American Journal of Agriculture and Forestry
2022; 10(1): 33-44
http://www.sciencepublishinggroup.com/j/ajaf
doi: 10.11648/j.ajaf.20221001.16
ISSN: 2330-8583 (Print); ISSN: 2330-8591 (Online)

Termites Distribution and Diversity in Different Land Uses in Mozambique: Implications for Management

Nhiuane Osorio Eufrasio Jose[1, *], Cumbula Sergio[1], Tetine Belincia[1], Sidumo Ivete[1], Buene Cesaltina[1], Mondlane Marcela[1], Chirinzane-Manhica Cacilda[2], Rombe Bandeira Romana[1]

[1]Forestry Department, Eduardo Mondlane University, Maputo, Mozambique

[2]Forestry Department, Agricultural Research Institute of Mozambique, Maputo, Mozambique

Email address:

osorionhiuane@gmail.com (N. O. E. Jose)

[*]Corresponding author

To cite this article:

Nhiuane Osorio Eufrasio Jose, Cumbula Sergio, Tetine Belincia, Sidumo Ivete, Buene Cesaltina, Mondlane Marcela, Chirinzane-Manhica Cacilda, Rombe Bandeira Romana. Termites Distribution and Diversity in Different Land Uses in Mozambique: Implications for Management. *American Journal of Agriculture and Forestry*. Vol. 10, No. 1, 2022, pp. 33-44. doi: 10.11648/j.ajaf.20221001.16

Received: December 17, 2021; **Accepted**: January 12, 2022; **Published**: February 9, 2022

Abstract: Termites play an important ecological role in ecosystems, mainly as decomposers. However, some species under certain conditions may become pests, causing damage in forests and cultivated fields. Termites are associated with native forests, forest plantations and croplands. Despite this, information regarding taxonomy, management, economic and ecological termite impacts for these land uses categories is not widely known. This study aimed to assess termite's distribution, incidence, damage, diversity, and affinity in different land use categories. In circular 0.28ha plots in native vegetation and croplands and 1ha rectangular plots in forest plantations, termites capture was performed and, tree infestation assessed by visual inspection. Plot allocation was random-stratified by land use category. Twenty-one termite species, from nine genera and two families (Termitidae and Rhinotermitidae) were found. Of these species, fourteen, thirteen, ten and nine were respectively associated with miombo woodlands, fallow, cultivated areas and forest plantations, suggesting that species richness decreases with increasing habitat disturbance. Termite incidence is highest in plantation forests, followed by native woodlands, fallow and croplands. In forests, fallow areas, and croplands, damage severity was low, while in forest plantations it ranged from low to moderate. These results suggest that in miombo woodlands, fallow areas, and croplands, termite incidence does not necessarily imply economic damage. Economic losses in *Eucalyptus* plantations reach up to US$ 542.13/ha, reducing with increased plantation age, reaching 1.77 m^3/ha in plantations two years old or less, and 0.73 m^3/ha in 6-year age plantations. Efforts to combat termites are needed at early plantation stages.

Keywords: Croplands, *Eucalyptus* Plantations, Infestation, Miombo Woodlands, Termites

1. Introduction

Miombo is the largest forest ecosystem in southern Africa, with a large socio-economic and ecological role [1]. Its importance extends from peoples' livelihoods through timber and non-timber forest products extraction to the commercial timber industry which contributes to the country's exports and GDP. Native forests in the world in general, and in Mozambique in particular, have come under increasing pressure [2, 3]. Recently, unsustainable exploration of the miombo woodlands involving mainly tree cutting and slash and burn practices has resulted in forest degradation, disruption of its natural equilibrium and a need for miombo woodlands restoration, conditions that could lead pest outbreaks [4].

Considerable areas of deforested or degraded miombo woodland in Mozambique are being replanted using *Eucalyptus* species. On the other hand, *Eucalyptus* plantations are a source of employment in economies such as Mozambique, contributing to the creation of well-being from foreign currency gain by exporting various products and providing wood for fuel and construction. This is one of the reasons that leads to the development of fast-growing species including artificial *Eucalyptus*, pine and *Corymbia* plantations for various uses. In Mozambique, *Eucalyptus*-dominated forest plantations have experienced substantial growth in recent years covering about 62,000 ha [5]. Globally, plantation areas have increased by more than 105 million ha since 1990 representing about 7% of the world's forest area. This increase is around 67% in tropical areas [6].

Species of the genus *Eucalyptus* have been severely attacked by pests [7–9] in particular species of the order Isoptera, family Termitidae (termites) [7, 10, 11], causing significant economic losses [10, 12]. The economic damage caused by termites can be as much as US$ millions, in production losses involving control costs. For example, in the United States, US $ 46 million were spent annually to fight termites [13], while in Brazil, about US $ 3,352 million would be needed to control this pest [11], and $ 8-10 million are spent in Malaysia on termite control [14]. In Mozambique, termites attack on *Eucalyptus* plantations have also been reported. Homogeneous plantations are relatively more vulnerable ecosystems to pest and disease outbreaks due to the availability of favorable conditions for their growth [4].

The occurrence of pests attacking *Eucalyptus* close to extensive native forest stands, a reality in some miombo woodlands restoration areas in Mozambique, may lead to the existence of common pests associated with the two land use cover categories. Miombo woodlands are characterized by the presence of numerous large termite (Termitidae: Isoptera) mounds. There are over 2600 species of termites, which are distributed across 280 genera [15–17]. These organisms have an ecological role in forest ecosystems [18]. These organisms live in colonies and are xylophagous, having cellulose as their main food [11, 19]. Termites are also of high economic importance because they infest the plants in both nursery and young plantations, feeding on tree bark and roots. Through their eating habits, they directly damage the root system of the trees, create tunnels in the core of the trunks, and the damage can affect 50-100% of the tree [12, 19, 20]. Most termites are polyphagous, and as such, able to feed on several tree species from different families, meaning potential risk to attack native miombo tree species as well as *Eucalyptus*. There is a huge diversity of termites, particularly in Africa, of which about 10% are of economic importance, mostly of the *Macrotermes* and *Odontotermes* genera [16]. In case of pests' occurrence, it is imperative that it does not spread, since the narrower the area of occurrence, the greater the probability of success in the control of degradation.

The protection of forest areas against the destruction by pests, with the emphasis on termites aims at preventing or reducing injury and consequent economic damage in order to increase the production of wood, pulp, paper, energy, resin, forest seeds and other products, to the benefit of society that depends on the forest industry as a source of employment. However, to ensure these benefits, it is necessary to take action towards the monitoring and management of termites in the different land uses that they can damage.

For effective pest management and monitoring it is necessary to identify pest species, assess their distribution, incidence, severity, economic damage and techniques and costs of control. Although Mozambique has a wide range of ecosystems and habitats that include native forest, forest plantation and cropland where termites can occur and result in severe negative impacts, studies on the distribution, ecology and damage of these pests are still limited. It was in this perspective that there was a need to urgently conduct this research in order to achieve the following objectives: to identify main termite species on *Eucalyptus* and *Corymbia* plantations surrounding miombo woodlands; to estimate economic damage caused by termites in *Eucalyptus* and *Corymbia* plantations; to determine spatial termites occurrence, distribution, diversity, infestation, severity and interspecific similarity in different land use categories namely miombo woodlands, fallow areas, croplands, *Eucalyptus* and *Corymbia* plantations; and to determine association between main termite species in different land use types.

With this study efficient decision tools for proper control of termites can be developed. Furthermore, this will contribute to forest industry success and socioeconomic stability of the native and planted forests and cropland.

