Annals of Silvicultural Research
46(2), 2021: 141-147
https://journals-crea.4science.it/index.php/asr

Research paper

The diversity of termite species on natural forest and agroforestry land in Sulawesi tropical forests in Indonesia

Zulkaidhah Zulkaidhah[1*], Adam Malik[2], Abdul Hapid[2], Hamka Hamka[2], Ariyanty Ariyanti[2], Nurulhuda Rahman[3]

Received: 8/06/2020 *Accepted: 12/04/2021* *Available online: 3/06/2021*

ABSTRACT The conversion of natural forest to agroforestry causes physical changes in the forest, which affects the availability of organic matter. Therefore, this could influence the diversity of termites which act as decomposers in forest ecosystems. This study aims to determine the effect on the diversity of termite species of changes in tropical forest due to conversion. The study was carried out in the Educational Forest area of Tadulako University, Indonesia. The observations of environmental biophysical conditions include vegetation diversity, biomass, soil physical and chemical properties. Furthermore, using the transect method, the diversity of termite species was monitored. The results showed that the diversity of termite species decreased along with the conversion, because 13 species were found in natural forests, while only seven species were found in agroforestry land. This implies that changes in the biophysical environmental conditions due to forest conversion of tropical rainforests significantly reduced the number and composition of vegetation types at all growth rates, necromass and litter biomass. This decrease affects the availability of soil organic matter and carbon. Furthermore, these changes led not only to the loss of individual species but also to the emergence of previously unrecorded ones such as *Microcerotermes dubius*.

KEYWORDS: Tropical forest, forest conversion, agroforestry, termite diversity.

Introduction

Tropical rainforests are among the richest ecosystems in biodiversity and help stabilize the world's ecosystems by absorbing carbon dioxide from the atmosphere and producing oxygen (Gillison et al. 2013, Jones et al. 2019) and Tropical rainforests are home to half the world's flora and fauna population. Tropical rain forests are also a refuge for the organisms that are in these ecosystems (Gillespie et al. 2015, Abbas et al. 2019). Deforestation of tropical rainforests and conversion of forest lands to other land-use systems leads to loss of biodiversity and poses a threat to the ecosystem functioning and to sustainable land use (Muchane et al. 2012, Neoh et al. 2015).

Changes in forest structure due to land conversion causes physical changes (Kulakowski et al. 2011, Trumbore et al. 2015), which reduces the diversity of termite species, both in terms of species composition, loss of native forest species and the emergence of previously unrecorded ones (Bandeira et al. 2003).

Besides, these changes affect the availability of organic matter, a source of food for termites, which turns them into destructive pests (Abe et al. 2000, Bignell and Eggleton 2000). Deforestation affects their role in the ecological cycle because most species in the primary forest are sensitive to habitat perturbations (Bignell and Eggleton 2000, Eggleton et al. 2002).

Termites play an essential role as decomposers in the forest ecosystem by breaking down organic materials in the nutrient cycle to return to the ecosystem (Jouquet et al. 2011, Lenz et al. 2011). The change in the role of termites is caused by a decrease in the diversity of vegetation types due to changes in habitat conditions from natural forest to agroforestry land and the high management activity on the agroforestry land (Genet et al. 2001, Hanis et al. 2014). The response of termites to landuse change permits their usage as bio-indicators to assess environmental quality (Jones and Eggleton 2000, Jones et al. 2003, Gathorne-Hardy et al. 2002, Alves et al. 2011, Pribadi et al. 2011, Viana et al. 2014). Currently, the tropical rainforest in Indonesia, especially Sulawesi, is lacking, which reported the effects on termite diversity of changes in habitat conditions. Therefore, this study aims to fill this gap.

Materials and methods

Time and Location

This study was carried out from February to August 2017 in the Educational Forest of Tadulako University, Parigi Moutong Regency, Central Sulawesi

