Functional structures of termite assemblage in changing habitats and ecosystems

S K Himmi¹, B Wikantyoso¹², A Fajar¹, D Tarmadi¹ and S Yusuf²

¹Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI), Jl. Raya Bogor km 46 Cibinong, Bogor 16911, Indonesia
²Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

Email: khoirul_himmi@biomaterial.lipi.go.id

Abstract. Termite species diversity and assemblage structures differ in ecosystems and habitats. Termite distribution is also highly influenced by temperature, humidity and altitude. Greater species richness and greater density have been reported in humid forests than in arid or semiarid environments. However, termites biodiversity is known to be strongly affected by anthropogenic alteration, which affect their functional assemblage structure. The humus-feeders were as the most sensitively affected, while the wood-feeders were the most resilient group among others. Therefore, the functional structures of termite communities in changing habitats and ecosystems are important subject to discuss in order to capture more understanding on termite and ecosystem relationship.

1. Introduction
Termites are considered as the dominant macroarthropod detritivores in many tropical soils, as well as the major decomposers that play an important role in soil processes [1]. Lowland tropical forests are reported to be the most species-rich habitats [1-3], where their density and biomass may reach 10400 individuals/m² and 120 g/m², respectively [4]. However, continued degradation of the environment, deforestation, and dramatic changes of land-use have been affecting termites biodiversity and functional assemblage structure. The ecological disturbance is associated with the extinction of species, and termites can be one of the most important biocological indicator [5, 6] in both biotic and abiotic that exposed them, as they form the bulk of species and have significant influence toward ecosystem processes.

The disturbance and degradation on termite habitats can influence termites’ diversity, considering their dietary preferences, foraging, and nesting habits. The assemblage structure of termites can vary significantly among areas, even in the same ecosystem, depend on exposure degree of anthropogenic disturbance [7]. The modification of natural forest areas to form agro-forest ecosystems (Figure 1), for instance, can result in significant loss of species richness, abundance, and diversity. Another important factor is the varied habitats in dry and humid ecosystems [8], in which greater species richness and density (7000 individuals/m² and 1100 individuals/m², respectively) have been observed in humid forests than in arid or semiarid environments [9, 10]. Termites play an important role in mediating nutrient cycle and carbon fluxes at the decomposer levels in humid to semiarid regions of the earth. The magnitude of their ecological role is related to their population density and biomass [11].

The present study captures the functional structure of termite community in changing habitats and ecosystems in Indonesia. The data are to include the profile of termite community in urban settlements,
the areas that were previously a monoculture rubberwood plantation; and an urban conservation area that experiencing a change in land-use from agricultural to conservation purposes.

Figure 1. The change of land-use from natural tropical forest to commercial agro-forest mono-culture plantation in Indonesia.

2. Materials and Methods

2.1. Sampling sites
The survey was conducted in 3 urban settlement areas and an urban conservation area (6°48’ S, 106°84’ E; 189 ha with altitude of 135 – 150 m above sea level) in Cibinong, Bogor District, Indonesia. The urban settlements were previously a rubberwood plantation while the conservation area was previously a plantation land. Both areas were cleared before subjected to their respective new purpose land-use. The temperature and humidity for the area was 20 to 35°C all year round and humidity of 60 to 90%. The area was a no seasonal zone with annual rainfall 3456 mm with >2000 mm of rainfall between November to April.

2.2. Specimens collection
The sampling were conducted in 2019, in which random-encounter collection was employed in urban settlement areas, while the collections in the conservation area were employing a belt-transect (100m x 2m) at 3 different random location [6, 12, 13] and random-encounter collection in buildings and surrounding areas. All of the collected specimens, preferably soldier, were kept in a vial coded for the corresponding origin.

2.3. Specimens identification
The collected specimens were then classified into the wood feeder, fungus feeder, and humus/soil feeder, and were sorted and clustered to their functional groups (Table 1), the grouping that reflects feeding preferences along the humification gradient of the dietary substrates [14, 15]. The identification to species level was made using morphological character. The character was observed using digital microscope Leica S8 APO B (Leica Microsystems CMS GmbH, Germany). All of the observed characters were compiled and compared to the guideline, based on their morphological characteristics provided by Ahmad [16-18], Sornnuwat et al. [19], Takematsu & Charunee [19], and Tho [20]. The
collected specimens were deposited in Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI).

| Feeding Group | Feeding habit |
|---------------|--------------|
| I             | Deadwood and grass feeders. The only group with flagellate protists in their guts |
| II            | Feed on miscellaneous type of grass, dead wood, leaf litter, and microepiphyte |
| IIIf          | Feed on grass, dead wood, and leaf litter, with the help of fungal symbionts grown inside the nest (fungus-growing termites) |
| III           | Feed on organically rich upper soil layers (Humus feeders) |
| IV            | Feed on organically impoverished soil or mineral soil (True soil feeders) |

Note. The entire list of genera with its corresponding functional group is listed in the Donovan [14] and Jones & Eggleton [15].

