The influence of slope gradient on termite assemblages and some soil properties in Koudi secondary forest patches (Centre Region of Cameroon)

ABSTRACT

The influence of relief on termites'diversity was extensively studied. However, the effect of the slope gradient on termite diversity and functional groups remains less studied. We evaluated termite assemblages in relation to some edaphic parameters,with emphasis on gradual changes in soil slope. The study was conducted in Koudi, in the semi-deciduous forest zone of SouthernCameroon. We aimed toevaluate (1) the effect of slope gradient on termite diversity and some soil physico-chemical factors; (2) the influence of somephysico-chemical soil properties on termites. To achieve this, three slope gradients:gentle slope: A [0 - 15°];moderate slope: B [15.1°- 31°];and steeper slope: C [x > 31°[were chosen.The experimental design was composedof 66 rectangular quadrats of 5m x 2m in order to determine the presence or absence of termites. Two soil samples were taken per slope gradient for the determination of physico-chemical parameters.Termite community was characterized using species richness, Shannon diversity,Pielou Evenness and Simpson dominance indexes. Data were subjected to Spearman correlation test and ANOVA followed by the Tukey HSD test at a threshold p = 0.05. Our findings suggested thirty-fivetermite speciesbelonging to eighteen genders six subfamiliesthat were sampled and identified. Termites' diversity and species richness decreased as slope gradient increased; slope gradient displayed a significant detrimental correlation with sand (%) and total organic (g/kg) content, with a positive significant correlation with clay (%) content, according to Spearman's test.It appeared that variations of slope at soil surface have been identified as one of the factors controlling nutrients and termite diversity.

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Key words: slope, termites, physico-chemical parameters, semi-deciduous forest

Introduction

A nation's primary economic driver and a valuable natural resource for agriculture is the soil. Both Physico-chemical and biological factors influence soil fertility, directly affecting agricultural production. Topography through slope aspect is one of the soil-forming factors that influences soil characteristics and controls soil erosion processes by redistributing soil particles and soil organic matter (OM) [1,2]. Soil loss is typically expected to increase with increasing slope gradient due to increased surface runoff velocity and decreased infiltration rate [3,4]. Several studies show differences in some soil characteristics may be related to slope gradient [5]. With differences in solar radiation between northern and southern slopes, this variation in slope gradient at some scales can result in distinct climates and raise temperatures and evapotranspiration in one hemisphere relative to another [6,7]. Consequently, topographic characteristics significantly affect plant functional traits and diversity. It is possible that the observed changes in plant communities in response to slope also had cascading impacts on nearby wildlife [8].The accompanying fauna may have been affected in a cascading pattern by the observed changes in plant communities in response to slope [8].

One of the organisms that alter the soil qualities is the termite (Order: Blattaria, Infraorder: Isoptera). According to [9]there are 3106 extant or fossil termite species in the world, divided into 12 families, with more than 75% of all known species belonging to the Termitidae family[10,11].The humid tropical region has the highestdiversitydue to its physical complexity and small-scaleheterogeneity[12]. Termites play a crucial ecological role by influencing pedogenesis and the physico-chemical properties and functions of soils. They are directly or indirectlyinvolved, in a variety of soil processes, such as organic matter dynamics, aeration, water transport, and water holding capacity [13]. They are soil engineersas they participatein organic matter breakdown, concentration, storage and redistribution of mineral and organic elements. Physicochemical changes in the soil can affect termite assemblages. Numerous factors can influencesoilqualities. Based on functional or taxonomic groups, previous studies have investigated the distribution of termites at different spatial scales [14, 15]. However, determining the spatial scale is crucial for assessingthe impact of environmental factors on termite communities; spatial scale has been shown to assess biotic processes, such as dispersal, intraand interspecific interactions [16]. In tropical forests, spatial heterogeneity affects the distribution of soil-level nutrients and environmental attributes that influencespecies activity. However, it is still unclear how environmental factors influence the spatial distribution of termite communities.

Topography is likelyto be one of the most significant factors. Depending on the slope's gradient, drainage and runoff encourage erosion andalterthe physico-chemical characteristics of the soil by moving soil nutrients from steep slopes to gentle slopes [1].As a result, nutrients are unevenly distributed in the soil depending on the landform.The relief of Cameroon's semi-deciduous forests is complex, with moderate to steeply sloping hills alternating with undulating land interspersed with plains having relatively flat topography [1, 17].This has an impact on the diversity and distribution of nutrients in the soil. Fewstudies have beenconducted to evaluate the effect of slope gradient on termite diversity. So, weaimed toevaluate:

(1) The effect of slope gradient on termite diversity;
(2) The effect of slope gradient on somesoil physico-chemical properties;
(3) The relationship between some soilphysico-chemical properties and termites.

