck et al., 1996). However, the paucity of studies in tropical woodlands and forests comparative to temperate and boreal ones should be considered. Yet, the abundance of EcM fungi species was highlighted at continental level. In West Africa, Sanon et al (1997) found 37 EcM fungi during rainy season 1994 and 1995 in savanna and open riparian forests in southwestern Burkina Faso. 126 EcM species were censured after various surveys in different areas of Benin, ranging from protected areas to farms (Yorou, 2010). In Southern Guinea rainforests, Diédhiou et al. (2010) identified 39 EcM fungal taxa. In central Africa, Onguene et al (2012) reported the collect of 100 EcM fungi in forest habitats of South Cameroon during a three-year survey. Numerous species have been also collected in Congo and are documented in two series, "Flore Iconographique des Champignons du Congo" and "Flore illustrée des Champignons d'Afrique Centrale". Highest species richness and number of EFFB were found in IW. According to Nara et al., 2003, such values reflected host development stage. Indeed, highest cumulative values of tree partners' stems density and basal area were found in plots of IW. Some of those tree species were estimated aging more than 200 years with regard to their dbh (Tedersoo, personal communication). In disturbed areas of tropical zones, EcM Fabaceae and Dipterocarpaceae stands (I. doka and M. kerstingii respectively in our case) are considered climax stands which establishment is facilitated by Uapaca spp. (Lawton, 1978; Högberg and Piearce, 1986; Onguene, 2000; McGuire, 2007; Tedersoo et al., 2011; Onguene and Kuyper, 2012). According to Poilecot et al. (1991), CNP is included of 93.3 % of fire climax vegetation from which 6.7 % is made of woodlands. Indeed, understorey vegetation in IW and MW were burned either totally or partially according to plot by the annual fire that passed in December 2013, four months before our arrival at the park. However, no plot in UW was burnt. Moreover, EcM fungi species belonging to genus Scleroderma previously described as characteristic of disturbed and elevated soil temperature areas (Ingleby et al., 1985; Nara et al., 2003) were collected within burnt plots of IW and MW. Three of the five Scleroderma species were recruited in IW and the latter two in MW. Consequently, IW is likely older than the others whilst UW is the youngest and MW at an intermediate stage. This assumption is strengthened by the different proportions of U. togoensis and presence/absence of I. doka in the different habitats. First, IW harboured many stems of the EcM tree partners Monotes kerstingii Gilg and Uapaca togoensis but it is dominated by Isoberlinia doka. Second, few stems of I. doka were censured in MW whilst the tree species is completely absent from UW plots. Another support of that assumption is the presence of Inocybe sp. and the number of species of genus Cortinarius in IW are other supports of that assumption since those EcM fungi were depicted late successional symbionts (Nara et al., 2003).

Sampling representativeness

Sampling representativeness assessment demonstrated that a large number of symbiotic fungi were not detected in the different habitats monitored. This result is

corroborated by the important values of uniques species that reflected rare species. That number of observed rare species give an estimate of the number of unseen species (Chiarucci et al., 2011) as captured by the estimated species richness in each habitat. That result is a support of the limitation of fruit body based study of EcM fungi species (Horton and Bruns, 2001; Taylor, 2002). Nevertheless, climate impact is more appreciable on fruit bodies than on below-ground tips (Andrew and Lilleskov, 2009; Pickles et al., 2012).

Spatial distribution of symbiotic fungi

Phytosociological study of permanent plots evidenced important floristic richness and especially numerous stems with dbh above 10 cm. EcM tree partners thrive in dominant and sometimes almost mono-dominant stands. Such habitats have been demonstrated as niche for abundant EcM fungi. *I. doka* and *U. togoensis* were the main dominant species in prospected habitats. Sites grouping were correlated with their density more than stands age. Indeed, though only stems with dbh above 10 cm were considered in data analysis, numerous juveniles and sprouts were present within plots. This was favorable to the establishment of both early- and late-successional EcM fungi. In addition, the grouping also reflected fire impact within study sites evidencing the "drought-tolerant" capacity of some collected fungi species. There is therefore an urgent need to monitor such disturbed stands to adequately address that assumed capacity.