3. Results and discussion

Termite genera and their functional structure across three sampling location in the urban conservation area are presented in Table 2. The areas were occupied by the group IIIf (feed on wood/fungus-growing termites) from the genera of Macrotermes, Microtermes and Odontotermes; and the group III (humus-feeder) from the genera of Pericapritermes. The absence of the group I can be explained by the lack of deadwoods, common dietary materials for the group I, as the living vegetations were dominance in the surveyed areas. Arboreal nesters from the genera of Nasutitermes were also not recovered from the surveyed areas, which may related to the history of land-use, i.e., agricultural fields. Arboreal nesters are mostly recovered from natural forest [3] or a changing ecosystems that were previously forest [21], which our studied area differ.

| Table 2. | List of termite genera and their functional structure across three sampling location in the conservation area |
|-----------|---------------------------------------------------------------|
| Family/ Sub-Family | Genus           | Functional structure       | Location (%) |
| Macrotermitinae | Macrotermes       | IIIf – wood/fungus  | 21.4  | 23.5  | 10.5  |
|              | Microtermes       | IIIf – wood/fungus  | 14.3  | 11.8  | 7.9   |
|              | Odontotermes      | IIIf – wood/fungus  | 21.4  | 23.5  | 28.9  |
| Microcapritermitinae | Pericapritermes | III – humus      | 42.9  | 41.2  | 52.6  |
| Total collected termite specimens | | | 14  | 17  | 38     |

Some parts of the conservation area are consisted of buildings designated for offices and research centers. The survey in buildings and surrounding areas recovered termite specimens that are presented in Table 3. The functional structures was different with those in Table 2, indicated that landscape changes and anthropogenic alteration had influenced termite assemblage dynamics, indicated by the
absence of soil feeder groups. The genera of Coptotermes and Cryptotermes (the group I) were recovered from inside buildings and found to feed on wooden structures and furniture, while the group III genera were collected from yard and surroundings.

Table 3. List of termite genera and their functional structure across buildings and surroundings in the urban conservation area

| Family/Sub-Family | Genus     | Functional structure | Location (%) |
|-------------------|-----------|----------------------|--------------|
|                   |           |                      | I  | II | III |
| Rhinotermitidae   | Coptotermes | I – wood             | 41.7| 25.0| 33.3|
|                   | Cryptotermes | I – wood             | -  | 8.3 | -   |
| Macrotermitinae   | Macrotermes | IIf – wood/fungus    | 25.0| 16.7| 33.3|
|                   | Microtermes | IIf – wood/fungus    | 8.3 | 16.7| 8.3 |
|                   | Odontotermes | IIf – wood/fungus    | 25.0| 8.3 | 8.3 |
| Total collected termite specimens | | | 12 | 9  | 10  |

The results from the survey in urban settlement areas are presented in Table 4. The survey was conducted in buildings and surrounding yards, indicated the absence of soil feeder groups. The genera of Coptotermes and Cryptotermes (the group I) were recovered from inside buildings and found to feed on wooden structures and furniture, while the group III genera were collected from yard and surroundings. The genera recovered from the surveyed urban settlements were also found in buildings and surroundings in the conservation area, minus Odontotermes. The absence of Odontotermes can be explained by the lack of tree canopy in the settlements that affect soil moisture in the areas. It was reported that soil moisture has influence on Odontotermes incipient colony and in mound-nest building [22, 23]. Davies [13] stated that moisture stress of micro-environments and structure of ground cover vegetation play an important role in termite distribution in a tropical area, and that environmental factors (temperature, relative humidity and precipitation) have impact on the population dynamics, density and foraging activities of termite communities [24] in the respective areas.