II-Material and methods

II- 1 Study site

The study was conducted in a semi-deciduous forest zone with a bimodal rainfall regime in Cameroon at the Koudi locality (3°95'22.06"N; 11°26'40.9 East;altitude: 681 ± 3 m) in the Centre Region, Department of the Lekiéand LoboDistrict from 14 April to 31May, 2021 (Figure 1). This area is characterized bythe Guinean equatorial climate type with alternating four seasons, including two rainy seasons (mid-March to mid-June; mid-September to mid-December) and two dry seasons(mid-June to mid-August; mid-December to mid-

March)[17,18]. The average annual rainfall is 1800mm, with a difference of about 280 mm between the driest and the wettest month. The average annual temperature is 23.6°C, with a thermal variation of 2.1°C[17]. The CentreRegion is part of the Southern Plateau of Cameroon. The average altitude of this large plateau is 600-700m;the predominant vegetation is dense tropical forest, which gradually turns into savannah in the northern part; this is a point of severe ecosystem degradation. The vegetation in our study area is of the mosaic type, with remnants of primary forest on the hilltops and secondary forest and fallow predominating on the plains. The vegetation is characterized by the richness of the epiphytic flora caused by the extremely high humidity of these environments, being the most distinctive physiognomic link. Species such as *Allanblackiagabonensis, Cola verticillata, Beilschmiediaobscura, Leonardoxaafricana, Garciniapolyantha, and Myrianthusserratus*predominated others[19].The main cash and consumption crops are *Theobroma cacao*, *Manihot esculenta*, *Arachishypogaea*, *Zea mays*. Soils are clayey in consistency and reddish in colour with an irregular slope [18].A secondary forest plot over 40 years old was selected in this forest.

II- 2 Methods

The experimental set-up consisted of a 5 ha forest plot in which 66 non-contiguous 5m x 2m quadrats were randomly delimited. These quadrats were at least 10 m apart to cover the entire topographic profile of the study area. The slope was measured using a digital inclinometer that previously calibrated on a horizontal plane; termite sampling was carried out in each quadrat according to[20]approach. Subsequently, 12 soil samples (20 cm x 20 cm x 10 cm) were collected using an entomological trowel, placed on a tray, and thoroughly studied for 30 minutes by two collectors. Termite activity and the presence or absence of both young and old epigean nests were documented. Soldiers and workers from the various termite castes were collected and preserved in tubes containing 80% alcohol. These samples were sent to the Entomology laboratory of the IRAD (Institut de RechercheAgricole pour le Developpement) for identification using the keys of[21],[10]and [22].

Two soil samples were taken per slope gradientusing 100 cm^3 cylindrical rings whichhad previously been weighed for the determination of physico-chemical parametersof the soil.The soil (0–10 cm) was collected after litter removal.Chemical and textural analyses were then carried out. Soil samples were taken from each slope gradient to determine soil particle size and certain chemical parameters. Soil samples were then sent to the soil laboratoryof Dschang's University,where all samples were crushed and sieved to a size of 2 mm and 0.5 mm after air drying. Bulk density, organic carbon, total nitrogen, assimilable phosphorus, water pH, exchangeable cations, carbon/nitrogen ratio, and particle size were measured.

Bulk density: Fresh 100 cm^3 soil samples were weighed, oven-dried at 105°C, and weighed again to estimate water content and bulk density.

Soil texture:The Bouyoucos hydrometer method was used to analyzethe soil textural fractions (sand, silt, and clay), in which 15 g of air-dried soil sieved to 2 mm were weighed into 500 ml beakers and subjected to organic matter removal treatment with H_2O_2, followed by dispersion of the soils with sodium hexametaphosphate [23].The resulting mixtures were agitated on a mechanical shaker for 3 hours. The suspensions were then transferred to sedimentation apparatusand built up to a capacity of 1000 ml with distilled deionized water in sedimentation measuring cylinders. To suspend the particles, the mixtures were extensively stirred with a mechanical rotator. A hydrometer was then used to take readings after 40 seconds (first reading, R1) and two hours (second reading, R2) respectively[24].

