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Soil Macrofauna Diversity and Litter Decomposition Rate in the Buffer Zone of Lore Lindu Biosphere Reserve Indonesia

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ABSTRACT

Conversion of forest to agricultural land (agroforestry and monoculture) has a negative impact on soil macrofauna diversity. Soil macrofauna have a key role in maintaining soil fertility through decomposition and supporting the productive capacity of ecosystems. This study aimed at determining the soil macrofauna diversity and the litter decomposition rate in agroforestry and monoculture and investigating the correlation between soil macrofauna diversity and litter decomposition rate. This study involved field and laboratory activities. Litter traps were installed for soil macrofauna observation, macrofauna identification was carried out in the laboratory, and litter bags were used for decomposition rate observation. Data analysis was conducted to determine species diversity and similarity of soil macrofauna on agroforestry and monoculture plantations. The calculation of the diversity index (H') shows that complex agroforestry and simple agroforestry have moderate, while candlenut monoculture has low diversity of soil macrofauna. The similarity of soil macrofauna in these sites is low (similarity index below 50%). The decomposition rate of litter is relatively high (0.01 g/day). The correlation between species diversity and the decomposition rate of litter in complex agroforestry and candlenut monoculture is very strong. Meanwhile, in simple agroforestry, the correlation is relatively low.

1. INTRODUCTION

The largest conservation area in Central Sulawesi, Lore Lindu National Park, is 229,000 ha and has become the core area of the Lore Lindu Biosphere Reserve recognized by the UNESCO MAB Program since 1977 [1-4]. Located in the center of Sulawesi Island, it is divided into three main zones: Lore Lindu National Park as the core area (217,991.18 ha), buffer zone (503,735 ha), and transition area (1,461,263 ha) [2, 5]. The presence of buffer zone is important as its management is directed at managing and utilizing land through community forests, community plantation forests, horticulture, food crops, and so on [6, 7]. The buffer zone of Lore Lindu National Park has been converted to agricultural land (agroforestry and monoculture) and utilized by the community, causing a significant reduction of available soil organic matter (SOM) [8]. The main reasons for the reduction are the decreasing number of individuals and type of vegetation and the disturbances to the physical soil due to land cultivation [1]. It is exacerbated by environmental changes in soil temperature, humidity, soil pH, and canopy density. These conditions also threaten the biodiversity and ecosystem functions as they cause a reduction or loss of forest vegetation that has a range of ecosystem services, and the loss of various types of soil fauna that live in the habitats [1, 9].

Soil fauna is one of the soil organisms that part or the entire of life cycle is in the soil [10]. The soil organic matter significantly affects the diversity of soil macrofauna compared to its effect on the diversity of microfauna or mesofauna [11]. Soil macrofauna play a role in the process of decomposition and aggregation, increase soil aeration and nutrient cycling, and sustain the supply of nutrients in the long term [12]. They support the productive capacity of ecosystems through energy flows and mineralization of nutrients from various sources of organic matter as well as supporting soil function and resilience against the risks of environmental change [13]. In the decomposition process, macrofauna have a direct role in the dynamics of soil organic matter and an indirect role in soil biogeochemical cycles through their influence in the dynamics of soil microbial populations [14].

The role of soil macrofauna in maintaining ecosystem stability highlights its importance [15]. Meanwhile, their presence is influenced by habitat conditions, including the availability of organic matter as a source of nutrition for soil fauna [10]. The composition and abundance of soil macrofauna species decreased along with changes in habitat type [1]. It implies that each type of macrofauna plays an important role in the ecosystem cycle: the higher the species diversity of macrofauna, the higher the stability of the forest ecosystem [8]. In addition, each type of soil macrofauna showed a different response to the environmental conditions

[15]. The species diversity of soil macrofauna serves as a biological indicator of soil quality since it has a major role in improving soil functional properties [14]. Essentially, soil macrofauna improve the chemical, physical, and biological properties of soil, increasing the level of soil fertility [16].

The massive changes in habitat types (from natural forests to agroforestry and monoculture) around the buffer zone of the Lore Lindu Biosphere Reserve are the basis for research to investigate the effects of different land uses on the species diversity of soil macrofauna that potentially affect the decomposition rate. The aims of this study were to determine: (i) soil macrofauna diversity in agroforestry and monoculture plantation, (ii) litter decomposition rate in agroforestry and monoculture plantation, and (iii) the correlation between soil macrofauna diversity and litter decomposition rate in agroforestry and monoculture.