The study's specific objectives included: to determine spatial termites occurrence, distribution, diversity, infestation, severity and interspecific similarity in different land use categories namely miombo woodlands, fallow areas, croplands, *Eucalyptus* and *Corymbia* plantations; to determine the association between main termite species in different land use types; to identify main termite pest species on *Eucalyptus* and *Corymbia* plantations surrounding miombo woodlands; and to estimate economic damage caused by termites in *Eucalyptus* and *Corymbia* plantations.

2. Materials and Methods

2.1. Study Area

The study area covers the District of Gondola in Manica Province and the District of Muanza in Sofala Province, both located in the central part of Mozambique (Figure 1). This region is characterized by a humid tropical climate, with average rainfall ranging from 850 to 1500 mm [21, 22]. The average annual temperature ranges from 16°C to 26°C in Gondola [21] and from 18°C to 30°C in Muanza [22]. The District of Gondola has a surface area of 5,739 km^2 and has an estimated population of 201,735 inhabitants, and the District of Muanza has a surface area of 7,533 km^2 and an estimated population of 42,289 inhabitants [23].

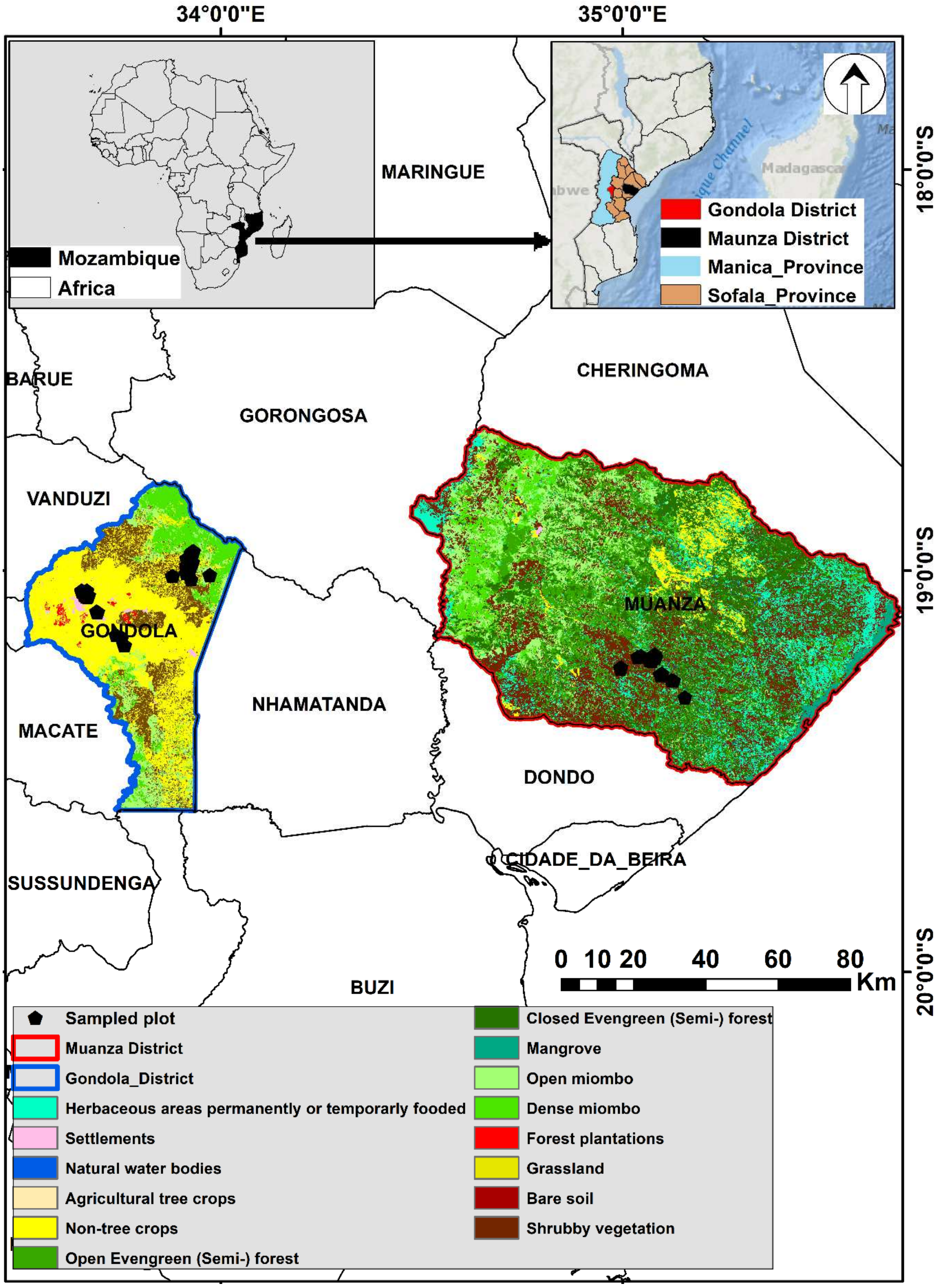

Figure 1. *Location of study site, overlaid on Land Use and Land Cover map (Source: REDD+ Monitoring, Reporting and Verification Unit. Access link: MRV - Início (fnds.gov.mz).*

In both districts shifting agriculture is the main economic activity and practiced by the majority of households. This agriculture is characterized by interspersing the production period with the fallow period in order to ensure the recovery of soil fertility for the subsequent production cycle [24]. Shifting agriculture has been a model of cultivation that contributes most to deforestation and degradation of the Mozambique's forests [25].

Regarding forest cover, Gondola has large diversity of vegetation, comprising a mosaic of grassland, miombo, forest plantations and mountain evergreen forests [26]. However, this diversity of habitats has been under threat due to the expansion of shifting agriculture associated with uncontrolled burning [27]. In Muanza a diversity of ecosystems occurs, from coastal marine to terrestrial. In terms of land cover, shrublands are the most predominant, and are scattered throughout the district and are interspersed with other vegetation types that include dense forests, scrublands, savannahs and forest plantations [26].

2.2. Sampling Site Characterization

The termite sampling followed a land use gradient according to the level of disturbance, having included the almost intact miombo woodlands, areas considered to be with low level of disturbance; fallow areas considered to be areas with intermediate disturbance; and cropland and forest plantations areas intensely disturbed.

In this study we considered areas of almost intact miombo woodlands characterized by the presence of few vestiges of disturbance, presence of mature or nearly mature trees with heights ranging from 8-12 m and with a predominance of species of *Brachystegia spp*., *Julbernardia globiflora* (Benth.) Troupin and *Dyplorhyncus condylocarpon* Müll. Arg. The fallow areas were considered all areas with secondary forest with age between 5-20 years, whose forest results from regeneration after being cleared to give way to anthropogenic activities that include agriculture, logging and other activities.

Cropland were considered areas with the presence of agricultural crops or areas that have been prepared for cultivation even without presenting agricultural crops, as well as areas that have been recently cultivated or harvested. The forest plantations considered in the study were *Eucalyptus* with ages ranging from 1 to 6 years. The *Eucalyptus* plantations were composed by the species *Eucalyptus urophylla* and *Eucalyptus grandis.* Sites in southern Mozambique comprised mostly native vegetation with grasslands, open woodlands, *Eucalyptus* and *Corymbia* plantations.