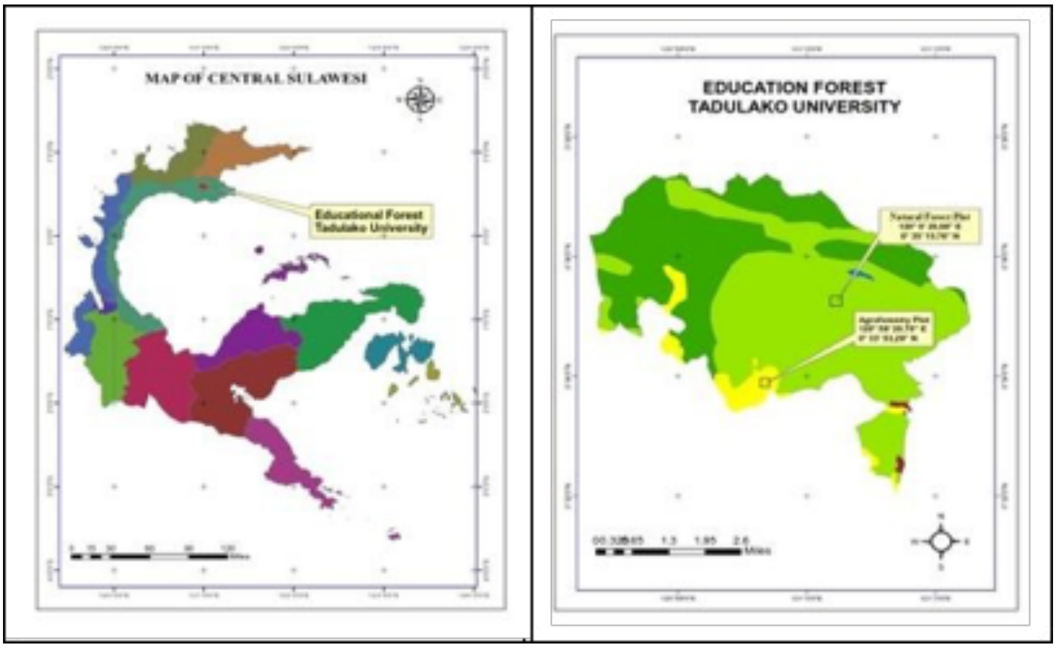
1 - Tadulako University, Palu, Central Sulawesi – Indonesia
2 - Tadulako University – Forestry, Palu, Sulawesi Tengah – Indonesia
3 - Tadulako University – Agribusiness, Palu, Sulawesi Tengah – Indonesia
*Corresponding author: zulkaidhahuntad@gmail.com

http://dx.doi.org/10.12899/asr-2228

(120° 0' 26,68 "E and 0° 35.' 15,78" N and 120° 59' 20,70" E and 0° 33' 53,29" N). It was carried out on two types of land, natural forest and agroforestry land (Figure 1).

- The measurement of litter biomass was carried out within a quadrant measuring 0.5m x 0.5m, which was placed systematically along with the upper vegetation observation plots with a distance of 5m between them, each with five replications. In addition, litter and understorey were collected from each observation plot. The dry litter biomass was calculated using the formula:

Figure 1 - Study sites at Education Forest Tadulako University in Sulawesi tropical forests, Parigi Moutong Regency, Central Sulawesi, Indonesia.



Environmental Parameters

Measured environmental parameters, include: vegetation diversity, necromass, litter biomass, soil pH, soil organic matter (SOM), soil organic carbon (SOC), total nitrogen content (TNC), soil carbon to nitrogen (C:N), porosity and bulk Density (B.D.) of soil.

- Vegetation data collected on an observation plot measuring 20m x 100m in each land-use type. They were divided into five sub-plots measuring 20m x 20m. Furthermore, nested sampling was carried out, and the plots were divided into three, namely 20m x 20m for the tree/pole level (dbh ≥ 10cm), 5m x 5m for the sapling level (2cm ≤ dbh <10cm) and 2m x 2m for seedlings and understorey levels using systematic sampling (Bonham 2013, Kirdyanov et al. 2011). Afterwards, the plants were identified, while pictures or samples of the unidentified plants were taken for further identification at the Herbarium Celebense, Tadulako University Palu.
- The measurement of necromass was carried out on a subplot measuring 5m x 25m.

The formula for calculating the necromass is shown below:

Necromass (kg) = (π/40) ρHD2 (eq. 1)

where: π = 3,14; ρ = wood density, H height/length of stem, D = diameter breast height (dbh) (Larjavaara and Muller-landau 2009, Jones et al. 2019).

$$\text{Oven – dry litter biomass } (Kg m^{-2}) = \frac{\text{Total Wet Weight (Kg) } x \text{ Dry Sample Weight } (g)}{\text{Total Wet Weight } (g) \ x \text{ Sample Plot Area } (m^2)}$$

(eq. 2)

(Hairiah et al. 2011, Jones et al. 2019)

- Soil physical and chemical properties were derived from transects of termites (see below). Samples of soil chemical properties were obtained from a composite soil, while soil physical properties were obtained from solid soil using a sample ring at a depth of 15 cm from the ground (Jones et al. 2019). Afterwards, laboratory and data analysis were carried out at the Natural Resources and Environmental Analysis Laboratory, Faculty of Agriculture, Tadulako University.