Indicator species analysis evidenced four species associated to site groups (three species associated with G1 and one species with G2). Those species, *Russula congoana*, *Pulveroboletus* sp 1 and *A. xanthogala* were good indicators of G1 and *A. cf virosa* was for G2 taking into account specificity and fidelity. Indeed, those species were collected either exclusively in plots assigned to each group or predominantly in them. Association of *R. congoana* and *A. xanthogala* to *I. doka* was also documented in Benin by De Kesel et al. (2002). Those species are mentioned in literature as edible fungi in various part of Africa (Boa, 2004). As for the two remaining indicators species, they need to be characterised and compared to available monographs and / or keys to ascertain their identity at species level. However, they are likely associated to *U. togoensis*.

Conclusion

A six-month monitoring of EFFB ascertained their occurrence at Comoé National Reserve in the Sudanian climatic zone of Côte d'Ivoire. Woodlands of the reserve harboured high plant species diversity from which known EcM tree partners were frequently dominant. In these habitat types estimated of more than 200 years old, 123 EFFB species fruited and were collected. Their abundance and spatial distribution were significantly correlated to the stem density of *U. togoensis* and *I. doka* that were respectively the dominant species in each site group. *R. congoana*, *Pulveroboletus* sp 1 and *A. xanthogala* were good indicators of site group G1 and *A. cf virosa* for G2. However, further studies on contrasting soil types, fungal and forest succession, site microclimate as well as fire impact are needed to improve the understanding of fungal community dynamics in West African woodlands.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This work was funded by the German Federal Ministry of Education and Research (BMBF) through the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL, www.wascal.org) initiative. The authors gratefully acknowledge the helpful assistance of master students Bakari Soro and Guillaume K. L. Kra during field work. They acknowledge also the technical assistance of Laboratoire Central de Biotechnologie of the Centre National de Recherches Agronomiques CNRA (Côte d'Ivoire), the Laboratory of Systematic Mycology of Ludwig-Maximilians-University LMU Munich (Germany) and the Botanical Garden Meise (Belgium). They are also grateful to Drs. Souleymane Konaté, Kanvaly Dosso and Edson Bomisso for their invaluable advices. The authors also thank the two anonymous reviewers for their comments to improve the manuscript.

REFERENCES

AFNOR (1995). NF ISO 10694 (X31-409). Soil quality- Determination of organic and total carbon after dry combustion (elementary analysis). French norm AFNOR.

AFNOR (1999). NFX 31-130 soil quality. Chemical methods, Determination of Cation Exchange Capacity (CEC) and Cation Extraction, AFNOR, Paris.

AFNOR (2003). NFX 31-107 standard. Qualité du sol. Détermination de la distribution granulométrique des particules du sol. Méthode à la pipette. AFNOR, Paris.

Andrew C, Lilleskov EA (2009). Productivity and community structure of

Arbonnier M (2004). Trees, shrubs and lianas of West African dry zones. Margraf Publishers.

Bâ AM, Duponnois R, Moyersoen B, Diédhiou AG, (2012). Ectomycorrhizal symbiosis of tropical African trees. *Mycorrhiza.* Springer-Verlag.

Bahram M, Põlme S, Kõljalg U, Zarre S, Tedersoo L (2012). Regional and local patterns of ectomycorrhizal fungal diversity and community structure along an altitudinal gradient in the Hyrcanian forests of northern Iran. New Phytol. 193(2):465-473.

Beeli M (1935). Amanita, Volvaria. Flore Iconographique des Champignons du Congo, 1:1-28.