2.3. Data Collection and Processing

The study completed data collection from May to June 2019 in the dry season in Mozambique, a period considered favorable for termite sampling due to the fact that they forage more evidently at this season [28]. Using the method designed by Eggeton et al. [29], a total of 17, 14 and 10 circular plots with a radius of 30 meters were randomly allocated in intact forest, fallow areas and croplands, respectively. In each plot, 5 sub-plots of 5 x 2 m were established, with one in the center and the remaining four established in a radius of 15 m in the quadrants. In these sub-plots, obeying a sampling effort of 15 minutes per sub-plot, all possible microhabitats of termites were inspected, including termite mounds, tunnels, woody debris, litter, to assess termite distribution, infestation level and severity of termites, as well as collecting specimens for identification at the Entomology Laboratory of Gorongosa National Park (EO Wilson Biodiversity Laboratory).

Data collection to assess the level of infestation and severity of termites was completed by visual inspection of all trees or plants within the sub-plots. For incidence, the presence or absence of termites' under attack was evaluated; plants without signs were considered non-infested and plants with signs were considered infested. The level of termite incidence in percentage, is given by the number of infested plants divided by total number of observed plants [30].

For severity, the severity of attack was attributed to the plants where the incidence of termites was verified, which varied on a scale of 1 to 5, with 1 representing plants that were not harmed, which implies that the plants are healthy, and 5 for severely attacked plants, which implies that these plants have more than 75% of branches, stem or stem attacked [30]. Using equation 1 the damage severity was calculated [31].

$$Damage\ severity\ \frac{n*f}{Z*N}*100 \qquad (1)$$

Where:

n- scale rank given to the plant;

f- frequency of the marks in the total of the plants evaluated

Z- maximum rank of the scale

N- total observations

The same approach used in forests, fallow land and cropland to collect termites for identification, assessment of infestation level and severity was used in forest plantations, differing only in the size of the plots and the method of plot allocation. For the plantations, square plots of 1 hectare in size were systematically distributed throughout the plantation, with a separation of 300 m. This resulted in the allocation of 17 plots to the forest plantations. A systematic approach is recommended when the reference system is easily accessible and the existence of variability within the landscape or target group is low, as is the case in forest plantations [32].

In the plots allocated in forest plantations the inspection was done along diagonal transects, an approach that allows inspecting at least 20 trees in plots up to five hectares in size, the minimum effort recommended in studies aimed at assessing the level of pest infestation in forest plantations [33, 34]. In the same plot, diameter at breast height (DBH), total tree height (H) in infested and non-infested stands were measured. These data were used to estimate tree volume. Additionally, forest plantation managers provided information on termite control costs and timber market prices in order to estimate economic damages and losses using equations described by Bonetti [35].

Many parameters were calculated to assess the economic damage and losses. The tree stem volume was estimated for each age and infested and non-infested trees using the dendrometric data based on equation (2), and subsequently the volume lost by termite infestation was determined by the difference of volumes in the infested and non-infested fields [35]. Cost of control (Cc) was estimated, that is, the amount the company spends to be able to control termite infestation, using equation (3). Economic loss in Meticais (Mozambican currency) per hectare was calculated by multiplying wood loss (m^3/ha) by value of wood in market (Mtn/m^3). The economic damage was quantified through the damage caused by the sum of the economic losses and control costs [35].

$$Vt = \frac{\pi}{4} x\ Dap2\ x\ h \qquad (2)$$

Where:

Vo = wood volume m^3/ha, obtained in infested fields with age x

Vi = wood volume m^3/ha, obtained in uninfested fields with age x

$$Cc = Cm + Cp \quad (3)$$

Where:

Cm = labor cost (Mtn/ha)

Cp = pesticide cost (Mtn/ha)

and

$$Cm = \left(\frac{Nh}{A}\right) x\, Vh$$

Where:

Nh = Number of workers used for combat

A= infested area (ha)

Vh = amount spent by each worker (food, transport, salary and administrative charges) (Mtn/worker)

$$Cp = \left(\frac{Qt}{A}\right) x\, Vp$$

Where:

Qt = Amount of pesticide used per plot (L or Kg/ha)

A = field area (ha)

Cp = pesticide value (Mtn/L or Mtn/Kg).

2.4. Data Analysis

The termite relative abundance, incidence level and damage severity were calculated using Microsoft Excel spreadsheet version 16.

To assess the distribution of termites the occurrence (presence-absence) approach was used, recommended for insects of social habit rather than the number of individuals [36]. This occurrence information was used to determine the relative abundance of termites, which is considered to be the number of occurrences of each species per plot, assuming that the presence of a species in a quadrat (sub-plot) represents an occurrence [37].

In turn, the relative abundance of termites of the land use classes was used to generate the similarity dendrogram of the distribution of termites among the land use classes in the JMP Pro statistical package, using the Average-linkage method also called Unweighted Pair-Group Method using arithmetic Average (UPGMA), recommended for unequal cluster size [38].

To determine termite diversity by land use and land cover classes, integrated rarefaction/extrapolation curves based on the first three Hill numbers were constructed. Hill numbers are mathematically unified families of diversity indices (differing from each other only by the exponent q) that incorporate relative abundance, incidence, or species richness [39]. Total termite species richness was determined by counting the number of species observed in all plots by land use class. Termite species composition similarity was performed by a dendrogram analysis.

The rarefaction method uses the multinomial probability distribution model of the Hill numbers q=0 (species richness), q=1 (Shannon diversity) and q=2 (Simpson diversity) which converts the indices to effective number of species [40]. Thus, we assessed species richness and diversity at each site by rarefaction curves and extrapolation of Hill numbers to incidence data, using the procedures and functions proposed by Chao et al. [39], by means of the iNEXT package version 2.0.9 [40] of the R program version 3.6.2 (R Development Core Team, 2020).

To evaluate the statistical differences in termite richness and diversity among the land use classes the bootstrap method was used which consists of generating confidence intervals at 95% with the application of 200 replicates. The non-overlapping of 95% confidence intervals, whether rarefied or extrapolated curves, are considered to indicate significant differences, and the overlapping of these are to indicate non-significant differences, at 5% significance level [39].

Comparison tests of lost volumes for different ages was based on t-test analysis of variance (ANOVA) followed by *Kruskal-Wallis* at 5% significance through the statistical package JMP Pro (JMP, SAS Team, 2021).

3. Results

3.1. Sampling Efficiency

The interpolated curves, i.e observed species accumulation curves were close to those of estimated species or extrapolated in all land use types except for the Croplands (Figure 2). In the croplands, the trends indicated that additional samplings were required to provide an accurate picture of the local species richness. In this land use, the observed species richness represented only 53% of the expected species richness. Whereas in the other land use types the observed species richness corresponded to at least 75% of the expected species.

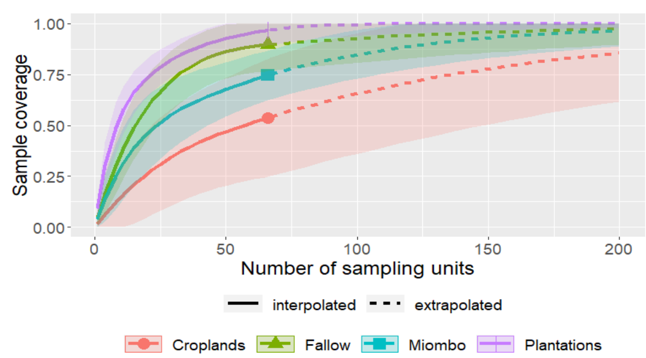

Figure 2. *Sampling coverage-based in interpolation (solid curve) and extrapolation (dashed curve) across four land use types.*

3.2. Species Richness and Diversity Across Land Use Types

Twenty-one termite species from nine genera and two families (Termitidae and Rhinotermitidae) were found. The species richness (q=0), and species diversity (Shannon, q=1 and Simpson, q=2) varied significantly across land use types (Bootstrap, 95% confidence level). The miombo woodlands had the highest termite diversity and richness species, and differed significantly from other land use types, which were not statistically different among them. This may be seen by overlapping the confidence intervals of its graphics (red, green, and violet for croplands, fallow and forest plantation respectively) (Figure 3).