2. RESEARCH METHOD

2.1 Research sites

This research was conducted in the buffer zone of Lore Lindu Biosphere Reserve, Sigi Regency, Central Sulawesi, Indonesia (Table 1). The research sites were divided into three: complex agroforestry (CAF), simple agroforestry (SAF), and candlenut monoculture (CM). Identification of macrofauna was carried out at Plant Pests and Diseases Laboratory of Faculty of Agriculture, and Forestry Sciences Laboratory of Faculty of Forestry, Universitas Tadulako.

2.2 Litter sampling

Litter samples were obtained using 18 litter traps of 1.5 m above the ground with 20m×20m square plots distance. They were installed for 30 days at each site. Subsequently, 100 g of air-dried litter was inserted to each litter bag. The litter bags were placed at each research site for the observations of macrofauna and litter decomposition rates [16].

2.3 Macrofauna observation

Soil macrofauna found in each litter bag were preserved in *eppendorf* with alcohol 70% for identification purposes. The collected samples were grouped based on the similarity of their morphological characteristics by thoroughly examining the outward appearance. Identification was conducted based on the guide [17].

2.4 Decomposition rate observation

The measurement of decomposition rate was carried out using a litter bag of 20cm×20cm in size containing 100 g of air dried litter. Litter bags were placed in each research site with a distance of 20m×20m. Monitoring was done every month by randomly collecting three litter bags from each location. Observations were made for six months (180 days). Monitoring litter bags every month determines the total litter mass loss in the monthly decomposition process. And Macrofauna observations were carried out every month to determine the type of soil macrofauna that played a role in each stage of the decomposition. Knowing the pattern of litter decomposition it cannot be done only on one observation factor, but observations must include the amount of litter mass loss, changes in nutrient concentration, and the abundance and activity of soil macrofauna [18]. Litter bags separated from macrofauna are cleaned and dried at 70℃ to constant weight [19].

2.5 Microclimate measurement

Microclimate measurements involved the data of humidity, temperature, and light intensity. The secondary data was obtained from rainfall data issued by the Meteorology, Climatology, and Geophysics Agency (BMKG).

2.6 Data analysis

2.6.1 Species diversity index (*H'*)

The species diversity of soil macrofauna is calculated using the Shannon-Wiener Index (*H'*) in [20]. The equation is:

$$H' = \sum_{i=1}^{s} (\text{Pi} \ln \text{Pi}) \quad (1)$$

where, Pi=ni/N; ni=Number of individuals of each species (*i*); *N*=Total number of individuals; *S*=Total number of species in the sample.

Species diversity ranges from 1.5 to 3.5, with a value of 1.5 signifying low diversity, values of 1.5 to 3.5 signifying moderate diversity, and values of 3.5 signifying high diversity [1].

2.6.2 Similarity index

The similarity of species composition for research sites is measured using the Sorensen index [21] by the equation:

$$\text{Cs} = \frac{2C}{(A+B)} \text{X}100 \quad (2)$$

where, *Cs*=Sorensen similarity index, *A*=The number of species found in habitat 1, *B*=The number of species found in habitat 2, *C*=The number of species shared by the two habitats.

2.6.3 Decomposition rate

The decomposition rate of litter is calculated using the Olson formula [17] as follows:

$$\text{R} = \frac{Wo - Wt}{T} \quad (3)$$

where, *R*=Decomposition rate (g/day), *T*=Time/period of observation (day), *Wo*=The initial mass (g), *Wt*=The weight of litter at each time/period of observation (T).

Table 1. Characteristics of research sites in the buffer zone of Lore Lindu Biosphere Reserve, Indonesia

Characteristics	Type of land		
	Complex agroforestry	Simple agroforestry	Candlenut monoculture
Altitude (masl)	582	679	711
Coordinate	01˚03'45.6" 120˚00'41.1"	01˚05'53.9" 119˚59'09.3"	01˚05'47.3" 119˚58'58.1"
Transect plot direction	158˚	262˚	307˚
Rainfall (mm/year)	2210	2210	2210

Comparison of decomposition rates for different types of land use (complex agroforestry, simple agroforestry, and candlenut monoculture) were analyzed using one-way ANOVA Subsequently, the honestly significant difference test (HSD) is used to test differences among samples for significance [22-25]. Differences were evaluated at $P < 0.05$. The relationship between soil macrofauna and decomposition rate was analyzed using Spearman's correlation [22].