Termites

Biodiversity is simply measured through species diversity index, which describes the size by considering differences in the number of species on a land (Zulkaidhah et al. 2014). Termite samples were collected from transects made with 2m x 100m, divided into 20 subplots measuring 2m x 5m, which were arranged sequentially. Identification to species level was carried out using soldier caste. This was because insects in this caste have a distinct mandible shape which differs, permitting easy identification (Subekti et al. 2018), using the available literature (Tho 1974, Thapa 1982). Sampled termites were used to calculate the level of diversity, namely number of species (S).

Table 1 - Statistical analysis and number of tree species in the three growth levels in natural forest and agroforestry in Sulawesi tropical forests.

Vegetation	Mean	SD	t	df	p-value
Tree (Number of Species)					
- Natural Forest	29.40	1.87	16.43	8.00	0.000**
- Agroforestry Land	11.20	1.58			
Sapling (Number of Species)					
- Natural Forest	49.40	2.74	40.01	8.00	0.000**
- Agroforestry Land	0.00	0.00			
Seedling (Number of Species)					
- Natural Forest	73.80	1.58	49.00	8.00	0.000**
- Agroforestry Land	24.80	1.58			

** Significant at 0.01 level

The decrease in the number of vegetation types at all growth levels due to changes in land shape was followed by a significant reduction in the amount of organic matter (Tab. 2). Land clearing, followed by intensive processing activities, caused a rapid decline in the amount of vegetation (Wang et al. 2017), and affected micro-climatic conditions, soil physical and chemical properties, including the quality and quantity of existing litter (Kulakowski et al. 2011, Trumbore et al. 2015).

Table 2 - Statistical analysis and total organic matter in natural forests and agroforestry lands in Sulawesi tropical forests.

Organic Matter	Mean	SD	t	df	p-value
Necromass (Mg/ha)					
- Natural Forest	7.31	0.59	9.83	8.00	0.000**
- Agroforestry Land	3.97	0.47			
Litter (Mg/ha)					
- Natural Forest	19.00	1.41	6.32	8.00	0.000**
- Agroforestry Land	13.00	1.58			

** Significant at 0.01 level

Necromass experienced a significant decrease in agroforestry lands by 45.69% (Tab. 2). Decreasing dramatically its availability (Murray et al. 2015, Olorunfemi et al. 2019). The high amount of necromass in natural forests comes from many unloaded forest logs due to illegal logging, fallen trees, branches and twigs (Murray et al. 2015, Olorunfemi et al. 2019).

Meanwhile, in agroforestry land, necromass comes from the remains of seasonal crop trimmings and logs left during land clearing. This condition was in line with the study carried out in the Lore Lindu National Park, Central Sulawesi, which stated that the biomass of necromass from natural forest to agroforestry has decreased by 51.10% (Zulkaidhah et al. 2014).

Necromass is one of the environmental variables that play an essential role in termites' presence (Neupane et al. 2015). It serves as a source of food as nesting site, for some species (Zulkaidhah et al. 2017). Apart from necromass, surface litter also dramatically influences the presence and diversity of termite species in a land (Neupane et al. 2015). It is a micro-habitat and most preferred food source for termites.

Most importantly, it is the primary nutrient provider in an ecosystem (Attignon et al. 2005).

Coarse litter (twigs) was the dominant type found in both study locations. Litter biomass in the natural forest was much higher compared to agroforestry, experiencing a decrease of 31.58%.

The Litter biomass is mostly determined by the land use system and its management (Nascimento et al. 2019). The composition and amount of vegetation in the natural forest are more extensive and denser than the vegetation in agroforestry land. Therefore, the litter biomass is also much more abundant in natural forests, whilst in agroforestry land it is also reduced by intensive crop management such as weeding and land clearing (Hapid and Zulkaidhah 2019).