Table 4. List of termite genera and their functional structure across urban settlement areas

| Family/Sub-Family | Genus     | Functional structure | Location (%) |
|-------------------|-----------|----------------------|--------------|
|                   |           |                      | I  | II | III |
| Rhinotermitidae   | Coptotermes | I – wood             | 50.0| 33.3| 50.0|
|                   | Cryptotermes | I – wood             | 16.7| 33.3| -   |
| Macrotermitinae   | Macrotermes | IIf – wood/fungus    | 16.7| 16.7| 16.7|
|                   | Microtermes | IIf – wood/fungus    | 16.7| 16.7| 16.7|
| Total collected termite specimens | | | 6   | 6  | 5   |

Different habitats and ecosystems generate different functional structure of termite communities. In the building areas and urban settlements, the functional structures were dominated by wood-feeder termites from the group I, accounted an average of 36.1% and 61.1% of total collected specimens, respectively (Tables 3 and 4). The group I consist of two genera, subterranean termite Coptotermes spp.
and invasive drywood termite *Cryptotermes* spp.. Those genera are considered as two most destructive and dominant termite pests in urban area, and two of the most economically important genera in regional and global pest management [25]. Various monitoring methods [26-33] and controls [34-38] have been employed in order successfully to manage them.

The group IIIf genera, feed on deadwood and fungus-growing termites, are everpresent in all surveyed areas. Their fungus-farming abilities may contribute to their adaptability on changing habitats and ecosystems. In the conservation area, their functional structure accounted an average of 55.4% of the total collected specimens (Table 2). However, settlements areas, their dominance had been reduce to an average of 38.9% (Table 4). Macrotermes, in particular, is a major genus that pose threat in both agricultural and settlement areas.

The group III (humus feeders) were found dominance in the conservation area, accounted an average of 45.6% of the total collected specimens (Table 2). However, their absence in both area of buildings and settlement indicated that this group is the most susceptible to land clearance, cultivation and other anthropomorphic activities than others types of termites such as wood feeders [9, 39]. Soil feeders have beneficial function for the soil environment, as they engineer soil conditions to be favorable for plant growth, increase soil exchangeable cations by releasing of nitrogen and phosphorus, mediate organic matter humification and stabilization, and improve soil drainage and aeration.

**Acknowledgment**

The authors thank Research Institute for Sustainable Humanosphere (RISH) Kyoto University, as part of this work is also supported by Kyoto University “Japan-ASEAN Science, Technology and Innovation Platform (JASTIP)” Program, within the framework of the Collaboration Hubs for International Research Program (CHIRP) funded by the Strategic International Collaborative Research Program (SICORP) of Japan Science and Technology Agency (JST). S Khoirul Himmi is the main contributor for this work. The authors declare that they have no conflict of interest.

**References**

[1] Jones, D.T., F.X. Susilo, D.E. Bignell, S. Hardiwinoto, A.N. Gillison, and P. Eggleton, *Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia*. Journal of Applied Ecology, 2003. 40(2): p. 380-391.

[2] Kartika, T., S.K. Himmi, B. Wikantyoso, A.S. Lestari, M. Ismayati, D. Zulfiana, N.P.R.A. Krishanti, A. Zulfitr, A.H. Prianto, and S. Yusuf, *Biodiversity of termites and fungi in two botanical gardens in Batam, Riau Island Province and Kuningan, West Java Province*. IOP Conference Series: Earth and Environmental Science, 2018. 166(1): p. 012008.

[3] Himmi, S.K., B. Wikantyoso, M. Ismayati, A. Fajar, D. Meisyara, N.P.R.A. Krishanti, D. Zulfiana, A.S. Lestari, D. Tarmadi, T. Kartika, S. Yusuf, Y. Takematsu, and T. Yoshimura, *Termite assemblage structure in Batam Island, Indonesia*. IOP Conference Series: Earth and Environmental Science, 2019. 361: p. 012026.

[4] Eggleton, P., D.E. Bignell, W.A. Sands, N.A. Mawdsley, J.H. Lawton, T.G. Wood, and N.C. Bignell, *The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, Southern Cameroon*. Philosophical Transactions: Biological Sciences, 1996. 351(1335): p. 51-68.

[5] Brown, K.S., *Conservation of neotropical environments: Insects as indicators*, in *The Conservation of insects and their Habitats*, N.M. Collins and J.A. Thomas, Editors. 1991, Academic Press: London. p. 349 - 404.

[6] Jones, D.T. and P. Eggleton, *Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol*. Journal of Applied Ecology, 2000. 37(1): p. 191-203.