3. RESULTS AND DISCUSSION

3.1 Species diversity of soil macrofauna

Based on the identification of soil macrofauna, 21 orders and 35 families of soil macrofauna were found in the three types of land use. The results are presented in Table 2.

The results of identification showed that 67 types of macrofauna (21 orders and 35 families) were identified. Specifically, 44 species were found in complex agroforestry, 37 species in simple agroforestry, and 20 species in candlenut monoculture. The finding implies that the practice of agroforestry system in the buffer zone of the Lore Lindu Biosphere Reserve can be a solution to support the diversity of soil macrofauna. The survival of species is not only affected by the different types of vegetation, but also by the density of vegetation that greatly affects the availability of litter as a food source as well as the micro habitat of macrofauna [4, 17].

Agroforestry can be a means of soil conservation with its role in intercepting rainwater and reducing the power of rainwater exposure. In addition, agroforestry can also cause the formation of a layer of litter on the soil surface. Agroforestry systems generally use shade plants, causing the formation of stratified plant crowns. This agroforestry system is considered a system that can resemble a forest [26]. Agroforestry experiencing succession can function better because it can resemble a natural forest ecosystem in terms of structure, diversity, and ecological interactions [27]. The similarity between natural forest and agroforestry can be seen from the colonization of macrofauna, where there is a similarity between density during the rainy season and shows the efficiency of agroforestry systems in improving soil quality and increasing diversity and macrofauna in degraded soils [28-30].

Several insects classified as surface macrofauna on the heterogeneous and homogeneous forests, including *Formicidae, Vespidaceae, Gryllinae, Coleoptera, Siphonoptera,* and *Diptera* [31]. The diversity of plant species in teak (*Tectona grandis*) and elephant ear (*Xanthosoma sangittifolium*) agroforestry systems affected the diversity of soil macrofauna, enhancing the soil fertility [32]. The results of data analysis on the species diversity of soil macrofauna are presented in Table 3.

Based on the data, the species diversity index (H') of soil macrofauna on complex agroforestry and simple agroforestry is 2.10 and 1.88, respectively. The diversity index on these types of agroforestry system is classified moderate to high. Meanwhile, in candlenut monoculture, the diversity index is low (0.78). The diversity index (H') above 2 (H'>2) is categorized high, indicating that the soil macrofauna of a habitat is very stable [21]. The high diversity index of soil macrofauna indicates that agroforestry system fairly supports the existence of macrofauna [1, 19, 33]. This condition is strongly influenced by the amount and composition of the type of litter produced by the vegetation on both complex and simple agroforestry systems [32]. The amount and composition of different litters will affect the number and composition of macrofauna species [32-34]. It confirms Denni et al. [35] that the C-organic content in the soil is influenced by the input of litter which determines the availability of carbon in the soil, affecting the presence of macrofauna in the decomposition process. Furthermore, Marsden et al. [32] explain that the soil in the agroforestry system contains higher species richness and species abundance of soil macrofauna compared to that of grassland soil. This difference is caused by the presence of leaf litter from various tree species that serves as a source of organic matter and micronutrients and is beneficial in terms of microclimate for some species. In contrast to monoculture plantation, the low diversity of soil macrofauna on candlenut monoculture is possibly caused by the low number and diversity of vegetation [6, 12, 14]. In addition, management activities are one of the factors of the low diversity of macrofauna species [34]. It verifies the low abundance of macrofauna in monoculture plantations, which is mainly caused by intensive land management and the loss of litter due to tillage and land clearing activities [1, 31].