Soil pH was determined in a water suspension with a soil/ water ratio of 2:5. Exchangeable bases ($Ca^{2+,}$ Mg^{2+} K^{+} and Na^{+}) were extracted using 50 ml of ammonium acetate (1.0 M NH_4OAc) solution buffered at pH 7. Using complexometric titration and a flame photometer, the concentrations of magnesium (Mg2+), calcium (Ca 2+), potassium (K+), and sodium (Na+) were determined in the extract, respectively. After that, phosphorus was detected using a Malachite green colourimetric method. Organic carbon was determined by chromic acid digestion and spectrophotometry. Total Nitrogen was determined using the Kjeldahl method for digestion as well as ammonium electrode determination [25, 26].

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II- 2 Data analysis

Assessment of sampling effort and termites community diversity

To assess the sampling effort, the diversity obtained from non-parametric biodiversity estimators using rare species in the community was compared to the theoretical diversity of the siteto predict the number of missing species [27]were used to compare the obtained diversity to the theoretical diversity of the site. Chao1 is a non-parametric species richness estimator based on abundanceand correlated with other diversity measures. Jackknife1 is non-parametric estimator of species richness based on abundance and incidence. Bootstrap is a simulation of standard deviation by randomly generating samples to estimate the potential number of observed and theoretical termite species in each gradient slope.We also calculated the Simpson's dominance index (D), as well as the Pielou evenness index (J) and the Shannon-Wiener diversity index (H') per slope gradient.Species rarefaction curves were plotted using species accumulation as a function of sample number.All these analyses were performed using Primer (Plymouth Routines In Multivariate Ecological Research) software version 6.0 and Past 4.02.

The numbers of termites in the different quadrats were subjected to a logarithmic transformation of the Log(N+1) type to normalize them, then subjected to a simple analysis of variance (ANOVA) followed by the Tukey HSD test for pairwise comparison.

Relationship between soil property and diversity parameters:A Canonical Correspondence Analysis (CCA) was applied according to[28]to analyze the variation of slope gradient versustermites' variables and soil physicochemical parameters. Non-metric multidimensional scaling analysis (NMDS) was applied to show similarities in the composition of termiteassemblages among slope gradients using the Bray–Curtis similarityindex.

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Spearman's correlation was used to find the relationship between environmental parameters, species richness and termite abundance. All statistical analyses and tests were carried out using Past 4.0.2 and STATISTICA 6.0 software, and the results were appreciated at a 5% confidence interval.

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III- Results

1 Evaluation of sampling effort

A total of 1404 termites from 18 genders and 35 species were gathered from four different slope gradients. Apicotermitinae (nine species), Cubitermitinae (seven species), Microcerotermitinae (one species), Macrotermitinae (two species), Nasutitermitinae (one species), and Termitinae (15 species) all belonged to the same family, Termitidae.In terms ofthe functional groups, soil feeding (94.80%), wood-feeding (1.64%) and fungus growers (3.56%) constituted the total sampledpopulation.

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In terms of sampling effort, independent of slope, estimated species richness was substantially higher than measured ones using the Chao, Jackknife1, and bootstrap estimators. While the Chao1 estimate for the species was 38.63, the Jackknife estimate was 42.87, and the bootstrap estimate was 38.80. Chao1 estimations were more conservative, with 10.37 percent more species estimated than observed (Figure 2). It should be noticed that these three curves continue to increase, implying that certain species were not sampled.

2 Effect of slope gradient on termite's community diversity

The diversity of termites may indicate the effect of the slope on the ground. As shown in Figure 3 and Table 1, Anova followed by Tukey's tests revealed that the number of species decreasedas the level of the slope gradient increased, but not substantially (2ddl; F (2, 63) = 1,885; p=0, 16). Furthermore, the Shannon-wiener index (H) decreased as the level of the slope gradients increased. On the contrary, Simpson's dominance index (D) gradually increased. All of the species studied were divided into three functional groups: fungus growers (Gr II_F), wood-feeding (Gr II), and soil-feeding (Gr III & IV). The results collected reveal that fungus growers (2ddl; F (2, 63) = 0.07; p=0.93), wood-feeding (2ddl; F (2, 63) = 0.015; p=0.85), and soil-feeding termites (2ddl; F (2, 63) = 0.063; p=0.93), did not differ between slope gradient.