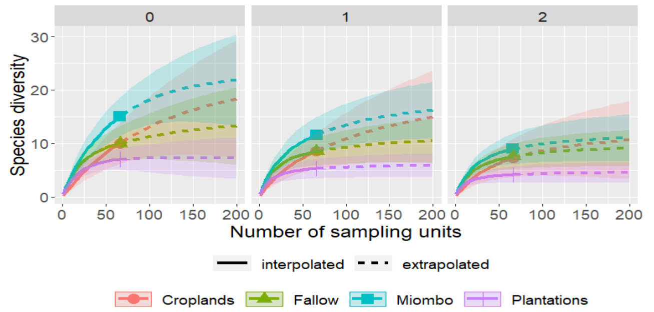

Figure 3. *Comparison of species diversity, species richness (q = 0), Shannon diversity (q = 1) and Simpson diversity (q = 2), across four land use types.*

3.3. Species Composition Across Land Use Types

The cluster analysis showed that species composition was affected by land use change, since two distinct clusters were formed. These land use types were grouped according to the similarity of the termite's community composition in (Figure 4). The croplands and forest plantations formed one cluster, and the miombo woodlands and fallow were grouped together. The assessment of community complementarity of termites in varying land use types highlighted that the croplands and forest plantations grouped together had relatively similar species compositions, sharing 51% of their species (Table 1), such as: *Macrotermes mossambicus*, *Nasutitermes* cf. *kempae*, *Macrotermes sp*., *Cubitermes sp*., and *Pseudocanthotermes sp.* Also, the termite communities in miombo woodlands or native forest were relatively similar to those in fallow, sharing 56% of their species (Table 1), highlighting the *Apicotermes sp*., *Cubitermes sp*., *Macrotermes sp*., *Microtermes* sp1., *Nasutitermes infuscatus, Nasutitermes* cf. *kempae, Schedorhinotermes lamanianus* (Figure 4). The termites species composition in the forest plantations was dissimilar to those of the miombo woodlands. The *Ancistrotermes latinotus* occurred only in miombo woodlands, whereas *Trinervitermes rapulum* occurred only in forest plantations.

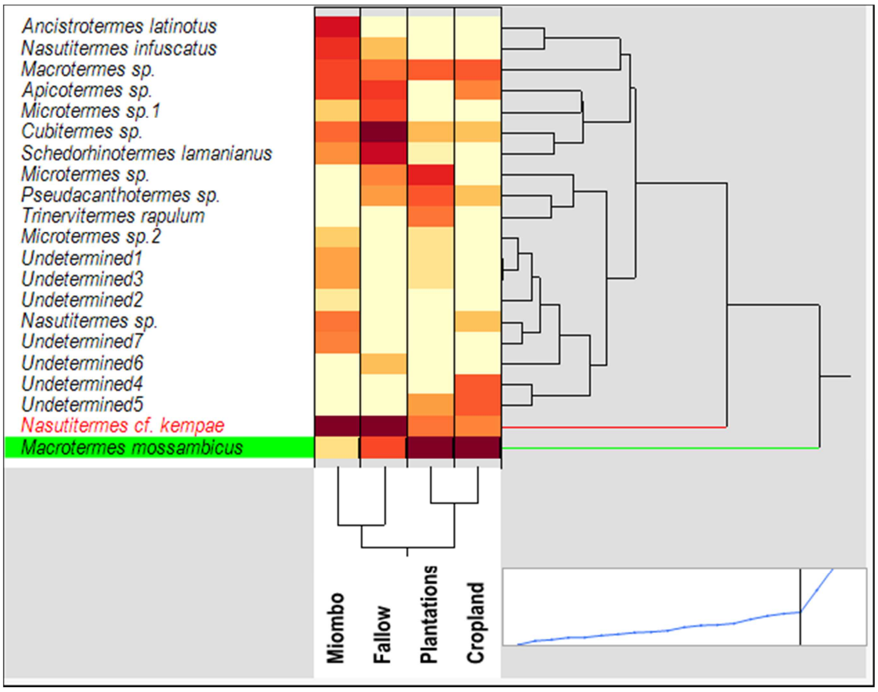

Figure 4. *Dendrogram of species composition comparison between different land use type. In this diagram darker colors indicate species with higher frequency/occurrence and lighter ones indicate low frequency. Land uses with similar colors indicate similarity in species composition, and with different colors indicate species dissimilarity.*

Table 1. *Assessment of community complementary of termites in different land use types in studies area.*

Habitat 1	Habitat 2	No. of total species	No. of shared species	Complementarity (β-diversity)
Croplands	Fallow	13	7	0.47
Croplands	Forest	16	7	0.44
Croplands	Plantations	13	6	0.49
Fallow	Forest	17	7	0.44
Fallow	Plantations	11	5	0.62
Forest	Plantations	18	4	0.73

3.4. Termite Incidence and Damage Severity

Termites infested native and exotic plants of all land use types considered in this study. Among the land uses, termites showed the highest incidence rate 56% in forest plantations, followed by native miombo woodlands 34%, fallow areas 29% and finally agricultural areas with only 12% (Figure 5). Based on the same figure it is noted that in terms of severity, the termites reached the class of moderate damage to the plants of the forest plantations and in the other categories (native forest, fallow and cropland) the damage was limited to low.

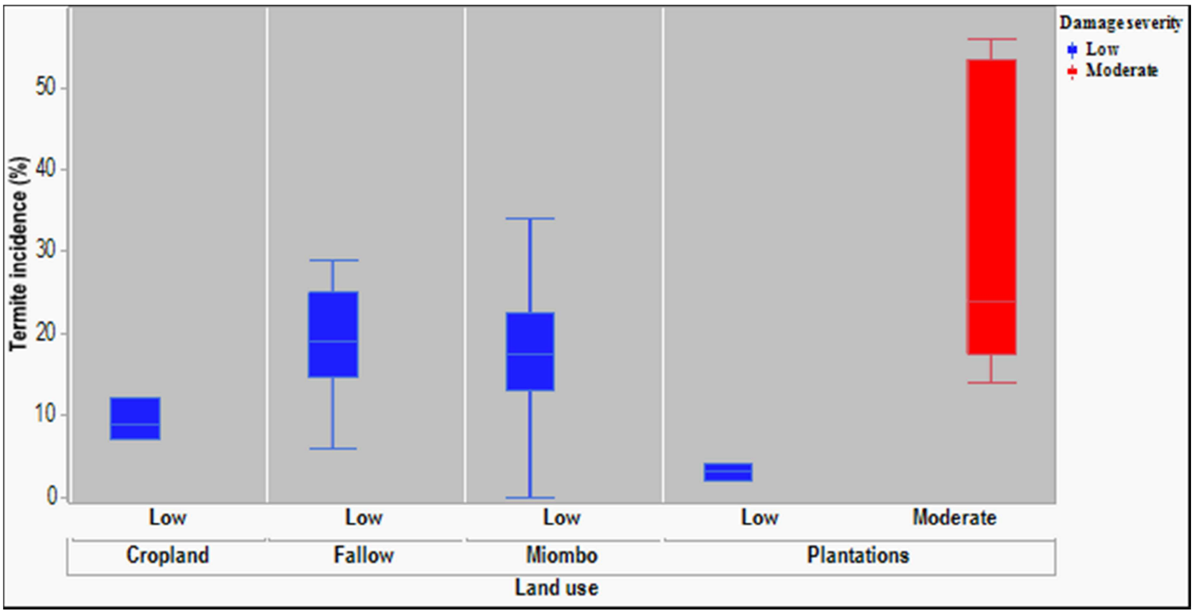

Figure 5. *Incidence and severity damage of termites in different land use type.*

3.5. Economic Losses in Eucalyptus and Corymbia Plantations

The economic damage caused by termites in forest plantations is presented in table 2. Younger stands with only 2 year suffered greater loss in volume around 1.77 m^3/ha compared with old stand with 6 years where the losses were only 0.77 m^3/ha, and consequently, higher economic damage.