Physical and Chemical Properties of Soil

The results of the analysis of soil physical and chemical properties in natural forest and agroforestry land are shown in Table 3.

All measured physical and chemical properties of the soil changed significantly except for soil pH, after the conversion of natural forest to agroforestry land (Tab. 3). Furthermore, the soil organic carbon in agroforestry land decreased from 2.41% to 2.17% after the conversion of natural forest.

The high amount of soil organic carbon in natural forests was due to the abundant vegetation cover and was directly proportional to the available amount of soil organic matter. The soil organic matter in natural forest was 4.11% and decreased in agroforestry to 3.77%. The accumulation of organic matter affects the microclimate and soil microorganisms, which play a role in the decomposition process (Oliveira et al. 2019).

The high activity of microorganisms in natural forests causes the nitrification process to be slow. Therefore, the total nitrogen content in natural forests is lower (0.21%) compared to agroforestry (1.16%). Fertilization activities for plantation crops on agroforestry land cause a higher total nitrogen content than natural forests. This was because the nitrogen element presents in fertilizers assist in increasing the soil nitrogen content (Alegre et al. 2017).

The intensive land processing activity on agroforestry land affects accumulated organic matter and soil density (Bulk density) (Atapattu et al. 2017). Therefore, its soil density (1.19 g/cm3) was higher compared to the natural forest (1.15 g/cm3). This condition was inversely proportional to the porosity value of both land types. The value of soil porosity tends to be higher on lands with a high amount of organic matter and microorganism activity (Sollins and Gregg 2017).

Table 3 - Physical and chemical properties of soil in natural forests and agroforestry lands in Sulawesi tropical forests.

Soil Properties	Mean	SD	t	df	p-value
Soil pH (H_2O)					
- Natural Forest	6.63	0.02	-0.68	8.00	0.518ns
- Agroforestry Land	6.72	0.06			
Soil Organic Matter (%)					
- Natural Forest	4.11	0.10	4.04	8.00	0.004**
- Agroforestry Land	3.77	0.15			
Soil Organic Carbon (%)					
- Natural Forest	2.41	0.11	2.89	8.00	0.020*
- Agroforestry Land	2.17	0.14			
Total Nitrogen (%)					
- Natural Forest	0.21	0.01	-4.44	8.00	0.000**
- Agroforestry Land	1.16	0.08			
Soil C: N Ratio					
- Natural Forest	10.87	0.20	2.68	8.00	0.028*
- Agroforestry Land	10.52	0.21			
Porosity (%)					
- Natural Forest	51.15	0.11	20.79	8.00	0.000**
- Agroforestry Land	49.27	0.16			
Bulk Density (g/cm³)					
- Natural Forest	1.15	0.15	-4.00	8.00	0.004**
- Agroforestry Land	1.19	0.15			

* * Significant at 0.01 level; * Significant at 0.05 level; ns Not Significant

B. Termites

We found 13 species (7 genera) in natural forests, and seven species (5 genera) in agroforestry, 14 species grouped into seven genera from 2 families, namely: Termitidae and Rhinotermitidae (Tab. 4). Stem and log volume estimation

The morphological characteristics of termite generally used to identify the species include their mandible shape, fontanelle or depression on the head, shape of pronotum, marginal teeth, shape of antenna and number of antennal segments. Identification of the species of termites is elaborated in the following Figures 2.

After the conversion of natural forest to agroforestry land, some species disappeared (*Nasutitermes matangensis*, *Odontotermes* sp.1, *Coptotermes kalshoveni*, *Coptotermes sepangensis*).

This occurred because they cannot adapt to changes in habitat (Sanabria et al. 2016, Liu et al. 2019). Although several species were lost, one species specie was gained (*Microcerotermes dubius*).

Table 4 - Diversity of types of termites in natural forests and agroforestry land in Sulawesi tropical forests.

Diversity of Termite Species	
Natural Forest	Agroforestry Land
Nasutitermes neoparvus (Thapa)	*Nasutitermes neoparvus* (Thapa)
Nasutitermes havilandi (Desneux)	*Nasutitermes havilandi* (Desneux)
Nasutitermes matangensis (Haviland)	*Odontotermes* sp. 2
Bulbitermes constrictus (Haviland)	*Odontotermes* sp. 3
Bulbitermes contrictiformis (Holmgren)	*Microcerotermes dubius* (Haviland)
Odontotermes sp. 1	*Schedorhinotermes javanicus* (Kemner)
Odontotermes sp. 2	*Longipeditermes* sp.
Odontotermes sp. 3	
Coptotermes kalshoveni (Kemner)	
Coptotermes sepangensis (Krishna)	
Microcerotermes serrula (Desneux)	
Schedorhinotermes javanicus (Kemner)	
Logipeditermes sp.	