3 Effect of slope gradient on soil properties and termite distribution

Table 2 depicts the effect of slope gradient on the physical and chemical properties of the soil. According to the ANOVA, the pH-water and the values of C/N ratios decreased somewhat, although the water content increased slightly but not considerably (p>0.05). Concerning the exchangeable cations, a higher magnesium concentration was observed in the steeper slopes (C) than in the gentle and moderate slopes (A and B). Potassium (K) seemed to be influenced by the slope gradient with a lower concentration in the steeper slope (C). In the same way, exchangeable sodium (Na) and calcium (Ca) showed a difference in slope gradient with lower concentrations in the steeper slope (C). All these differences were not statistically different. In terms of soil texture, sand and silt content decreased while clay content increased with increasing slope gradient, with no significant difference at each level of slope gradient ($p > 0.05$); however, statistical differences in bulk density were observed, with moderate slope (B)being higher than gentle (A) and steeper (C) slopes (2ddl; $F(2,33)=1.37$; $p=0.009$).

CCA analysis was used to investigate the impact of the slope aspect on termite assemblages and soil physico-chemical parameters (Figure 4). According to this analysis, CCA1 and CCA2 accounted for 100 per cent of the total variance. Certain soil variables, such as Mg and clay concentration, appear to be associated with increasing slope, whereas sandy, silt and compounds such as Ca, K, Na, and C/N are associated with gentle (A) and moderate slopes (B). Regarding termites and soil variables, we found that termite abundance, species richness, fungus growers (FG), wood-feeding (WF), and soil feeding (SF) were unrelated to soil variables; however, the figure shows that some species, such as *Angulitermesfrontalis*, *Profastigitermesputnami*, *Isognathotermeshenghi*, Ap5 and WF (wood feeding) are positively associated with Mg. pH of water, bulk density, K, Na, P, C/N, and silt fraction are all positively associated with *Apilitermeslongiceps*, *Protermesprorepens*, *Proboscitermestubuliferus, furculitermeswinifredae*, and Ap4.

Considering slope gradient, regardless of soil physico-chemical variables, NMDS analysis revealed clustering of some species based on slope gradient. Termite species that preferred gentle slope (A) were clearly distinguished from those that preferred moderate slope (B) and steeper slope (C) (Figure 5).

4. Correlation Analysis between slope gradient and Physico-Chemical Characteristics of Soil

As demonstrated in Table 3, the slope gradient level affected the soil's physical and chemical features. The clay fraction had a significant positive correlation with the slope gradient ($r=0.88$; $p<0.05$), but the sand ($r= -0.88$; $p<0.05$) and silt ($r=0.44$; $p > 0.05$) fractions had a negative correlation. In addition to this, we found significant and positive correlations of water content with clay fraction ($r = 0.90$; $p<0.05$) and a positive relationship of bulk density with slope gradient ($r = 0.60$; $p > 0.05$). However, there was a positive correlation between pH-water and bulk density ($r=0.9$; $p <0.05$).

Concerning soil organic carbon content, a negative correlation was found between slope gradient and organic carbon content ($r= -0.82$; $p<0.05$). Soil organic carbon content was positively correlated with sand ($r= 0.71$; $P > 0.05$) and silt ($r= 0.36$ $P > 0.05$) fractions and negatively correlated with clay fraction ($r= -0.71$; $P > 0.05$). The same trend was observed for total nitrogen content, which exhibited negative correlations with slope gradient ($r= -0.71$; $P > 0.05$), clay ($r= -0.48$; $p > 0.05$) fraction and positive correlations with silt ($r= 0.14$; $p > 0.05$) and sand ($r= 0.48$; $p > 0.05$) fractions.

The result for available P showed that it was influenced by both slope gradient ($r= -0.46$; $p>0.05$) and soil particle size through sand ($r= 0.67$; $p>0.05$), silt ($r= 0.49$; $p>0.05$) and clay ($r= -0.67$; $p>0.05$) fractions. It was also positively correlated with soil nitrogen content ($r= 0.81$; $p<0.05$) and C/N ratio ($r= 0.89$; $p<0.05$). The cation exchangeable capacity (CEC) was not significantly ($r= 0.08$; $p>0.05$) affected by the slope gradient. It was positively correlated with clay ($r = 0.42$; $p>0.05$), while it was inversely correlated with sand ($r=-0.42$; $p>0.05$) and silt ($r=-0.77$; $p>0.05$) fractions. Concerning Exchangeable cations, Exchangeable calcium ($r = -0.57$; $p>0.05$), potassium ($r = -0.41$; $p>0.05$), sodium($r = -0.35$; $p>0.05$) were negatively correlated with slope gradient, but Magnesium was positively correlated ($r = 0.42$; $p>0.05$).