[7] Ackerman, I.L., R. Constantino, J. Gauch, Hugh G., J. Lehmann, S.J. Riha, and E.C.M.
Fernandes, Termite (Insecta: Isoptera) species composition in a primary rain forest and agroforests in Central Amazonia. Biotropica, 2009. 41(2): p. 226-233.

[8] Couto, A.A.V.O., A.C. Albuquerque, A. Vasconcellos, and C.C. Castro, Termite assemblages (Blattodea: Isoptera) in a habitat humidity gradient in the semiarid region of northeastern Brazil. Zoologia (Curitiba), 2015. 32: p. 281-288.

[9] Eggleton, P., The species richness and composition of termites (Isoptera) in primary and regenerating lowland depterocarp forest in Sabah, East Malaysia. Ecotropica, 1997. 3: p. 119-128.

[10] Bignell, D.E. and P. Eggleton, Termites in ecosystems, in Termites: evolution, sociality, symbioses, ecology, T. Abe, D.E. Bignell, and M. Higashi, Editors. 2000, Kluwer Academic Publishers. p. 363-387.

[11] Ueckert, D.N., M.C. Bodine, and B.M. Spears, Population density and biomass of the desert termite Gnathamitermes Tubiformans (Isoptera: Termitidae) in a shortgrass prairie: Relationship to temperature and moisture. Ecology, 1976. 57(6): p. 1273-1280.

[12] Eggleton, P., D.E. Bignell, W.A. Sands, B. Waite, T.G. Wood, and J.H. Lawton, The species richness of termites (Isoptera) under differing levels of forest disturbance in the Mbalmayo Forest Reserve, southern Cameroon. Journal of Tropical Ecology, 1995. 11(1): p. 85-98.

[13] Davies, R.G., Termite species richness in fire-prone and fire-protected dry deciduous depterocarp forest in Doi Suthep-Pui National Park, northern Thailand. Journal of Tropical Ecology, 1997. 13(1): p. 153-160.

[14] Donovan, S.E., P. Eggleton, and D.E. Bignell, Gut content analysis and a new feeding group classification of termites. Ecological Entomology, 2001. 26(4): p. 356-366.

[15] Jones, D.T. and P. Eggleton, Global biogeography of termites: a compilation of sources, in Biology of Termites: A Modern Synthesis, D. Bignell, Y. Roisin, and N. Lo, Editors. 2011, Springer: Dordrecht, The Netherlands. p. 477-498.

[16] Ahmad, M., On the identity of Odontotermes (Isoptera, Termitidae). American Museum novitates ; no. 1392. 1949.

[17] Ahmad, M., New termites from the Indo-Malayan and Papuan regions. American Museum novitates ; no. 1342. 1947.

[18] Ahmad, M., Termites (Isoptera) of Thailand. Bulletin of the AMNH ; v. 131, article 1. 1965.

[19] Sornnuwat, Y., C. Vongkaluang, and Y. Takematsu, A systematic key to termites of Thailand. Kasetsart J (Nat Sci), 2004. 38: p. 349-368.

[20] Tho, Y.P., ed. Termites of Peninsular Malaysia. ed. L.G. Kirton. 1992, Forest Research Institute Malaysia: Kepong, Kuala Lumpur.

[21] Jones, D.T. and A.H. Prasetyo, A survey of the termites (Insecta: Isoptera) of Tabalong District, South Kalimantan, Indonesia. The Raffles Bulletin of Zoology, 2002. 50(1): p. 117-128.

[22] Qizhen, Y., X. Ziyuan, and L. Limei, The influence of soil moisture on the incipient colonies of Odontotermes formosanus (Shiraki). Insects Knowledge (China), 1989.

[23] Zachariah, N., T.G. Murthy, and R.M. Borges, Moisture alone is sufficient to impart strength but not weathering resistance to termite mound soil. R Soc Open Sci, 2020. 7(8): p. 200485.

[24] Sattar, A., M. Naecem, and E. Ul-Haq, Impact of environmental factors on the population dynamics, density and foraging activities of Odontotermes lokanandi and Microtermes obesi in Islamabad. SpringerPlus, 2013. 2: p. 349-349.

[25] Evans, T.A., B.T. Forschler, and J.K. Grace, Biology of invasive termites: a worldwide review. Annu Rev Entomol, 2013. 58: p. 455-74.