3.2 Similarity index

Similarity index ranges from 0 to 100%, with a high similarity index value indicates a high level of species similarity between the two communities being compared [36]. In describing the composition of a forest community, the diversity of flora and fauna can be used as an assessment parameter. In this study, observations focused on the diversity of soil macrofauna species. The diversity of soil organisms could be used as a key species to assess an ecosystem [37, 38]. Invertebrates were the best indicators for assessing soil quality [39]. Different types of composting vegetation and planting systems will directly affect the population of soil invertebrate fauna, reducing their density and species diversity [40]. Soil macrofauna can be used to assess differences in the standing community of *Paraserianthes falcataria* [41].

The data analysis showed the similarity index of soil macrofauna in the three types of land as presented in Table 4.

At the beginning of the observation, the similarity index of macrofauna was the highest due to the higher amount of litter in the litter bag [14]. Therefore, the intensity of findings was relatively high. This condition occurred in all research sites. However, the intensity gradually declined in line with the time of observation. The amount of litter in the litter bag began to decrease and run out. It affected the similarity index of soil macrofauna on the sites. At the beginning of the observation, the similarity index ranged from 47% to 52% (high). However, at the end of the observation, it began to decline, ranging from 0% to 18% (low). In overall, the average similarity index during observations on the three sites is low, below 50% (21% to 35%). The behavior of macrofauna in food preferences during sufficient amount of litter is a factor causing the high similarity index at the beginning of the observation [42]. Meanwhile, the similarity index decreases in line with the decrease in the amount of litter.

Table 2. Species diversity of soil macrofauna in the buffer zone of Lore Lindu Biosphere Reserve, Indonesia

No	Order	Family	Morphospecies	CAF	SAF	CM	Role
1	Araneida	Linyphiidae	Linyphiidae species 1	√	-	-	Predator
2			Linyphiidae species 2	√	-	-	Predator
3		Lycosidae	Lycosidae species 1	√	√	-	Predator
4			Lycosidae species 2	-	√	-	Predator
5			Lycosidae species 3	√	√	√	Predator
6			Lycosidae species 4	√	-	-	Predator
7			Lycosidae species 5	√	-	-	Predator
8		Salticidae	Salticidae	√	√	-	Predator
9		Thomisidae	Thomisidae species 1	-	√	-	Predator
10			Thomisidae species 2	-	√	-	Predator
11			Thomisidae species 3	√	-	-	Predator
12	Blattaria	Blattellidae	Blattellidae species 1	√	√	√	Decomposer
13			Blattellidae species 2	-	-	√	Decomposer
14	Coleoptera	Cerophytidae	Cerophytidae	-	√	-	Decomposer
15		Coccinellidae	Coccinellidae	-	-	√	Decomposer
16		Dasyceridae	Dasyceridae species 1	√	√	√	Decomposer
17			Dasyceridae species 2	√	√	√	Decomposer
18			Dasyceridae species 3	√	-	-	Decomposer
19		Mycetophagidae	Mycetophagidae	√	-	-	Decomposer
20		Passalidae	Passalidae	-	√	-	Decomposer
21		Scarabaeidae	Scarabaeidae	-	√	-	Decomposer
22		Scolytidae	Scolytidae species 1	-	√	-	Decomposer
23			Scolytidae species 2	-	√	-	Decomposer
24	Collembola	Entomobrydae	Entomobrydae	-	√	-	Decomposer
25	Dermaptera	Forficulidae	Forficulidae species 1	√	√	√	Predator
26			Forficulidae species 2	√	√	-	Predator
27	Hemiptera	Cydnidae	Cydnidae species 1	√	√	√	Predator
28			Cydnidae species 2	-	-	√	Predator
29		Pyrrhocoridae	Pyrrhocoridae species 1	√	-	-	Predator
30			Pyrrhocoridae species 2	-	√	-	Predator
31	Hymenoptera	Formicidae	Formicidae species 1	√	√	-	Decomposer
32			Formicidae species 2	√	-	-	Decomposer
33			Formicidae species 3	√	√	-	Decomposer
34			Formicidae species 4	-	√	-	Decomposer
35			Formicidae species 5	√	√	√	Decomposer
36			Formicidae species 6	-	-	√	Decomposer
37			Formicidae species 7	√	-	√	Decomposer
38			Formicidae species 8	-	-	√	Decomposer
39			Formicidae species 9	-	√	-	Decomposer
40			Formicidae species 10	√	-	√	Decomposer
41			Formicidae species 11	√	-	√	Decomposer
42			Formicidae species 12	√	-	-	Decomposer
43			Formicidae species 13	√	-	-	Decomposer
44			Formicidae species 14	√	-	-	Decomposer
45	Isopoda	Armadillidiidae	Armadillidiidae	√	√	√	Decomposer
46		Cirolanidae	Cirolanidae	√	-	-	Decomposer
47	*Macrotermes* sp	*Macrotermes* sp	*Macrotermes* sp	√	√	√	Decomposer
48	Mantodea	Mantidae	Mantidae	-	√	-	Predator
49	Opiliones	Phalangidae	Phalangidae species 1	√	-	-	Predator
50			Phalangidae species 2	-	√	-	Predator
51	Opthoptera	Gryllacrididae	Gryllacrididae	-	-	√	Predator
52		Gryllidae	Gryllidae species 1	-	√	-	Decomposer
53			Gryllidae species 2	√	-	-	Decomposer
54		Mantidae	Mantidae	√	-	-	Predator
55	Polydesmida	Cryptodesmidae	Cryptodesmidae species 1)	√	-	-	Decomposer
56			Cryptodesmidae species 2	√	-	-	Decomposer
57	Pseudoscorpiones	Cheliferidae	Cheliferidae	√	-	-	Predator
58	Rhynchobdellida	Piscicolidae	Piscicolidae	√	√	√	Predator
59	Schizomida	Hubbardiidae	Hubbardiidae	-	√	-	Predator
60	Scolopendromorpha	Scolopendridae	Scolopendridae	√	√	-	Decomposer
61	Siphonaptera	Pulicidae	Pulicidae	√	-	-	Decomposer
62	Spirostreptida	Spirostreptidae	Spirostreptidae species 1	√	√	-	Decomposer
63			Spirostreptidae species 2	√	√	-	Decomposer
64	Stylommatophora	Polygyridae	Polygyridae	√	√	-	Decomposer
65		Subulinidae	Subulinidae species 1	√	√	√	Decomposer
66			Subulinidae species 2	√	-	-	Decomposer
67	Trombidiformes	Trombidiidae	Trombidiidae	-	√	-	Predator
		Total species		44	37	20	