Table 2. *Losses associated with termite infestation in plantations of Eucalyptus and Corymbia stands at different ages.*

Stand age (years)	Volume lost (m^3/ha)	Economic loss (Mtn/ha)	Costs (Mtn/ha)	Economic damage (Mtn/ha)
2	1.77	5,575.50	27,900.00	33,475.50
6	0.73	2,299.50	27,900.00	30,199.50

Mtn stands for local currency Meticais (MZN); exchange rate $ 1USD approximately 64,00 MZN.

4. Discussion

4.1. Sampling Efficiency

In miombo woodlands, fallow areas and forest plantations, at least 75% of the termite species richness expected in these habitats was observed during sampling conducted in these habitats. These results suggested a high efficiency of our sampling method in land use types except for the croplands where only 53% of the expected species were collected. Therefore, this result suggested that more than three plots needed to be sampled in croplands, in order to provide an accurate picture of local species richness. Ideally, all species accumulation curves would reach asymptote or stability, indicating that all representative elements of the area were collected [41].

Although, we found a low sampling coverage for croplands in this study, our objective of assessing changes in termite diversity along a gradient of land use intensification could be addressed using the method of rarefaction and extrapolation based on sample coverage. The rarefaction and extrapolation based on sample coverage allowed us to compare species richness of a set of communities with different sample size selecting the lowest among these maximum coverages as base coverage [42]. This method yields less biased comparisons of richness between communities [42].

4.2. Species Richness, Composition and Diversity Across Land Use Types

In this study, we found 21 species belonging to 9 genera, 5 subfamilies and 2 families. These findings were close to those observed by Nduwarugira et al. [43], who found 25 species belonging to 18 genera, 5 subfamilies and 2 families in miombo woodland in Burundi. Also, were similar to those found by Donovan et al. [44], who recorded 28 species belonging to three subfamilies in wet miombo in Malawi. However, the species richness observed in this study was lower than that recorded from Afrotropical rain forests [45–47], probably due to climatic differences, especially the temperature and rainfall. Additionally, termite diversity was highly influenced by the aridity of the environment along a rainfall gradient [46].

The results showed that the termite species richness and diversity declined with an increasing land use intensification gradient. Termite species richness was lower in agricultural areas than in miombo woodlands. It decreased from the miombo woodland to the forest plantations. These findings are consistent with the findings of [43, 48–51], who reported that termite species richness, diversity, abundance and biomass decreased along the gradient of human disturbance. Generally, areas with the same age of land use or that have undergone the same type of land use change tend to present similar species distributions [52].

The decline of the termite species richness and diversity in croplands and fallows may be explained by the removal of vegetation that affects the microclimate, quantity and quality of feeding and nesting sites [49, 53]. The decline in species richness and termite abundance was due to changes in canopy cover, which caused greater fluctuations in temperature and soil moisture content, which probably caused desiccation of other functional groups, such as soil feeders. Whereas, in the plantation forest, the decline in species richness and termite abundance was probably due to the modification of original habitats replaced by monoculture of exotic species [54]. The simplification of local environmental structures by reducing the number of native plant species and increasing the number of cultivated species has a negative impact on biodiversity [55]. In miombo woodland in the same study area it was noticed that termite species richness had a strong and positive correlation with native plant species richness [56]. Additionally, less disturbed habitats characterised by a diversity of species and microhabitats such as the miombo woodlands in this study contribute to the existence of high diversity and richness of termite species, as these habitats are more capable of providing a diversity of shelter and food conditions for termites, such as: litter, wool, excrement, living or dead wood, humus, plants roots [57]. Although, when looking at termite densities, high densities have been observed in disturbed environments such as croplands and plantation forests in comparison to undisturbed areas such as almost intact native forests [58].

However, the pattern observed in this study diverges from that observed by Materu et al. [59], who found that the gradient of land use intensification did not have a significant effect on the richness, abundance and diversity of termite species in Tanzania. A plausible explanation for the pattern observed by Materu et al. [59] is that the most disturbed habitat was an agroforestry system, inserted in a primary forest, which could host many species, serving as a refuge for species sensitive to disturbances; and later it would facilitate the recolonization of species that were initially eliminated [60].

The results showed that the land use intensification gradient affects the termite species composition. Miombo woodlands and fallows were similar, and both were dissimilar to the croplands and forest plantations. This pattern is in tandem with that obtained by Ackerman et al. [61], who noticed dissimilarity between forest and home-garden agroforests in central Amazonia. Similar results were also observed in other taxa of soil macrofauna. For example, Kone et al. [62] found that agricultural systems possess lower ant species richness and a strongly different species composition compared to forests.

The species similarity between miombo woodland and fallows could be explained by the similarity in the composition of native plant species richness, availability of organic matter, dead wood, litter and the proximity of the remaining forest patches to the fallows, which provide refuge for the original miombo woodlands termite species and subsequent recolonization of the fallows. In contrast to the dissimilarity with croplands and forest plantations, which was probably linked to the disappearance of native forest species and the colonization of the space by the most adapted species.

4.3. Termite Incidence and Damage Severity

In this study, the termite incidence occurred on all land uses, although forest plantations was the land category most infested by termites, while cropland was the least infested category. The high incidence of termites observed in the forest plantations in this study may be explained by the type of *Eucalyptus* species (*E. grandis* and *E. urophylla*) in these plantations, as *E. grandis* is considered to be one of the most susceptible species to attacks by termites [57, 63]. According to Nair [18], pest outbreaks are less frequent and less severe in natural forests, and when infestation does occur, tends to be small, it because in heterogeneous and diverse habitats such as natural forest, pests have difficulties in finding hosts due to lower suitable resources concentration for the pest and an increase in natural enemy abundance.

The low level of termite incidence and severity attack in croplands may have been due to the fact that the cropland included in this study that had a variety of agricultural crops which are environments that are expected to suffer less damage of termites than monocultures. The similar results were observed by Sekamatte et al. [64] and Mugerwa [65], where they report a decline in termite damage due to the integration of legumes crop into cereal crop in the fields. Additionally, Jactel et al. [66], reported that pest densities were significantly lower in mixed cultures than in monocultures in 60-62% of cases, as in intercropping fields pests have difficulties in finding hosts due to the existence of a variety of crops, as well as the fact that in intercropping fields increases the number of predatory ant nests. In that regard, the diversification of crops in agricultural ecosystems can serve as a successful strategy for termites control by naturally regulating the termite population [67].

In this study, although the termite attack was observed in all evaluated land uses, the highest level of termite attack severity was observed in the forest plantations. This can be explained by the fact that the substitution of native areas, which are characterised by a diversity of species, by plantations, which have only a few species, contributes to the adaptation of the diet of termites to the point where their diet is restricted to a few species, resulting in huge population of pests and more severe attack on the few species found in plantations [18, 68]. In addition, according to these authors, the species of termites, particularly pests, are able to present high incidence in environments with almost homogeneous conditions such as plantations because they are able to adapt to the conditions of homogeneous habitats and are resistant to these simplified environments. According to Nair [18], termites rarely damage native species, this may explain the low severity of termite attack observed in native forests and fallow areas in this study.