Boa ER (2004). Wild edible fungi: a global overview of their use and

importance to people. Food & Agriulture Organization.
Boddy L, Büntgen U, Egli S, Gange AC, Heegaard E, Kirk PM, Mohammad A, Kauserud H (2014). Climate variation effects on fungal fruiting. Fungal Ecol. 10:20-33.
Braun-Blanquet J (1932). Plant sociology. The study of plant communities. The study of plant communities. 1st Ed.
Büntgen U, Kauserud H, Egli S (2012). Linking climate variability to mushroom productivity and phenology. Front. Ecol. Environ. 10(1):14-19.
Büntgen U, Peter M, Kauserud H, Egli S (2013). Unraveling environmental drivers of a recent increase in Swiss fungi fruiting. Glob. Change Biol. 19(9):2785-2794.
Buyck B (1993). Russula I (*Russulaceae*). Flore illustrée des Champignons d'Afrique Centrale, 15:337-407.
Buyck B (1994). Russula II (*Russulaceae*). Flore Illustrée des Champignons d'Afrique Centrale, 16:411-539.
Buyck B (1997). Russula III (*Russulaceae*). Flore Illustrée des Champignons d'Afrique Centrale, 17:545-598.
Buyck B, Thoen D, Watling R (1996). Ectomycorrhizal fungi of the Guinea-Congo region. Proc. R. Soc. Edinb. Section B. Bio. Sci. 104:313-333.
Cao Y, Williams DD, Larsen DP (2002). Comparison of ecological communities: the problem of sample representativeness. Ecol. Monogr. 72(1):41-56.
Ceulemans R, Janssens I, Jach M (1999). Effects of CO2Enrichment on Trees and Forests: Lessons to be Learned in View of Future Ecosystem Studies. Ann. Bot. 84(5):577-590.
Chiarucci A, Bacaro G, Scheiner SM (2011). Old and new challenges in using species diversity for assessing biodiversity. Philos. Trans. R. Soc. Lond. B Biol. Sci. 366(1576):2426-2437.
Chidumayo EN, Gumbo ENCDJ, Gumbo DJ (2010). The Dry Forests and Woodlands of Africa: Managing for Products and Services. Earthscan 305p.
Colwell RK (2013). EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples. Version 9.
De Cáceres M, Jansen F (2015). indicspecies: Relationship Between Species and Group of Sites, R Package Version 1.7. 5.
De Cáceres M, Legendre P (2009). Associations between species and groups of sites: indices and statistical inference. Ecology, 90(12):3566-3574.
De Kesel A, Codjia J, Yorou S (2002). Guide des Champinons Comestibles du Bénin. Centre International d'Ecodéveloppement Intégré (CECODI). Coco-Multimedia, Cotonou, République du Bénin, National Botanic Garden, Belgium.
Dickie IA, Koele N, Blum JD, Gleason JD, McGlone MS (2014). Mycorrhizas in changing ecosystems. Botany, 92(2):149-160.
Dissing H, Lange JMC (1963). Gasteromycetales. Ministère de l'agriculture, Jardin botanique de l'État.
Duchaufour P, Blum WE (1997). Abrégé de pédologie: sol, végétation, environnement. Masson.
Ducousso M, Louppe D, Ouattara N, Eyssartier G, Buyck B (1999). Des mycorhizes très diversifiées dans les jachères naturelles au nord de la Côte d'Ivoire. La jachère en Afrique tropicale: rôle, aménagements, alternatives, Dakar, Sénégal.
Dufrêne M, Legendre P (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67(3):345-366.
ectomycorrhizal fungal sporocarps under increased atmospheric CO_2 and O_3. Ecol. Lett. 12(8):813-822.
Eyi Ndong H, Degreef J, De Kesel A (2011). Champignons comestibles des forêts denses d'Afrique Centrale. In: Samyn Y, VandenSpiegel D, Degreef J (eds.) Taxonomie et identification. ABC Taxa.
Gange AC, Gange EG, Sparks TH, Boddy L (2007). Rapid and Recent Changes in Fungal Fruiting Patterns. Science, 316(5821):71-71.
Gardes M, Bruns TD (1993). ITS primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. Mol. Ecol. 2(2):113-118.
Gerakis A, Baer B (1999). A Computer Program for Soil Textural Classification. Soil Sci. Soc. Am. J. 63(4):807-808.
Heim R (1955). Les Lactaires d'Afrique intertropicale (Congo belge et Afrique Noire francaise). Bulletin du Jardin Botanique de l'État Bruxelles, 25:1-91.