Figure 2 - (A) *Nasutitermes* sp., (B) *N. neoparvus*, (C) *N. havilandi*, (D) *N. matangensis*

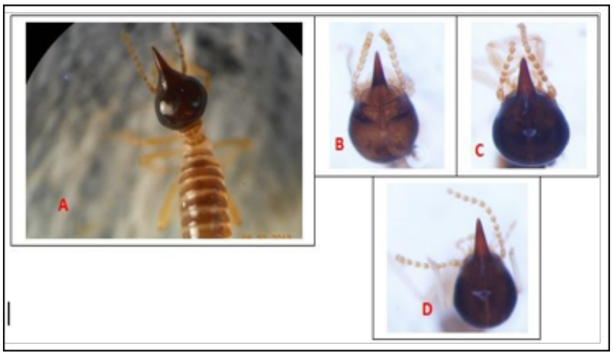


Figure 3 - A) *Bulbitermes* sp., (B) *B. constrictus*, (C) *B. constrictiformis*

Figure 4 - (A) *Odontotermes* sp., (B) *Odontotermes* sp. 1, (C) *Odontotermes* sp. 2, (D) *Odontotermes* sp. 3.

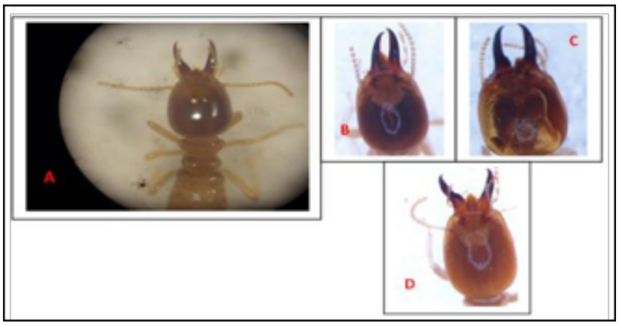


Figure 5 - (A) *C. sepangensis,* (B) *C. kalshoveni*, (C) *C. javanicus*.

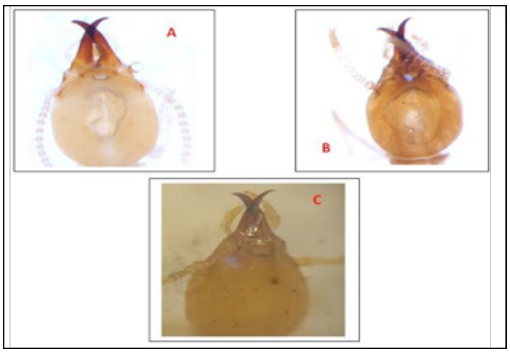


Figure 6 - (A) *Microcerotermes* (B) *M. dubius*, (C) *M. serrula*.

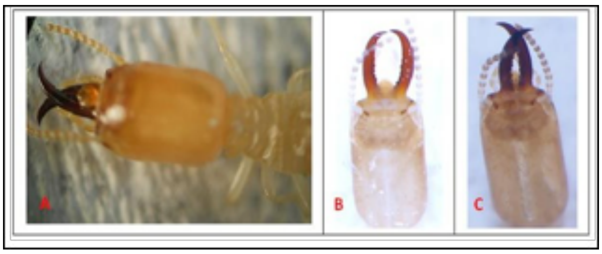
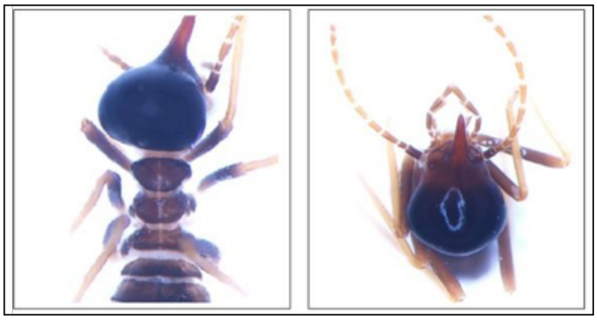


Figure 7 - *Schedorhinotermes javanicus.*

Figure 8 - *Longipeditermes* sp.