[26] Himmi, S.K., T. Yoshimura, Y. Yanase, M. Oya, T. Torigoe, and S. Imazu, X-ray tomographic analysis of the initial structure of the royal chamber and the nest-founding behavior of the drywood termite Incisitermes minor. Journal of Wood Science, 2014. 60(6): p. 453-460.
[27] Himmi, S.K., T. Yoshimura, Y. Yanase, T. Mori, T. Torigoe, and S. Imazu, *Wood anatomical selectivity of drywood termite in the nest-gallery establishment revealed by X-ray tomography*. Wood Science and Technology, 2016. **50**(3): p. 631-643.

[28] Himmi, S.K., T. Yoshimura, Y. Yanase, M. Oya, T. Torigoe, M. Akada, and S. Imadzu, *Nest-gallery development and caste composition of isolated foraging groups of the drywood termite, Incisitermes minor (Isoptera: Kalotermitidae)*. Insects, 2016. **7**(3).

[29] Choi, B., S.K. Himmi, and T. Yoshimura, *Quantitative observation of the foraging tunnels in Sitka spruce and Japanese cypress caused by the drywood termite Incisitermes minor (Hagen) by 2D and 3D X-ray computer tomography (CT)*. Holzforschung, 2017. **71**(6): p. 535.

[30] Himmi, S.K., T. Yoshimura, Y. Yanase, T. Torigoe, M. Akada, M. Ikeda, and S. Imazu, *Volume visualization of hidden gallery system of drywood termite using computed tomography: a new approach on monitoring of termite infestation, in Sustainable Future for Human Security: Environment and Resources*, B. McLellan, Editor. 2018, Springer Nature Singapore: Singapore. p. 61-68.

[31] Himmi, S.K., T. Yoshimura, Y. Yanase, T. Torigoe, and S. Imazu, *Assessment of Initial Colony Founding by Swarming Reproductives of the Western Drywood Termite, Incisitermes minor*. IOP Conference Series: Earth and Environmental Science, 2018. **166**(1): p. 012003.

[32] Fajar, A., S.K. Himmi, T. Kartika, and S. Yusuf, *Directional response of the subterranean termite Coptotermes curvignathus toward volatilized Pinus merkusii extract*. IOP Conference Series: Earth and Environmental Science, 2019. **374**: p. 012017.

[33] Zega, S.L.D., A. Fajar, S.K. Himmi, D.S. Adi, D. Tarmadi, D. Nandika, and S. Yusuf, *Examination of fecal pellet physical characteristics of an invasive drywood termite, Cryptotermes dudleyi (Isoptera: Kalotermitidae): A potential approach for species marker and non-destructive monitoring method*. IOP Conference Series: Materials Science and Engineering, 2020. **935**: p. 012050.

[34] Ismayati, M., S.K. Himmi, D. Tarmadi, D. Zulfiana, S. Yusuf, and B. Santososo, *The efficacy of organo-complex-based wood preservative formula against dry-wood termite Cryptotermes cynocephalus Light*. Insects, 2011. **2**(4): p. 491-498.

[35] Himmi, S.K., D. Tarmadi, M. Ismayati, and S. Yusuf, *Bioefficacy performance of neem-based formulation on wood protection and soil barrier against subterranean termite, Coptotermes gestroi Wasmann ( Isoptera: Rhinotermitidae)*. Procedia Environmental Sciences, 2013. **17**: p. 135-141.

[36] Yusuf, S., S.K. Himmi, B. Santososo, D. Tarmadi, and D. Zulfiana, *Semi-permanent immunization treatment (S.P.I.T): an alternative treatment for wood packaging materials under ISPM no.15 in Indonesia*. Procedia Environmental Sciences, 2013. **17**: p. 89-96.

[37] Tarmadi, D., S.K. Himmi, and S. Yusuf, *The efficacy of the oleic acid isolated from Cerbera Manghas L. seed against a subterranean termite, Coptotermes gestroi Wasmann and a drywood termite, Cryptotermes cynocephalus Light*. Procedia Environmental Sciences, 2014. **20**: p. 772-777.

[38] Meisyara, D., N.P.R.A. Krishanti, A. Zulfiri, A.S. Lestari, D. Tarmadi, S.K. Himmi, Y. Amin, D. Zulfiana, A. Fajar, S. Yusuf, and M. Ismayati, *Biological activity of local plant extracts from Toba Region as insecticide*. IOP Conference Series: Earth and Environmental Science, 2019. **374**: p. 012006.

[39] De Souza, O.F.F. and V.K. Brown, *Effects of habitat fragmentation on Amazonian termite communities*. Journal of Tropical Ecology, 1994. **10**(2): p. 197-206.