Heinemann P (1954). Boletineae. Flore iconographique des champignons du Congo 3:50-80.
Heinemann P (1959). Cantharellineae. Flore iconographique des champignons du Congo 8:153-165.
Heinemann P (1966). Hygrophoraceae, Laccaria et Boletineae II (compléments). Flore iconographique des champignons du Congo, 15:279-308.
Henkel TW, Aime MC, Chin MM, Miller SL, Vilgalys R, Smith ME (2012). Ectomycorrhizal fungal sporocarp diversity and discovery of new taxa in Dicymbe monodominant forests of the Guiana Shield. Biol. Conserv. 21(9):2195-2220.
Hennenberg KJ (2004). Vegetation ecology of forest-savanna ecotones in the Comoé National Park (Cote d'Ivoire): Border and ecotone detection, core-area analysis, and ecotone dynamics. Mathematical and Natural Sciences PhD Thesis. University of Rostock Fakultäder, Rostock, pp. 101.
Hennenberg KJ, Goetze D, Kouamé L, Orthmann B, Porembski S, Austin M (2005). Border and ecotone detection by vegetation composition along forest-savanna transects in Ivory Coast. J. Veg. Sci. 16(3):301-310.
Högberg P, Piearce G (1986). Mycorrhizas in Zambian trees in relation to host taxonomy, vegetation type and successional patterns. J. Ecol. 775-785.
Hollister RD, Webber PJ, Bay C (2005). Plant response to temperature in northern Alaska: implications for predicting vegetation change. Ecology, 86(6):1562-1570.
Horton TR, Bruns TD (2001). The molecular revolution in ectomycorrhizal ecology: peeking into the black-box. Mol. Ecol. 10(8):1855-1871.
Hui W, Gel YR, Gastwirth JL (2008). lawstat: An R Package for Law, Public Policy and Biostatistics. 28(3):26.
Hyvönen R, Ågren GI, Linder S, Persson T, Cotrufo MF, Ekblad A, Freeman M, Grelle A, Janssens IA, Jarvis PG, Kellomäki S, Lindroth A, Loustau D, Lundmark T, Norby RJ, Oren R, Pilegaard K, Ryan MG, Sigurdsson BD, Strömgren M, van Oijen M, Wallin G (2007). The likely impact of elevated [CO2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review. New Phytol. 173(3):463-480.
Ingleby K, Last F, Mason P (1985). Vertical distribution and temperature relations of sheathing mycorrhizas of Betula spp. growing on coal spoil. For. Ecol. Manage. 12(3):279-285.
IPCC (2014). IPCC Fifth Assessment Synthesis Report - Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change (IPCC), pp.116.
Janssens IA, Freibauer A, Schlamadinger B, Ceulemans R, Ciais P, Dolman AJ, Heimann M, Nabuurs GJ, Smith P, Valentini R, Schulze ED (2005). The carbon budget of terrestrial ecosystems at country-scale - a European case study. Biogeosciences 2(1):15-26.
Kauserud H, Heegaard E, Semenov MA, Boddy L, Halvorsen R, Stige LC, Sparks TH, Gange AC, Stenseth NC (2010). Climate change and spring-fruiting fungi. Proc. R. Soc. Lond. B: Bio. Sci. 277(1685):1169-1177.
Kauserud H, Stige LC, Vik JO, Økland RH, Høiland K, Stenseth NC (2008). Mushroom fruiting and climate change. Proc. Natl. Acad. Sci. 105(10):3811-3814.
Körner C, Asshoff R, Bignucolo O, Hättenschwiler S, Keel SG, Peláez-Riedl S, Pepin S, Siegwolf RTW, Zotz G (2005). Carbon Flux and Growth in Mature Deciduous Forest Trees Exposed to Elevated CO2. Science 309(5739):1360-1362.
Koulibaly A (2008). Caractéristiques de la végétation et dynamique de la régénération, sous l'influence de l'utilisation des terres, dans des mosaïques forêts-savanes, des régions de la Réserve de Lamto et du Parc National de la Comoé, en Côte d'Ivoire. PhD thesis, UFR Biosciences, Botanical Laboratory, University of Cocody, Abidjan, 111p.
Krebs CJ, Carrier P, Boutin S, Boonstra R, Hofer E (2008). Mushroom crops in relation to weather in the southwestern Yukon. Botany, 86(12):1497-1502.
Krebs CJ, Kenney AJ (2002). Programs for ecological methodology, 2nd Ed. version 6.1. Department of Zoology, University of British Columbia, Vancouver, B. C. Canada.