The change in species assemblages in agroforestry land are caused by changes in vegetation composition and structure. Only certain types of termites (*N. neoparvus*, *N. havilandi*, *Odontotermes* sp.2, *O.* sp.3, *S. javanicus* and *Longipeditermes* sp.) can survive these conditions (Liu et al. 2019). Changes in the number of species and composition of termite communities significantly affect the ecological cycle in an ecosystem (de Paula et al. 2016).

The diversity of termite communities in tropical forests is presented in Table 5.

Table 5 - Level of diversity of termites in natural forests and agroforestry land in Sulawesi tropical forests.

LT	S	H’	E	Dominant Species
NF	13	2.43	0.90	*Bulbitermes constrictus*
AL	7	1.91	0.89	*Nasutitermes neoparvus*

Information: LT (Land Type), NF (Natural Forests), AL (Agroforestry Land), S (Number of Types), H’ (Shannon Index), E (Evennes Index)

Conclusion

Environmental biophysical conditions have significantly changed after the conversion of natural forests into agroforestry lands. The number of tree species strongly decreased, and the composition of vegetation changed significantly. These changes were followed by a reduction in necromass and litter biomass affecting the availability of soil organic matter and carbon, which also decreased significantly after the conversion. The change in environmental biophysical conditions dramatically affects the richness and composition of termites’ communities. 13 species of termites (7 genera), which were found in natural forests experienced a reduction in number after the conversion to agroforestry in which only seven species (5 genera) were found. Interestingly, in agroforestry land we found *Microcerotermes dubius* not found in natural forests. Therefore, changes in environmental biophysical conditions affect diversity and composition of termite communities.

Acknowledgment

The authors express gratitude to the International Publication & Collaborative Center (IPCC) Team of Tadulako University, for their assistance in the completion of this research and the students of the Faculty of Forestry of Tadulako University for their support in field data collection.

References

Abbas S., Nichol J. E., Zhang J., Fischer G. A. 2019 - *The accumulation of species and recovery of species composition along a 70 year succession in a tropical secondary forest*. Ecological Indicators 106: 105524.

Abe T., Bignell D. E., Higashi M. 2000 - *Termites: evolution, sociality, symbioses, ecology*. Springer Science & Business Media.

Alegre J., Lao C., Silva C., Schrevens E. 2017 - *Recovering degraded lands in the Peruvian Amazon by cover crops and sustainable agroforestry systems*. Peruvian Journal of Agronomy 1 (1): 1–7. doi:10.21704/pja.v1i1.1005

Alves W. de F., Mota A. S., de Lima R. A. A., Bellezoni R., Vasconcellos A. 2011 - *Termites as bioindicators of habitat quality in the caatinga, Brazil: is there agreement between structural habitat variables and the sampled assemblages?* Neotropical Entomology 40 (1): 39–46.

Atapattu A. A. A. J., Senarathne S. H. S., Raveendra S. A. S. T., Egodawatte W. C. P., Mensah S. 2017 - *Effect of short term agroforestry systems on soil quality in marginal coconut lands in Sri Lanka*. Agricultural Research Journal 54 (3): 324.

Attignon S. E., Lachat T., Sinsin B., Nagel P., Peveling R. 2005 - *Termite assemblages in a West-African semi-deciduous forest and teak plantations*. Agriculture, Ecosystems and Environment 110: 318–326.

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 by*. Sociobiology 42 (1): 1–11.

Bignell E., Eggleton P. 2000 - *Termites in Ecosystem*. In Springer.

Bourguignon T., Dahlsjö C. A. L., Salim K. A., Evans T. A. 2018 - *Termite diversity and species composition in heath forests, mixed dipterocarp forests, and pristine and selectively logged tropical peat swamp forests in Brunei*. Insectes Sociaux 65: 439–444.

de Paula R. C., de Moraes Lima Silveira R., da Rocha M. M., Izzo T. J. 2016 - *The restoration of termite diversity in different reforestated forests*. Agroforestry Systems 90 (3): 395–404.

Eggleton P., Hauser S., Norgrove L., Eggletona P., Bignellb D. E., Hauserc S., Diboga L., Norgrovec L., Madonge B. 2002 - *Termite diversity across an anthropogenic disturbance gradient in the humid forest zone of West Africa gradient in the humid forest zone of West Africa*. Agriculture, Ecosystems and Environment 90: 189–202.