Also, generally, the level of severity of termites in natural forests is due to the fact that native plant species have the ability to develop effective defenses against termites and this contributes to the existing balance between plant growth and termite feeding. This plant defense mechanism is provided by the secreting chemicals such as oils, resins and lignins existing in the walls of woody cells [69, 70]. In this regard, termites would only cause damage to unhealthy, immature, or stressed native trees [70]. The degree of susceptibility to termite attack on plants varies and is influenced by several factors such as species, age, forest site quality and physical anatomical and chemical properties of the plant to termite attack, floristic diversity, microclimate, spatial and structural arrangement and tree management, may have implications in plants susceptibility to termite attack [71].

It is relevant to mention that most of the species of termites that are found in natural forests cannot be described as pests, as their presence is not correlated with yield losses, when they are not pests their presence has essential ecological functions that support the sustainability of ecosystems because the following benefits, improvement of water permeability and nutrient availability [63, 72, 73].

4.4. Economic Losses in Forest Plantations

Termites can attack eucalyptus stands from the nursery to the adult phase. However, the most severe damage is seen in the nursery and in the first years after establishment of the plantations [63], the similar result found in this study. The greater economic damage seen in the younger plantations can be explained by the fact that the lignin and cellulose in the initial phases is still small and with the growth of the individuals it increases and becomes more rigid which makes it more difficult for the plants to be attacked by termites and consequently less economic damage [74].

The results of this study clearly show that termites have an effect on tree growth, which compromises the expected volume at the end of the production cycle. In *Eucalyptus* plantations in Brazil it was observed a loss of volume caused by termites of 0.32 m^3/ha for *E. camaldulensis* and 0.65 m^3/ha for seven-year-old *E. urophylla* [75]. For the case of the *Eucalyptus* and *Corymbia* plantations under study, costs of control can be considered reasonable since, according to Anjos [76], using chemical termicides in *Eucalyptus* plantations for control can reach 5% of total forest implantation cost. With regard to economic damage, Zanetti et al. [75], observed in their study a damage by termites of US$ 2.82/ha at the end of each *Eucalyptus* cycle for charcoal production (seven years), also referring that volume losses by termites could reach 6,580.00 m^3/year which represents about US$ 39,480/year for the area they studied. Bonetti [35], in his study, observed a 50% loss in production corresponding to US$ 12.33/ha.

5. Conclusions

Termite species composition was affected by land use change, grouped according to the similarity of termite community composition with croplands and forest plantations forming one cluster, and the miombo woodlands and fallow forming other. Also, the termite's species richness was affected by land use changes, it decreases with increasing habitat disturbance.

Termite incidence is highest in plantation forests, followed by native woodlands, fallow areas and croplands; while the severity of termite damage was low in natural forests, fallow areas, and croplands, and ranged from low to moderate in forest plantations. The termites damage in forests plantation decreases with the plantation ages, implying that effective control is needed in young plantations to avoid yield losses. In addition, the dissimilarity in termite species composition between forest plantations and miombo woodlands suggest that in the miombo woodlands, fallow areas and croplands, termite incidence does not necessarily imply economic damage but they likely contribute for maintenance of the ecological functions of these habitats.

Acknowledgements

The authors wish to thank the Faculty of Agronomy and Forestry, Department of Forestry of the Eduardo Mondlane University (UEM) and the National Institute of Agricultural Research for providing logistics such as transportation and allowing working time of its staff. We thank the UEM-Suécia 2017-2022 programme, sub-programme 1.2.3. (Forests and Agroforestry Systems for Poverty Reduction in Rural Zones of Moçambique), funded by the Swedish Agency for International Development (SIDA) for funding students' field work. We are grateful to the National Research Fund for funding the research project coordinated by the UEM, in which we were granted funds to publish this article.

Our thanks are extended to the entomology lab EO Wilson Biodiversity Laboratory in Gorongosa in particular Prof. Piotr Naskrecki, Museum of Comparative Zoology, Harvard University, US, for species identification, instrumental in this research. Finally, but not the least, our gratitude goes to the forestry company Investimento Florestal de Moçambique, Lda (IFM) for their support during field work including accommodation, staff availability in guiding field work, constant technical assistance in the field, local transportation, and allowing its plantations to be used as part of the study sites. We would also like to extend our deepest thanks to Eric Wilburn for helping us with the language revision of the manuscript.

References

[1] Campbell, B. M. (1996). The Miombo in transition: woodlands and welfare in Africa. In Campbell, B. (Ed.), *The Miombo in transition: woodlands and welfare in Africa*. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/000465.

[2] FAO. (2010). *Global Forest Resources Assement: Mozambique*. Food and Agriculture Organization of the United Nations, pp. 54.

[3] Pirard, R., Dal Secco, L., & Warman, R. (2016). Do timber plantations contribute to forest conservation? In *Environmental Science and Policy* (Vol. 57, pp. 122–130). Elsevier Ltd. https://doi.org/10.1016/j.envsci.2015.12.010

[4] Chamshama, S. A.., Nwonwu, F. O.., Lundgren, B., & Kowero, G.. (2009). Plantation Forestry in Sub Saharan Africa: Silvicultural, Ecological and Economic Aspects. *Discovery and Innovation*, *21* (3), 42–49. https://doi.org/10.4314/dai.v21i3.48210

[5] WRN. (2013). *Moçambique: plantações industriais de árvores prometem lucros para investidores, deixando impactos negativos para comunidades camponesas*, pp. 23.

[6] FAO. (2015). Global Forest Resources Assessment 2015. In *Desk Reference*. Food and Agriculture Organization of the United Nations.

[7] Namujehe, G., & Orikiriza, L. J. B. (2013). Natural Durability of Eucalyptus Clones against Termite Attack. *International Journal of Sciences: Basic And\rApplied Research*, *10* (1), 176–183.

[8] Nyeko, Philip, & Olubayo, F. M. (2005). Participatory assessment of farmers' experiences of termite problems in agroforestry in Todoro district, Uganda. *Agricultural Research and Extension Network*, *143*, 20.

[9] Nair, K. S. S. (2001). Pest outbreaks in tropical forest plantations: is there a greater risk for exotic tree species? In K. S. S. Nair (Ed.), *Pest outbreaks in tropical forest plantations: is there a greater risk for exotic tree species?* Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/000984.

[10] Adekayode, F. O., & Ogunkoya, M. O. (2009). Comparative study of clay and organic matter content of termite mounds and the surrounding soils. *African Crop Science Conference Proceedings*, *9*, 379–384.

[11] Amaral, R. D. D. A. M. (2002). *Diagnóstico da ocorrência de cupins xilófagos em árvores urbanas do bairro de higienópolis, na árvores urbanas do bairro de Higienópolis.* USP, pp. 85.

[12] Debelo, D. G., & Degaga, E. G. (2017). Study on termite damage to different species of tree seedlings in the Central Rift Valley of Ethiopia. *African Journal of Agricultural Research*, *12* (3), 161–168. https://doi.org/10.5897/ajar2016.11831

[13] Mill, A. E. (1992). Termites as agricultural pests in Amazonia, Brazil. *Outlook on Agriculture*, *21* (1), 41–46. https://doi.org/10.1177/003072709202100107

[14] Lee, C. Y. (2002). Subterranean termite pests and their control in the urban environment in Malaysia. *Sociobiology*, *40* (1), 3–9.

[15] Beltrão, F. L. S. (2012). *Ocorrência e Preferência Alimentar de Térmitas*. UFRRJ, pp. 40.