Table 3. Soil macrofauna diversity in the buffer zone of Lore Lindu Biosphere Reserve, Indonesia

Land Type	Species diversity (*H'*) of each time of observation (month)						
	1	2	3	4	5	6	Mean
Complex Agroforestry	2.40	2.40	2.30	2.10	2.03	1.39	2.10
Simple Agroforestry	2.11	2.31	1.91	2.08	0.64	2.25	1.88
Candlenut Monoculture	1.83	1.61	1.24	0.00	0.00	0.00	0.78

Table 4. Similarity index of soil macrofauna in the buffer zone of Lore Lindu Biosphere Reserve, Indonesia

Land types	Similarity index at each time of observation (month)						
	1	2	3	4	5	6	Mean
CAF and SAF	47%	34%	35%	47%	18%	26%	35%
CAF and CM	52%	47%	28%	0%	0%	0%	21%
CM and SAF	50%	50%	36%	0%	0%	0%	23%

Note: Complex Agroforestry (CAF), Simple Agroforestry (SAF), Candlenut Monoculture (CM)

Table 5. Decomposition rate of litter in the buffer zone of Lore Lindu Biosphere Reserve, Indonesia

Type of land	Decomposition rate at each time of observation (month)					
	1	2	3	4	5	6
Complex Agroforestry	0.98 a	0.62 a	0.55 ab	0.48 a	0.44 b	0.23 b
Simple Agroforestry	1.02 a	0.53 a	0.25 a	0.39 a	0.50 b	0.31 b
Candlenut Monoculture	1.01 a	0.90 b	0.71 b	0.44 a	0.00 a	0.00 a

3.3 Decomposition rate of litter

The calculation of the decomposition rate of litter in the buffer zone of Lore Lindu Biosphere Reserve was done and presented in Table 5.

The results of the analysis (Table 5) show that the litter decomposition rate in candlenut monoculture was significantly different from agroforestry systems. It is due to the type of vegetation that makes up the different types and quality of litter, causing the decomposition rate to vary for each type of species [43]. Bai et al. [44] explains that the decomposition rate above 0.01 is categorized high; 0.005 to 0.01 is moderate; and less than 0.005 is low. The average litter decomposition rates in complex agroforestry, simple agroforestry, and candlenut monoculture are 0.55, 0.50, and 0.51, respectively. In general, the litter decomposition rate in the three types of land is relatively high [34, 35, 43].