Gathorne-Hardy F. J., Syaukani, Davies R. G., Eggleton P., Jones D. T. 2002 - *Quaternary rainforest refugia in south-east Asia: Using termites (Isoptera) as indicators*. Biological Journal of the Linnean Society 75: 453–466.

Genet J. A., Genet K. S., Burton T. M., Murphy P. G., Lugo A. E. 2001 - *Response of termite community and wood decomposition rates to habitat fragmentation in a subtropical dry forest*. Tropical Ecology 42 (1): 35–49.

Gillespie G. R., Howard S., Stroud J. T., Ul-Hassanah A., Campling M., Lardner B., Scroggie M. P., Kusrini M. 2015 - *Responses of tropical forest herpetofauna to moderate anthropogenic disturbance and effects of natural habitat variation in Sulawesi, Indonesia*. Biological Conservation 192: 161–173.

Gillison A. N., Bignell D. E., Brewer K. R. W., Fernandes E. C. M., Jones D. T., Sheil D., May P. H., Watt A. D., Constantino R., Couto E. G., Hairiah K., Jepson P., Kartono A. P., Maryanto I., Neto G. G., van Noordwijk M., Silveira E. A., Susilo F. X., Vosti S. A. et al. 2013 - *Plant functional types and traits as biodiversity indicators for tropical forests: Two biogeographically separated case studies including birds, mammals and termites*. Biodiversity and Conservation 22: 1909–1930.

Hairiah K., Dewi S., Agus F., Velarde S., Andree E., Rahayu S., van Noordwijk M. 2009 - *Measuring Carbon Stocks Across land use systems: a manual*. Bogor, Indonesia. World Agroforestry Centre (ICRAF), SEA Regional Office, Brawijaya University and ICALRRD (Indonesian Center for Agricultural Land Resources Research and Development). 127 p.

Hanis J., Abu Hassan A., Nurita A. T., Che Salmah M. R. 2014 - *Community structure of termites in a hill dipterocarp forest of belum – temengor forest complex, Malaysia : emergence of pest species*. Raffles Bulletin of Zoology 62: 3–11.

Hapid A., Zulkaidhah Z. 2019 - *Keanekaragaman jenis rayap pada lahan agroforestri dan kebun kemiri di Desa Bakubakulu Kecamatan Palolo Kabupaten Sigi*. Biocelebes 13 (2): 195–202.

Jones D. T., Eggleton P. 2000 - *Sampling termite assemblages in tropical forests: Testing a rapid biodiversity assessment protocol*. Journal of Applied Ecology 37: 191–203.

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*. Journal of Applied Ecology 40 (2): 380–391.

Jones I. L., DeWalt S. J., Lopez O. R., Bunnefeld L., Pattison Z., Dent D. H. 2019 – *Above and belowground carbon stocks are decoupled in secondary tropical forests and are positively related to forest age and soil nutrients respectively*. Science of the Total Environment 697: 133987.

Jouquet P., Traoré S., Choosai C., Hartmann C., Bignell D. 2011 - *European Journal of Soil Biology Influence of termites on ecosystem functioning. Ecosystem services provided by termites*. European Journal of Soil Biology 47: 215–222.

Kirdyanov A. V., Academy R., Krasnoyarsk K., Moiseev P., Academy R. 2011 - *20th century tree line advance and vegetation changes along an altitudinal transect in the Putorana Mountains* Boreas: 1–12.

Kulakowski D., Bebi P., Rixen C. 2011 - *The interacting effects of land use change, climate change and suppression of natural disturbances on landscape forest structure in the Swiss Alps*. Oikos 120: 216–225.

Larjavaara M., Muller-landau H. 2009 - *Woody debris research protocol: Long transects*. CTFS Global Forest Carbon Research Initiative.: 1–15.

Lenz M., Lee C. Y., Lacey M. J., Yoshimura T., Tsunoda K. 2011 - *The potential and limits of termites (isoptera) as decomposers of waste paper products*. Journal of Economic Entomology 104 (1): 232–242.

Liu S., Lin X., Behm J. E., Yuan H., Stiblik P., Šobotník J., Gan J., Xia S., Yang X. 2019 - *Comparative responses of termite functional and taxonomic diversity to land-use change.* Ecological Entomology 44 (6): 762–770.