[16] Shiday, B. M.., Nkunika, P. O. Y., Sileshi, G. W., French, J. R. J., Nyeko, P., & Jain, S. (2011). Potential impact of climate change on Termite Distribution in Africa. *British Journal of Environment and Climate Change*, *1* (4), 172–189. https://doi.org/10.1115/OMAE2011-50162.

[17] Amaral-Castro, N. R., Zanetti, R., Moraes, J. C., Zanuncio, J. C., Freitas, G. D., & Santos, M. S. (2004). Species of soil inhabiting termites (Insecta: Isoptera) collected in *Eucalyptus* plantations in the State of Minas Gerais, Brazil. *Sociobiology*, *44* (3), 717–725.

[18] Nair KSS. (2007). Tropical Forest Insect Pests: Ecology, Impact, and Management. Cambridge. New York, pp. 424.

[19] Silveira, A. G., Santini, E. J., Trevisan, R., Cancian, L. C., & Mariano, L. G. (2015). Ocorrência e Danos de Térmitas na Madeira de Acacia mearnsii (Fabaceae) em Dois campos de apodrecimento. *Rev. Inst. Flor.*, *27* (2), 183–189.

[20] Jimu, L., & Mujuru, L. (2017). Pathogens and Pests Threatening Plantation Forestry in Zimbabwe. *East African Agricultural and Forestry Journal*, *82*, 2–4.

[21] MAEa. (2005) Perfil do distrito de Gondola, Província de Manica. Maputo, Mozambique: Ministério de Administração Estatal, pp. 50.

[22] MAEb. (2005). Perfil do distrito de Muanza, Província de Sofala. Maputo, Mozambique: Ministério de Administração Estatal, pp. 45.

[23] INE. (2020). Anuário Estatístico 2019- Moçambique.

[24] Pollini, J. (2014). Slash-and-burn agriculture Synonyms: shifting cultivation, swidden cultivation. *Encyclopedia of Food and Agricultural Ethics*, *January*. https://doi.org/10.1007/978-94-007-0929-4

[25] CEAGRE & Winrock Internacional. (2016). Identificação e análise dos agentes e causas directas e indirectas de desmatamento e degradação florestal em Moçambique. 2016, pp 36.

[26] Fundo Nacional de Desenvolvimento, Sustentável. (2019). Uso e Cobertura da Terra para o ano de 2016. Monitoria Relatório e Verificação, REDD+. Maputo, Mozambique: FNDS, MITADER.

[27] Mavie E. B. (2012). Estimativas de Perdas de Carbono Associadas com Mudanças da Cobertura Florestal. Maputo, Mozambique: UEM/FAEF, pp. 56.

[28] Dosso, K., Deligne, J., Yéo, K., Konaté, S., & Linsenmair, K. E. (2013). Changes in the termite assemblage across a sequence of land-use systems in the rural area around Lamto Reserve in central Côte d'Ivoire. *Journal of Insect Conservation*, *17* (5), 1047–1057. https://doi.org/10.1007/s10841-013-9588-2.

[29] Eggleton, P., Homathevi, R., Jeeva, D., Jones, D. T., Davies, R. G., & Maryati, M. (1997). The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, east Malaysia. *Ecotropica, 3*, 119–128.

[30] Mello, A. P. De, Guedes, B., Avany, M., & Gusmao, B. (2014). Termite infestation in historical buildings and residences in the semiarid region of Brazil. *Sociobiology*, *6* (3), 318–323. https://doi.org/10.13102/sociobiology.v61i3.318-323.

[31] Mckinney, H. H. (1923). Influence of soil temperature and moisture on infection of wheat seedlings by Helminthosporium sativum. *Journal of Agricultural Research*, *26*, 195–217.

[32] Aune-Lundberg, L., & Geir-Harald, S. (2014). Comparison of variance estimation methods for use with two-dimensional systematic sampling of land use/land cover data. *Environmental Modelling & Software*, *61*, 87–97.

[33] Nyeko, P., Mutitu, E. K., & Day, R. K. (2009). *Eucalyptus* infestation by Leptocybe invasa in Uganda. *African Journal of Ecology*, *47*, 299–307.

[34] Sobrinho R. B., Mesquita A. L. M., Hawerroth F. J., Kavati R., Silva K. S. (2011). Identifcação e Monitoramento de Pragas na Produção Integrada da Gravioleira. Fortaleza, Brazil: Empresa Brasileira de Pesquisa Agropecuária (Embrapa). pp. 26.

[35] Bonetti R. Z. (1988). Estimativa do Nível de Danos Económicos Causado por Formigas Cortadeiras em Eucaliptais. Minas Gerais, Brasil: Universidade de Viçosa, pp. 92.

[36] Andersen, A. N. (1991). Sampling communities of ground-foraging ants: Pitfall catches compared with quadrat counts in an Australian tropical savanna. *Australian Jourtial of Ecology*, *16*, 273-279.

[37] Magurran A. (2004). Measuring Biological Diversity. Oxford: Blackwell Publishing Company. 256 p.

[38] Dawyndt, P., Meyer, H., & Baets, B. (2005). UPGMA clustering revisited: A weight-driven approach to transitive approximation. *International Journal of Approximate Reasoning*, *42*, 174–191.

[39] Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K., & Ellison, A. M. (2014). Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecological Monographs*, *84*, 45–67.

[40] Hsieh, T. C., Ma, K. H., & Chao, A. (2016). Application of iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution. *British Ecological Society*, *7*, 1451–1456.

[41] Evangelista A. L. (2009). Impacto do fipronil sobre a comunidade de cupins (Insecta: Isoptera) em áreas cultivadas com eucalipto no Cerrado. Lavras, Brasil: Universidade Federal de Lavras, pp. 50.

[42] Chao, A., & Jost, L. (2012). Coverage-based rarefaction and extrapolation: standardizing samples by completeness rather than size. *Ecology*, *93* (12), 2533–2547.

[43] Nduwarugira, D., Mpawenayo, B., & Roisin, Y. (2016). The role of high termitaria in the composition and structure of the termite assemblage in Miombo woodlands of southern Burundi. *The Royal Entomological Society, Insect Conservation and Diversity*. https://doi.org/doi:10.1111/icad.12207y.

[44] Donovan, S., Eggleton, P., & Bignell, D. E. (2002). Gut content analysis and a new feeding group classification termites. *Ecological Entomology, 26* (4), 356–366. https://doi.org/http://dx.doi.org/10.1046/j.1365-2311.2001.00342.x.

[45] Aanen, D. K., & Eggleton, P. (2005). Fungus-Growing Termites Originated in African Rain Forest. *Current Biology*, *15* (9), 851–855.

[46] Davies, A. B., Eggleton, P., van Rensburg, B. J., & Parr, C. (2013). Assessing the relative efficiency of termite sampling methods along a rainfall gradient in African savannas. *Biotropica*, *45*, 474–479. https://doi.org/doi:10.1111/btp.12030.

[47] Koné, N. A., Silué, K. S., Konaté, S., & Linsenmair, K. E. (2018). Determinants of Termite Assemblages' Characteristics within Natural Habitats of a Sudano-Guinean Savanna (Comoe National Park, Côte d'Ivoire). *Insects*, *9*, 189. https://doi.org/doi:10.3390/insects9040189.

[48] Muvengwi, J., Mbiba, M., H. G. T, N., Nyamadzawo, G., & Nhokovedzo, P. (2017). Termite diversity along a land use intensification gradient in a semi-arid savanna. *J Insect Conserv*, *40*, 380–391. https://doi.org/.Doi:10.1007/s10841-017-0019-7.