The litter decomposition process in both agroforestry and monoculture plantation is relatively fast at the beginning of the observation and began to slow down in line with the decreasing amount of litter in the litter bag [42, 43]. However, the time required for the decomposition process is basically different for each land type. This is due to differences in the composition of the constituent vegetation that affect the litter composition. Sohng et al. [45] suggest that differences in the composition of vegetation affect the litter decomposition rate due to diverse quality of litter and decomposition rate of plant. In addition, microclimate also influences the litter decomposition rate [46]. Temperature and humidity, which are highly influenced by rainfall, are climatic factors that play a key role in the decomposition rate as they accelerate the litter decomposition [47].

3.4 Correlation between soil macrofauna and decomposition rate

Guidelines for interpreting the correlation coefficient are: 0.00 to 0.199 is very weak, 0.20 to 0.399 is weak, 0.40 to 0.599 is moderate, 0.60 to 0.799 is strong, and 0.80 to 1,000 is very strong [48]. Based on the guidelines, the correlation between soil macrofauna diversity and litter decomposition rate in complex agroforestry, simple agroforestry, candlenut monoculture is very strong (0.971), low (0.314), and very strong (0.955), respectively.

The positive relationship indicated by the correlation coefficient shows that the high diversity of soil macrofauna in complex agroforestry is directly proportional to the litter decomposition rate [32-35]. It is allegedly caused by the high diversity of plants that make up the complex agroforestry system, leading to the availability of abundant and diverse litter as a source of food and habitat for soil macrofauna [19, 44, 49]. The composition and amount of litter significantly determine the type and density of soil fauna [50]. In complex agroforestry, the species diversity of soil macrofauna is higher than others, and most of these macrofauna are decomposers (Table 2). Soil macrofauna such as snails, earthworms, millipedes, ants, and termites contribute in biting and chewing litter into smaller sizes, making it easier for soil microorganisms in the decomposition process [33].

In simple agroforestry system, the correlation between species diversity and decomposition rate is relatively weak. The moderate diversity of soil macrofauna in this site contributes to the weak correlation. The properties of organic matter in cocoa litter are relatively difficult to decompose compared to candlenut and avocado litter. It is indicated by the accumulation of cocoa litter on the ground. Intensive human activities such as land clearing and the application of chemical fertilizers and pesticides have led to the decline in the number and composition of soil macrofauna species [51]. The diversity index of soil macrofauna on cocoa plantations was relatively low due to the use of synthetic pesticides [31]. Excessive use of pesticides causes the extinction of certain soil macrofauna, decreasing the species diversity of soil macrofauna in cocoa plantations [1].

The correlation between soil macrofauna and decomposition rate of litter in candlenut monoculture was very strong/perfect (0.955). This positive correlation demonstrates that the consumption rate of soil macrofauna is relatively high, accelerating the decomposition process of litter [35, 52]. The decomposition rate of litter in monocultures is higher due to limited decomposers or food preferences [53]. In addition, it is also influenced by the condition of candlenut litter, which is easy to decay. Candlenut monoculture has relatively low vegetation density, causing sunlight to reach the ground and supporting the acceleration of chemical and biological reaction processes, one of which is the decomposition of soil organic matter [35, 42, 47].

4. CONCLUSIONS

The analysis of soil macrofauna identifies the presence of 67 species, consisting of 44 species in the complex agroforestry, 37 species in simple agroforestry, and 20 species in candlenut monoculture. The diversity index (H') of soil macrofauna in complex agroforestry and simple agroforestry can be classified as moderate. Meanwhile, species diversity in candlenut monoculture is relatively low. The similarity of soil macrofauna in the three types of land is low with a similarity index below 50%. The decomposition rate of litter is relatively high, above 0.01 g/day. The correlation between the species diversity of soil macrofauna and the decomposition rate of litter in both complex agroforestry and candlenut monoculture is very strong. Meanwhile, in simple agroforestry, the correlation is relatively weak.

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