5. Correlation Analysis betweentermite's diversity and some Physical and Chemical Characteristics of Soil

As can be seen under different slope gradients seemed to have a negative impact on species richness(r=-0.24; p>0.05) and diversity (r=-0.5, p >0.05); the physical and chemical characteristics of the soil had a greater effect on termite attributes. The correlation was significant between species richness and pH-water (r=0.85; p <0.05); it was the same trend withpotassium (r=0.43, p>0.05) sodium (r=0.35, p>0.05)and C/N(r=0.16, p>0.05). Concerning the functional groups,CECshowedpositive correlation withsoil-feeding (r=0.77, p>0.05) as opposed towood feeders(r=-0.39, p>0.05) and fungus growers (r=-0.13, p>0.05).Taking into account soil particles size, the results revealed that sand(r=0.33, p >0.05), silt(r=0.3, p >0.05) fractions seemed to favour species richness contrary toclay fraction (r=-0.33, p >0.05).

IV- Discussion

Our study revealed that the slope gradient has an inverse effect on the sandy and clayey fractions of the soil, with the sandy fraction being higher on gentle slopes and the clayey fraction being higher on steeper slopes. The results for the sandy fraction are due to the geomorphology of the soil, which influences pedogenesis through its influence on erosion and leaching, as well as through the intermediary of the climate. The steeper the slope, the greater the runoff, which causes the movement of large particles, and the more unstable sands are evacuated from the upper slopes to the lower slopes, confirming previous findings[29]. On the other hand, the results for the clay fraction confirm those of[30]who obtained the lowest values on gentle slopes while the highestwere observed on higher slopes.The prevalence of clayey texture on the steeper slopes may be related to the recent history of cultivation and logging.

The slope gradient has a significant negative correlation with total organic carbon. This is due to erosion, a geomorphological process that transports particles from steep slopes to gentler slopes. The lowest organic carbon content was found on higher slopes, while the highest was found on lower slopes. Studies reveal an increase in organic carbon content on lower slopes; this could be explained by the soil materials being moved downwards with run-off water from the upper slope and accumulating at the bottom slope position.[31, 32, 33,and 34].

We observed that soil water content and clay increased as slope gradient increased, this resulted to the higher water-holding capacities of clay fraction with water [35]. Our findings seem to contradict some studies that stated that soil water content declines as the slope gradient increases. According to these studies, the higher soil water content in moderate slope can be explained by long-term buildup of soil moisture[36, 37].

The pH-water data correlated negatively with slope gradient; indeed, the pH-water is lowest on steeply sloping soils (C), and highest on gently sloping soils (A and B)(Table 2). This could be attributable to the loss of base-forming cations due to leaching, as well as runoff caused by faster erosion, which reduces soil pH and consequently raises soil acidity [38]. In addition to this pH-water increased as slope gradient increased. This is likely due to the relatively greater amount of organic matter in moderate and lower slope. The release of hydrogen ions that were associated with organic anions during decomposition contributed to the lower pH [39]. Consequently, bulk density was positively correlated to pH-water.This may be explainedby the soil compaction decreases porosity and reduction of organic matterin steeper slope [40].Conversely, bulk density was negatively correlated to soil organic matter, confirming some researches thatrevealed the importance of organic carbon in soil aggregation,which decreases bulk density [41].

In general, diversity represents the structure of a community; this variable reflects changes in species richness as well as habitat quality [42, 43].We evaluated sampling efficiency using species accumulation curves within 66 quadrats of 5m X 2m. The value of the estimator of total observed species (Chao1, Jackknife 1 and Bootstrap), were all higher than 35 which was the total number of observed species in our study area. This indicates that species richness could be improved with additional sampling effort. Among the termite species sampled, soil-feeding species were the most abundant (94.80% of the total sample). Termites of this functional group are commonly found in habitats such as tropical rain forests and savannah woodland with higher concentrations of organic matter in the soil. It appears that the soil substrate of these areas is suitable for the development of termites of this functional group[44].Furthermore,the dominance index ranges from 0.07 to 0.085, which isregarded as a low value. This index's purpose is to determine whether any species or groups of species are distinctive in a certain environment[45]. The index seeks to determine the significance of species in relation to the entire community by taking into account the ethological differencesbetween taxonomic groups whose interactions may be synergistic or competitive [46]. The dominance index values in this study demonstrated that the slope gradient does not distinguish any particular functional group or species of termites from the others.