Kruskal W.H. & Wallis W.A., 1952. Use of Ranks in One-Criterion Variance Analysis. J. Am. Stat. Assoc. 47(260):583-621.
Lauginie F (2007). Conservation de la nature et aires protégées en Côte d'Ivoire. CEDA/NEI.
Lawton R (1978). A study of the dynamic ecology of Zambian vegetation. J. Ecol. pp. 175-198.
Maba DL, Guelly AK, Yorou NS, Verbeken A, Agerer R (2013). Two New Lactifluus species (*Basidiomycota, Russulales*) from Fazao Malfakassa National Park (Togo, West Africa). Mycol. Prog. 13(3):513-524.
McGuire KL (2007). Common ectomycorrhizal networks may maintain monodominance in a tropical rain forest. Ecology, 88(3):567-574.
Montoya JM, Raffaelli D (2010). Climate change, biotic interactions and ecosystem services. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 365(1549):2013-2018.
Moore D, Robson GD, Trinci AP (2011). 21st Century Guidebook to Fungi with CD. Cambridge University Press.
Morin X, Augspurger C, Chuine I (2007). Process-based modeling of species' distributions: what limits temperate tree species' range boundaries? Ecology 88(9):2280-2291.
Nara K, Nakaya H, Hogetsu T (2003). Ectomycorrhizal sporocarp succession and production during early primary succession on Mount Fuji. New Phytol. 158(1):193-206.
O'Dell TE, Ammirati JF, Schreiner EG (2000). Species richness and abundance of ectomycorrhizal basidiomycete sporocarps on a moisture gradient in the Tsuga heterophylla zone. Can. J. Bot. 77(12):1699-1711.
Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, gy Package. R pSolymos P, Stevens MHH, Wagner H (2015). vegan: Community Ecoloackage version 2.0-10. P 274.
Onguene N, Kuyper T (2002). Importance of the ectomycorrhizal network for seedling survival and ectomycorrhiza formation in rain forests of south Cameroon. *Mycorrhiza,* 12(1):13-17.
Onguene NA (2000). Diversity and dynamics of mycorrhizal associations in tropical rain forests with different disturbance regimes in South Cameroon. Landbouwuniversiteit Wageningen (Wageningen Agricultural University).
Onguene NA, Kuyper TW (2012). Habitat and diversity of ectomycorrhizal fungi in forests of South Cameroon. Cameroon J. Exp. Biol. 8(1):26-34.
Orwin K.H., Kirschbaum M.U., St John M.G. & Dickie I.A., 2011. Organic nutrient uptake by mycorrhizal fungi enhances ecosystem carbon storage: a model-based assessment. Ecol. Lett. 14(5):493-502.
Pickles BJ, Egger KN, Massicotte HB, Green DS (2012). Ectomycorrhizas and climate change. Fungal Ecol. 5(1):73-84.
Piepenbring M (2015). Introduction to Mycology in the Tropics. United States of America: APS PRESS, P 366.
Poilecot P, Bonfou K, Dosso H, Lauginie F, N'dri K, Nicole M, Sangare Y (1991). Un écosystème de savane soudanienne: le Parc National de la Comoé (Côte d'Ivoire), IVC/87/007. UNESCO.
Riviere T, Diedhiou AG, Diabate M, Senthilarasu G, Natarajan K, Verbeken A, Buyck B, Dreyfus B, Bena G, Ba AM (2007). Genetic diversity of ectomycorrhizal Basidiomycetes from African and Indian tropical rain forests. *Mycorrhiza,* 17(5):415-428.