Muchane M. N., Karanja D., Wambugu G. M., Mutahi J. M., Masiga C. W., Mugoya C., Muchai M. 2012 - *Land use practices and their implications on soil macro-fauna in Maasai Mara ecosystem*. International Journal of Biodiversity and Conservation 4 (13): 500–514.

Murray J. P., Grenyer R., Wunder S., Raes N., Jones J. P. G. 2015 - *Spatial patterns of carbon , biodiversity , deforestation threat , and REDD + projects in Indonesia*. Conservation Biology 29 (5): 1434–1445.

Nascimento A. E., Reis F., Chichorro F., Canhoto C., Ana L., Sim S. 2019 - *Effects of management on plant litter traits and consequences for litter mass loss and Collembola functional diversity in a Mediterranean agro-forest system.* Pedobiologia 75: 38–51.

Neoh K. B., Bong L. J., Nguyen M. T., Nguyen V. T., Nguyen H. Q., Itoh M., Kozan O., Yoshimura T. 2015 - *Termite diversity and complexity in Vietnamese agroecosystems along a gradient of increasing disturbance*. Journal of Insect Conservation 19: 1129–1139.

Neupane A., Maynard D. S., Bradford M. A. 2015 - *Consistent effects of eastern subterranean termites (Reticulitermes flavipes) on properties of a temperate forest soil*. Soil Biology and Biochemistry 91: 84–91.

Oliveira R. A. C., Marques R., Marques M. C. M. 2019 - *Plant diversity and local environmental conditions indirectly affect litter decomposition in a tropical forest.* Applied Soil Ecology 134: 45–53.

Olorunfemi I. E., Komolafe A. A., Fasinmirin J. T., Olufayo A. A. 2019 - *Biomass carbon stocks of different land use management in the forest vegetative zone of Nigeria*. Acta Oecologica 95: 45–56. doi:10.1016/j.actao.2019.01.004

Pribadi T., Raffiudin R., Harahap I. S. 2011 - *Termites community as environmental bioindicators in highlands: a case study in eastern slopes of Mount Slamet, Central Java*. Biodiversitas 12 (3): 235–240.

Sanabria C., Dubs F., Lavelle P., Fonte S. J., Barot S. 2016 - *Influence of regions, land uses and soil properties on termite and ant communities in agricultural landscapes of the Colombian Llanos*. European Journal of Soil Biology 74: 81–92.

Sollins P., Gregg J. W. 2017 - *Soil organic matter accumulation in relation to changing soil volume, mass, and structure: Concepts and calculations*. Geoderma 301: 60–71.

Subekti N., Nurvaizah I., Nunaki J. A. N. H., Wambrau H. L., Iyyatul R. O., Ah M. A. R. 2018 - *Biodiversity and distribution of termite nests in West Papua, Indonesia*. Biodiversitas 19 (4): 1659–1664.

Thapa R. S. 1982 - *Termites of Sabah*. Special issue. Sabah forest record (12): 1982.

Tho Y. P. 1974 - *The termite problem in plantation forestry in Peninsular Malaysia*. Malaysian Forester 37 (4): 278–283.

Trumbore S., Brando P., Hartmann H. 2015 - *Forest health and global change.* Science 349: 814–818.

Viana A. B., Souza V. B., Reis Y. T., Marques-Costa A. P. 2014 - *Termite assemblages in dry tropical forests of Northeastern Brazil: Are termites bioindicators of environmental disturbances*? Sociobiology 61(3): 324–331.

Wang J., Ren C., Cheng H., Zou Y., Bughio M. A., Li Q. 2017 - *Conversion of rainforest into agroforestry and monoculture plantation in China: Consequences for soil phosphorus forms and microbial community*. Science of the Total Environment 595: 769–678.

Zulkaidhah Z., Hapid A., Ariyanti 2017 - *Keragaman Jenis Rayap Pada Kebun Monokultur Kakao Di Hutan Pendidikan Universitas Tadulako Sulawesi Tengah*. J. ForestSains 14 (2): 80–84.

Zulkaidhah Z., Musyafa M., Soemardi S., Hardiwinoto S. 2014 - *Termites Community Impact of Forest Conversion to Agroforestry in Lore Lindu National Park, Central Sulawesi*. Journal of People and Environment 21 (2): 213–219.