Concerning the influence of some physico-chemical properties of soil on termites' assemblages, our results showed that slope gradient strongly affected termite species richness and diversity. However, there was no difference in termite species abundance. Some termite species were associated with some specific slope gradient (Figure 5). This indicates that the slope gradient appears to be one of the termite assemblages distributing factors at the soil level. Some studies suggest that a larger slope inclination leads to nutrients leaching towards the softer slope. This phenomenon governs the geographical distribution of elements and nutrients at ground level, disrupting the living conditions of the least resistant species and resulting in a decline in diversity [47].

Some soil physico-chemical variables affected termite attributes. pH-water was the most influential soil variable for termite species richness. Some studies demonstrated that, alkaline environment seem to favours some functional groups such as fungus-growing species; therefore, our results showed positive correlations between pH-water and all the termite functional groups, which confirmed the researches of [48, 49 ,50]. This is the consequence of the lack of organic matter in tropicalsoilsaccording to [51]. Others soil chemical variables such as potassium, sodium, and C/N ratio showed positive correlations, with termite species richness; in addition, soil feeding termites correlated positively with CEC. These results seemed to contradict some findings that showed no correlation between some soil properties and termites assemblages attributes [52], even though sodium enhanced litter termite abundance in some areas [53].

In our study, differences in the distribution of texture, water, carbon content, and other chemical elements between slope gradients resulted in differences within termite communities, with certain termites such as *Procubitermesniapuensis*, *Isognathotermessulcifrons*, and *Adaiphrotermes* sp. associated with gentle slopes and *Isognathotermes*, *heghipericapritermes* sp2. Being associated with steeper slopes, diversity was higher on moderate slopes than on steep slopes. These were confirmed by the CCA analysis supplemented by the NMDS ordination, which considered soil particle size chemistry and soil topography to explain the termite species distribution method according to soil slope. This research revealed changes in species richness composition along slope gradients, with a declining trend in the number of termite species with increasing slopes.

Conclusion

We evaluated the influence of the slope gradient on termite diversity in relation to certain edaphic factors; the results showed a decline in termite diversity. Additionally to this, the increase in soil slope had a negative impact on soil organic carbon,sandy andsilty fractions, but not on the clay fraction. Our findings demonstrated that slope gradient one of the factors controlling the soil's nutrient availability via leaching and runoff. The significative correlation between pH-water and termite species richness suggests that these abiotic factors had an impact on termite assemblages. In addition, NMDS analysis revealed the clustering of some termite species along specific slope gradients. However, these slope variations had no effect on termite abundance; this encourages us to conduct more detailed research. Based on these results, we can conclude that the slope gradient influences the spatial distribution of nutrients and termites at soil level.

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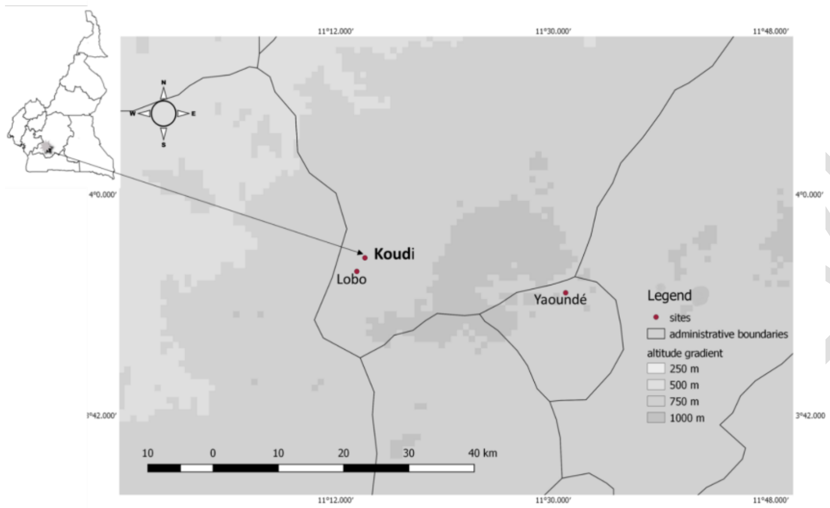