Sanon KB, Bâ AM, Dexheimer J (1997). Mycorrhizal status of some fungi fruiting beneath indigenous trees in Burkina Faso. For. Ecol. Manage. 98(1):61-69.
Simard S. & Austin M., 2010. The role of *mycorrhizas* in forest soil stability with climate change. INTECH Open Access Publisher.
Singh LP, Gill SS, Tuteja N (2011). Unraveling the role of fungal symbionts in plant abiotic stress tolerance. Plant Signal. Behav. 6(2):175-191.
Smith SE, Read DJ (2008). *Mycorrhizal Symbiosis.* London, UK: Academic press, P 800.
Tedersoo L, Bahram M, Jairus T, Bechem E, Chinoya S, Mpumba R, Leal M, Randrianjohany E, Razafimandimbison S, Sadam A (2011). Spatial structure and the effects of host and soil environments on communities of *ectomycorrhizal* fungi in wooded savannas and rain forests of Continental Africa and Madagascar. Mol. Ecol. 20(14):3071-3080.
Tedersoo L, Nara K (2010). General latitudinal gradient of biodiversity is reversed in *ectomycorrhizal* fungi. New Phytol. 185(2):351-354.
Van Der Heijden MGA, Horton TR (2009). Socialism in soil? The importance of *mycorrhizal* fungal networks for facilitation in natural ecosystems. J. Ecol. 97(6):1139-1150.
Van Der Heijden MGA,Bardgett RD, Van Straalen NM (2008). The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol. Lett. 11(3):296-310.
Vargas R, Baldocchi DD, Querejeta JI, Curtis PS, Hasselquist NJ, Janssens IA, Allen MF, Montagnani L (2010). Ecosystem CO2 fluxes of arbuscular and ectomycorrhizal dominated vegetation types are differentially influenced by precipitation and temperature. New Phytol. 185(1):226-236.
Vavrek MJ (2011). Fossil: palaeoecological and palaeogeographical analysis tools. *Palaeontologia* Electronica, 14(1)1.
Verbeken A, Walleyn R (2010). Vol. 2: Monograph of Lactarius in tropical Africa. Meise: National Botanic Garden of Belgium.
Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O, Bairlein F (2002). Ecological responses to recent climate change. Nature, 416(6879):389-395.
WMO W (2007). Scientific assessment of ozone depletion: 2006. World Meteorological Organisation, Global Ozone Research and Monitoring Project–Report, 50:572.
Yorou NS (2010). Higher mushrooms. In: Sinsin B. & Kampmann D. (eds.). Biodiversity Atlas of West Africa. Cotonou & Frankfurt/Main.
Yorou NS, Koné NGA, Guissou ML, Guelly AK, Maba LD, Ékué MRM, De Kesel A (2014). Biodiversity and Sustainable Use of Wild Edible Fungi in the Sudanian Centre of Endemism: A Plea for Valorisation. In: Bâ AM, McGuire KL, Diédhiou AG (eds.). Ectomycorrhizal Symbioses in Tropical and Neotropical Forests. pp. 241.
Yorou S, De Kesel A, Sinsin B, Codjia J (2001). Diversité et productivité des champignons comestibles de la forêt classée de Wari-Maro (Bénin, Afrique de l'Ouest). Syst. Geogr. Plants 71:613-625.