[49] Jones, D. T., Susilo, F. X., Bignell, D. E., Hardiwinoto, S., Gillison, A. N., & Eggleton, P. (2003). Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *J Appl Eco, 2003.*

[50] Barros, E., Pashanasi, B., Constantino, R., & Lavelle, P. (2002). Effects of land-use system on the soil macrofauna in Western Brazilian Amazonia. *Biol Fertil Soils*, *35*, 338–347.

[51] Eggleton, P., Bignell, D. E., Hauser, S., Dibog, L., Norgrove, L., & Madong, B. (2002). Termite diversity across an anthropogenic disturbance gradient in the humid forest zone of West Africa. *Agric Ecosyst Environ*, *90*, 189–202. https://doi.org/doi:10.1016/ S0167-8809(01)00206-7.

[52] Santos, J. C. (2014). *Distribuição espacial e plano de amostragem de Syntermites spp (Isóptera Termitidae) em áreas de implementação de eucalipto no Bioma Cerrado*. Universidade Federal de Lavras, pp. 58.

[53] Bandeira, A. G., Vasconcellos, A., Silva, M. P., & Constantino, R. (2003). Effects of habitat disturbance on the termite fauna in a highland humid forest in the Caatinga domain, Brazil. *Sociobiology*, *42* (1), 117–127.

[54] Davies, R. G., Eggleton, P., Dibog, L., Lawton, L. H., Bignell, D. E., Brauman, C. H., Nunes, L., Holt, J., & Rouland, C. (1999). Successional response of a tropical forest termite assemblage to experimental habitat perturbation. *Journal of Applied Ecology*, *36*, 946-962.

[55] Altieri, M. A., Silva, E. N., & Nicholls, C. I. (2003). *A biodiversidade e seu papel ecológico na agricultura*. In A. M. A., E. N. Silva, & N. C. I. (Eds.), *O papel da biodiversidade no manejo de pragas*, pp. 17–23.

[56] Cumbula, S. (2021). *Diversidade de térmites nas florestas de miombo: Efeito dos factores ambientais e antropogénicos*. Maputo, Mozambique: UEM/FAEF, pp. 77.

[57] Filho, E. B, Mariconi, F., M. D. A, Wilcken, C. F., Dietrich, C. R. R. C, Costa, V. A., Chaves, L. E. L., & Cerignoni, J. A. (1993). *Manual de pragas em florestas: cupins ou térmitas*. Third edit. Brasil.: IPEF/SIF, pp. 56.

[58] Valério, J. R, Lapointe, S. L, Kelemu, S., Fernandes, C. D, Morales, F. J. (1996). *Pest and Diseases of Brachiaria Species*. In: Miles JW, Maass BL, Valle CB, editors. Cali, Colombia: Centro Internacional de Agricultura Tropical (CIAT), pp. 87–105.

[59] Materu, C., Yarro, J., & Nyundo, B. (2013). Termite (Isoptera) Assemblages in Rufiji District Tanzania. *Journal of Biology, Agriculture and Healthcare*, *3* (14).

[60] Neoh, K. B., Bong, L. J., Itoh, A. M. M., Kozan, O., & Yoshimura, Y. T. T. (2015). Understanding the impact of fire on termites in degraded tropical peatlands and the mechanisms for their ecological success: current knowledge and research needs. *The Ecological Society*. https://doi.org/DOI10.1007/s11284-015-1289-8

[61] Ackerman, I. L., Constantino, R., Gauch, J. H. G., Lehmann, J., J., S., Riha, S. J., & Fernandes, E. C. M. (2009). Termite (Insecta: Isoptera) Species Composition in a Primary Rain Forest and Agroforests in Central Amazonia. *Biotropica*, *41* (2), 226–233. https://doi.org/10.1111/j.1744-7429.2008.00479.x.

[62] Kone, M., Konate, S., Yeo, K., Kouassi, P. K., & Linsenmair, K. E. (2012). Diversity and abundance of terrestrial ants along a gradient of land use intensification in a transitional forest-savannah zone of Côte d'Ivoire. *Journal of Applied Biosciences*, *29*, 1809 – 1827.

[63] Filho, E. B., Fontes, L. R. (1995). Aspectos actuais da biologia e controle de cupins. Piracicaba, Brasil: Fealq, pp. 184.

[64] Sekamatte, M. B., Ogenga-Latigo, M., & Russell-Smith, A. (2003). Effect of maize– legume intercrops on termite damage to maize, activity of predatory ants and maize yield in Uganda. *Crop Protect*, *22*, 87–93.

[65] Mugerwa, S. (2015). Magnitude of the termite problem and its potentialanthropogenic causes in Nakasongola district of Uganda. *Japanese Society of Grassland Science*, *61*, 75–82.

[66] Jactel, H., Brockeroff, E., & Duelli, P. (2005). A test of the biodiversity–stability theory: meta-analysis of tree species diversity effects on insect pest infestations, and reexamination of responsible factors. *Springer-Verlag*, 235–62.

[67] Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu. Rev. Entomol*, *45*, 175–201.

[68] Sales, M. J. D., Matos, W. C., Reis, Y. T., & Ribeiro, G. T. (2010). *Frequência e riqueza de cupins em áreas de plantio de eucalipto no litoral Norte da Bahia*. Pesquisa Agropecuária Brasileira.

[69] Osipitan, A. A., Jegede, T. O., & Adekanmbi, D. I. Ogunbanwo, I. A. (2013). Assessment of Datura metel, local soap and garlic (Allium sativum) in the management of Termite (Termitidae: Isoptera). *Munis Entomology & Zoology.*, 407–414.

[70] Adedeji, G. A., Emerhi, E. A., & Nyenke, E. (2015). Incidence and Severity of Termites Infestations on Azadirachta indica A. Juss. Used as Avenue Trees in University of Port Harcourt, Nigeria. *Journal of Agriculture and Veterinary Science*, *8*, 123–126.

[71] Gallio, E., Machado, S. F., Silva, F. J. T., Cruz, N. D., & Gatto, D. A. (2018). Caracterização de propriedades tecnológicas de quatro folhosas deterioradas por térmitas do gênero Nasutitermes. *Nativa, Sinop*, *6* (especial), 763–766.

[72] Khan, M. A., Ahmad, W., & Paul, B. (2018). Ecological impacts of termites. In Termites and Sustainable Management. *Biology, Social Behaviour and Economic Importance*, *1*, 201–216.

[73] Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, G. J., Karanja, E., Fiaboe, K. K. M., Muriuki, A., Mucheru-Muna, M., Vanlauwe, B., Berst, E., Messmer, M. M., Gattinger, A., Bhullar, G. S., Cadisch, G., Fliessbach, A., Mader, P., Niggli, U., & Foster, D. (2016). Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya. *Agriculture, Ecosystems & Environment*, *235*, 61–79.

[74] Anyango, J. J., Bautze, D., Fiaboe, K. K. M., Lagat, Z. O., Muriuki, A. W., Stöckli, S., Riedel, J., K., O. G., Musyoka, M. W., Karanja, E. N., & Adamtey, N. (2020). The impact of conventional and organic farming on soil biodiversity conservation: a case study on termites in the long-term farming systems comparison trials in Kenya. *BMC Ecology.*, *2020* (20), 13.

[75] Zanetti, R., Castro, N. R. A., Moraes, J. C., Zanuncio, J. C., Olieira, A. C., & Dias, N. (2005). Estimation of Wood Volume Losses by Heartwood Termites (Insecta: Isoptera) in *Eucalyptus* Plantations in the State of Minas Gerais, Brazil. *Sociobiology, 45* (3), 610–630.

[76] Anjos N. (2004). Cupins-de-raiz (Isoptera) em culturas florestais. In: Congresso Brasileiro de Entomologia. Brasil.: Empresa Brasileira de Pesquisa Agropecuária (Embrapa), pp. 110.