Figure 1: Location of the study area

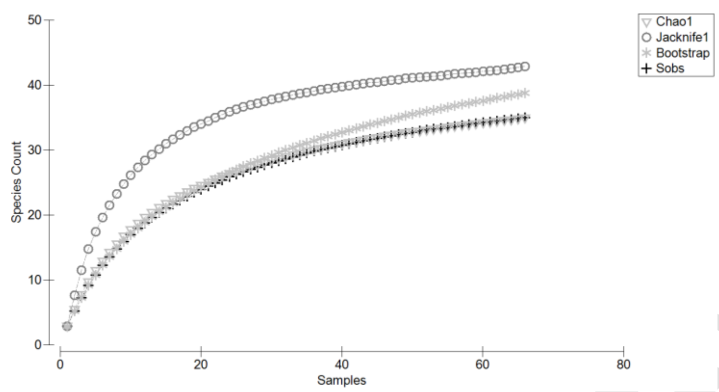

Figure 2: Rarefaction Curves of the global species richness observed in three sloped gradients, according to the nonparametric estimators

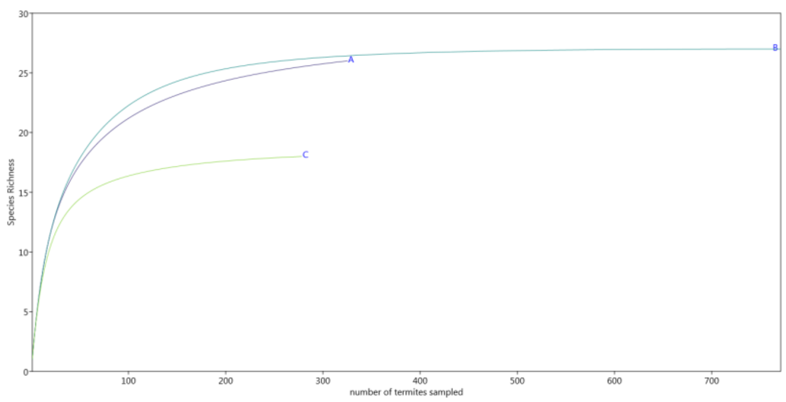

Figure 3: Rarefaction curves of species richness observed on different gradients slope A= [0°; 15°] ; B =[15.1°; 31°] and C= > 31°.

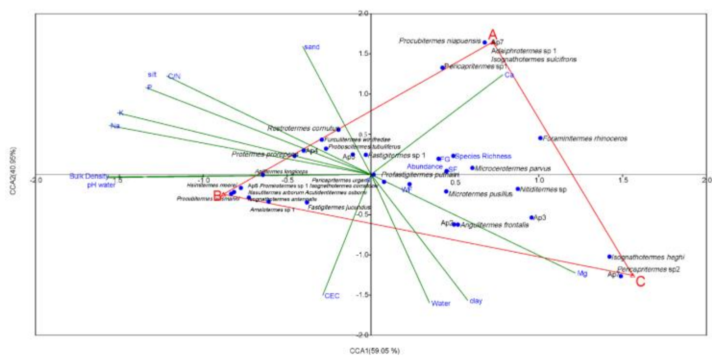

Figure 4: Canonical Correspondence Analysis (CCA). A bi-plot ordination of the 35 termite's species and functional groups according to environmental variables and slope gradient.

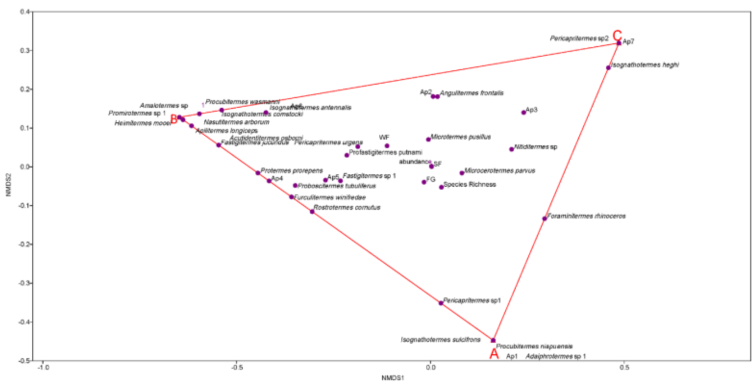

Figure 5: NMDS analysis of the different slope gradients based on the Composition of termites assemblages (FG: fungus growers, SF: soil Feeding; WF: wood feeding)