SUPPLEMENTARY DATA

Table 1. Relative frequency of occurrence of EcM fungi species within woodlands of Comoé National Park.

Distribution class	Taxon	Family	IW	MW	UW
Common to all habitat types	*Amanita* aff. *subviscosa*	Amanitaceae	1.56	0.58	2.14
	Amanita annulatovaginata sensu lato	Amanitaceae	0.58	1.56	0.39
	Amanita sp 13	Amanitaceae	1.17	0.78	0.78
	Amanita xanthogala	Amanitaceae	0.39	0.19	0.19
	Cantharellus addaiensis	Cantharellaceae	1.75	0.97	2.14
	Cortinarius sp 1	Cortinariaceae	0.19	0.19	0.39
	Lactifluus aff. *emergens*	Russulaceae	0.78	0.19	0.39
	Lactifluus luteopus	Russulaceae	0.19	0.78	1.56
	Phylloporus ampliporus	Boletaceae	0.39	0.58	0.19
	Pulveroboletus sp 1	Boletaceae	1.17	0.39	0.19
	Pulveroboletus sp 2	Boletaceae	0.58	0.78	1.36
	Russula aff. *cellulata*	Russulaceae	0.39	0.19	0.58
	Russula aff. *ochrocephala*	Russulaceae	0.58	0.78	0.97
	Russula cellulata	Russulaceae	0.78	0.58	0.39
	Russula cf *amoenolens*	Russulaceae	0.78	0.39	0.58
	Russula cf *flavobrunnea*	Russulaceae	0.97	0.39	0.58
	Russula cf *grisea*	Russulaceae	0.19	0.19	0.19
	Russula ciliata	Russulaceae	0.19	0.39	0.19
	Russula congoana	Russulaceae	2.53	0.78	0.19
	Russula sp 10	Russulaceae	0.58	0.19	0.78
	Russula sp 11	Russulaceae	0.19	0.19	0.39
	Xerocomus sp 4	Boletaceae	0.19	0.19	0.19
Shared by two habitat types	*Amanita congolensis*	Amanitaceae	0.00	0.78	0.97
	Amanita sp 12	Amanitaceae	0.19	0.39	0.00
	Amanita aff. *virosa*	Amanitaceae	0.00	1.36	1.95
	Amanita masasiensis	Amanitaceae	0.19	0.19	0.00
	Amanita sect *lepidella* sp 1	Amanitaceae	0.39	0.19	0.00
	Amanita sect. *lepidella strips xanthogala* sp 1	Amanitaceae	0.19	0.00	0.19
	Amanita sp 5	Amanitaceae	0.19	0.19	0.00
	Amanita sp 8	Amanitaceae	0.19	0.00	0.39
	Amanita strobilaceo-volvata sensu lato	Amanitaceae	0.58	0.00	1.95
	Boletus loosii	Boletaceae	0.00	0.97	0.78
	Boletus sp 2	Boletaceae	0.39	0.00	0.58
	Gyroporus castaneus	Gyroporaceae	0.19	0.00	0.58
	Lactarius afroscrobiculatus	Russulaceae	0.00	0.19	0.39
	Lactarius saponaceus	Russulaceae	0.19	0.19	0.00
	Lactarius tenellus	Russulaceae	1.95	1.56	0.00
	Lactifluus aff. *heimii*	Russulaceae	0.97	0.19	0.00
	Lactifluus sp 4	Russulaceae	0.19	0.19	0.00
	Octaviana ivoryana	Boletaceae	1.17	0.19	0.00
	Rubinoboletus cf *balloui*	Boletaceae	0.00	1.17	0.19
	Rubinoboletus cf *griseus*	Boletaceae	0.39	0.39	0.00
	Russula cf *sesenagula*	Russulaceae	0.58	0.39	0.00
	Russula sect *griseineae*	Russulaceae	0.00	0.19	0.19
	Russula sect. *archaeina*	Russulaceae	0.39	0.19	0.00
	Russula sp 7	Russulaceae	0.19	0.19	0.00
	Scleroderma sp 2	Sclerodermataceae	0.58	0.19	0.00
	Sutorius sp 1	Boletaceae	0.39	0.00	0.39

Table 1. Contd.

	Tylopilus sp 1	Boletaceae	0.00	0.19	0.39
	Xerocomus subspinulosus	Boletaceae	0.39	0.39	0.00
	Amanita aff. *craseoderma*	Amanitaceae	2.14	0.00	0.00
	Amanita cf *crassiconus*	Amanitaceae	0.00	0.97	0.00
	Amanita sp 1	Amanitaceae	0.19	0.00	0.00
	Amanita sp 2	Amanitaceae	0.00	0.19	0.00
	Amanita sp 3	Amanitaceae	0.19	0.00	0.00
	Amanita sp 4	Amanitaceae	0.00	0.00	0.19
	Amanita sp 6	Amanitaceae	0.19	0.00	0.00
	Amanita sp 7	Amanitaceae	1.75	0.00	0.00
	Amanita sp 9	Amanitaceae	0.19	0.00	0.00
	Amanita sp 10	Amanitaceae	0.19	0.00	0.00
	Amanita sp 11	Amanitaceae	0.19	0.00	0.00
	Amanita subviscosa	Amanitaceae	0.39	0.00	0.00
	Boletellus linderi	Boletaceae	0.97	0.00	0.00
	Boletellus longipes	Boletaceae	0.00	0.58	0.00
	Boletus pallidisimus	Boletaceae	0.00	0.19	0.00
	Boletus sp 1	Boletaceae	0.00	0.00	0.19
	Clavunila sp 1	Clavulinaceae	0.19	0.00	0.00
	Cortinarius aff violaceus	Cortinariaceae	0.39	0.00	0.00
	Cortinarius subgenus *telamonia* sp 1	Cortinariaceae	0.58	0.00	0.00
	Inocybe sp 1	Inocybaceae	0.58	0.00	0.00
	Lactarius sp 1	Russulaceae	0.00	0.00	0.19
	Lactarius sp 2	Russulaceae	0.00	0.00	0.19
Specific to one habitat type	*Lactarius* sp 3	Russulaceae	0.00	0.39	0.00
	Lactifluus flammans	Russulaceae	0.00	0.39	0.00
	Lactifluus gymnocarpoides	Russulaceae	0.00	0.00	0.19
	Lactifluus pelliculatus	Russulaceae	0.00	0.00	0.97
	Lactifluus sp 1	Russulaceae	0.00	0.19	0.00
	Lactifluus sp 2	Russulaceae	0.00	0.00	0.19
	Lactifluus sp 3	Russulaceae	0.19	0.00	0.00
	Lactifluus volemoides	Russulaceae	0.00	0.39	0.00
	Phylloporus cf *rhodophaeus*	Boletaceae	0.58	0.00	0.00
	Porphyrellus sp 1	Boletaceae	0.19	0.00	0.00
	Pulveroboletus sp 3	Boletaceae	0.00	0.00	0.58
	Russula aff. *flavobrunnea*	Russulaceae	0.19	0.00	0.00
	russula cf *annulata*	Russulaceae	0.00	0.00	0.39
	Russula cf *mairei*	Russulaceae	0.00	0.39	0.00
	Russula cf *ochrocephala*	Russulaceae	0.39	0.00	0.00
	Russula cf *subfistulosa*	Russulaceae	0.00	0.00	0.39
	Russula discopus	Russulaceae	0.00	0.00	0.19
	Russula oleifera	Russulaceae	0.00	0.19	0.00
	Russula sp 1	Russulaceae	0.00	0.19	0.00
	Russula sp 2	Russulaceae	0.00	0.19	0.00
	Russula sp 3	Russulaceae	0.19	0.00	0.00
	Russula sp 4	Russulaceae	0.39	0.00	0.00
	Russula sp 5	Russulaceae	0.00	0.19	0.00
	Russula sp 6	Russulaceae	0.00	0.00	0.19
	Russula sp 8	Russulaceae	0.00	0.00	0.19
	Russula sp 9	Russulaceae	0.19	0.00	0.00
	Russula sp 12	Russulaceae	0.19	0.00	0.00

Table 1. Contd.

	Russula sp 13	Russulaceae	0.00	0.19	0.00
	Russula sp 14	Russulaceae	0.00	0.00	0.19
	Russula sp 15	Russulaceae	0.00	0.00	0.19
	Russula sp 16	Russulaceae	0.58	0.00	0.00
	Russula sp 17	Russulaceae	0.19	0.00	0.00
	Russula sp 18	Russulaceae	0.00	0.00	0.19
	Scleroderma cf *cepa*	Sclerodermataceae	0.58	0.00	0.00
	Scleroderma cf *citrinum*	Sclerodermataceae	0.00	0.19	0.00
	Scleroderma sp 1	Sclerodermataceae	0.00	0.58	0.00
	Scleroderma aff. verrucosum	Sclerodermataceae	0.19	0.00	0.00
	Tubosaeta heterosetosa	Boletaceae	0.39	0.00	0.00
	Tylopilus griseus	Boletaceae	0.00	0.00	0.19
	Tylopilus niger	Boletaceae	0.39	0.00	0.00
	Boletoid sp 1	Boletaceae	0.00	0.00	0.19
	Tylopilus sp 2	Boletaceae	0.00	0.58	0.00
	Tylopilus sect. chromapes sp 1	Boletaceae	0.00	0.00	0.19
	Veloporphyrellus africanus	Boletaceae	0.00	0.00	0.97
	Xerocomus sp 1	Boletaceae	0.00	0.19	0.00
	Xerocomus sp 2	Boletaceae	0.00	0.00	0.19
	Xerocomus sp 3	Boletaceae	0.19	0.00	0.00
	Xerocomus sp 5	Boletaceae	0.00	0.19	0.00
	Xerocomus sp 6	Boletaceae	0.78	0.00	0.00
	Xerocomus sp 7	Boletaceae	0.00	0.19	0.00

IW: Isoberlinia Woodlands; MW: mixed wwoodlands: UW: Uapaca Woodlands.

Figure 1a, b. Russula congoana.

Figure 2a, b. Amanita xanthogala.

Figure 3a, b. Pulveroboletus sp 1.

Figure 4a, b. Amanita cf virosa.