ABUNDANCE, BIOMASS AND DIVERSITY OF SOIL FAUNA AT DIFFERENT ECOSYSTEMS IN JAKENAN, PATI, CENTRAL JAVA

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ABSTRACT

The assessment of soil fauna in three different ecosystems namely teak forest, home garden and fallow paddy field had been studied in Pati, Central Java. The soil fauna was collected using a soil corer of 20 cm diameter to the depth of 0-15 cm from 5 randomized points in the above ecosystems. The soil fauna was then extracted in a Berlese funnel extractor. Soil fauna in the home garden showed a highest abundance (2 940 individual m^{-2}), followed by teak forest (2 340 individual m^{-2}) and fallow paddy (1 790 individual m^{-2}). Home garden had also a higher soil fauna diversity (2.06) compared to the teak forest (1.82) and fallow paddy (1.67). In terms of soil fauna biomass, teak forest had a higher value (961 mg m^{-2}) compared to the home garden (368 mg m^{-2}) and fallow paddy (309 mg m^{-2}). In these three ecosystems, two fauna groups, i.e. Collembola and Acari were the most abundant animals. Poor vegetation cover tend to reduce the population of soil fauna in the fallow paddy field, whereas vegetation found in the home garden and teak forest protected the soil surface from direct sunshine and maintained soil moisture. This condition presumably provided a more favourable habitat for soil fauna. Thus, vegetation cover appears important to maintain soil moisture and soil living-organisms.

***Key words**: soil fauna, abundance, diversity, ecosystem, vegetation cover*

INTRODUCTION

Soil fauna groups like earthworms, termites, several group members of Coleoptera, Diptera, Acari, Collembola, etc. have an important role on the vital soil processes such as organic matter decomposition and nitrogen mineralization. Soil fauna contribute up to about 30% of the total net nitrogen mineralization in forest and grassland ecosystems (Verhoef and Brussaard, 1990). Earthworms participate in the nitrogen cycles through their production of casting and mucus and decomposition of dead tissue. Earthworm activity can increase the nitrogen availability for uptake by plants in shifting agriculture systems (Bhadauria and Ramakrishnan, 1996). As ecosystem engineers, earthworms, termites and ants can directly affect the availability of resources to other organisms through modification of the physical environment (Lavelle *et al.*, 1997). The nest mounds constructed by ants can increase the incidence and abundance of a plant community due to nutrient enrichment of the nest soils (Wilby *et al.*, 2001).

Maintaining soil animal diversity is important in order to sustain the ecosystem processes. Naeem *et al.* (1995), in their mesocosm experiment with direct manipulation of diversity under controlled environmental conditions, provided the evidence that ecosystem processes like community respiration, productivity, decomposition, etc., may be negatively affected by the decline of animal species diversity. A laboratory experiment to estimate the decomposition rate using three species of Plecoptera as detritivores indicated, that a number of species have significant effects on the leaf litter decomposition rate, which increases with the increase in animal species richness (Jonsson and Malmqvist, 2000).

Most land use practices reduce the abundance and/or diversity of soil macroinvertebrate communities by disturbing their physical environment and reducing the diversity and abundance of organic inputs that they normally use for feeding (Curry, 1987; Decaens *et al.*, 1994; Eggleton *et al.*, 1997). Therefore, management of soil fauna is important to be done to improve the soil fauna population and its function in ecosystem processes. Soil fauna management could be done by improving their physical environmental conditions, for instance by maintaining plant cover with a diverse types of vegetation. The vegetation cover protected the soil surface from direct sunshine and maintained soil moisture. This condition presumably provided a more favorable habitat for soil fauna (Saetre *et al.*, 1999).

In this study, the assessment of soil fauna in the study area aimed at obtaining a general overview of soil fauna abundance, biomass and diversity in the ecosystems of the region. Three different ecosystems were found in this area, namely secondary forest, which is mainly cultivated by teak (teak forest), home gardens dominated by cassava, and fallow paddy fields. Almost all of the soil surface in the teak forest was covered by vegetation and plant litter, meanwhile in the home garden, the soil surface was covered by vegetation like cassava, papaya, tomatoes, sweet potatoes, grasses, etc. During the dry season, the paddy fields lay fallow as they were completely dry. The field was covered only with grasses and weeds.

Materials and Methods

The study was conducted at the Jakenan, Pati, Central Java, Indonesia, situated at 6.75° South Latitude and

111.04° East Longitude. The average annual rainfall in the region is approximately 1 500 mm. Daily variations in the minimum temperature ranged between 18.0°C and 25.0°C; the maximum temperature ranged between 27.0°C and 36.0°C.

Study of soil fauna in different ecosystems

The soil samples were taken from the three ecosystems namely teak forest, home garden dominated by cassava, and rain fed paddy fields during the dry season in July 2002. Soil sampling was conducted during the midday. The soil fauna was collected using a soil corer of 20 cm diameter to the depth of 0-15 cm (Meyer, 1996) from five randomized points in the above ecosystems. The soil fauna was then extracted in a Berlese funnel extractor, a device for collecting and extracting the active stages of small invertebrate animals from soil or litter (Beck *et al.*, 1998).

The soil sample was put into a bucket of 20 cm diameter, which had a 2.0 mm screen at the bottom holding the soil samples but letting the animals pass through. The bucket was placed on top of the big plastic funnel. Ten cm above the bucket, a small lamp of 40 watt was placed as a source of heat. The animals within the soil samples were forced to move downward to avoid the heat. They then fell into a collecting vial containing ethylene glycol as a preservative. The extraction of soil fauna took place during seven to ten days. The soil fauna was stored in 70% ethanol and determined under a stereomicroscope.

Larger animals, especially earthworms, were sorted by hand (Meyer, 1996). In each ecosystem, 1 to 3 l of 0.2-0.4 % formalin solution was poured into an enclosed sampling area (0.5 m^2) repeated at 10-min intervals. Sampling took place during the 30 minutes following the application. The application of formalin was done in three times. The big earthworms expelled from the soil were collected by hand and small ones using a forceps. The earthworms were immediately fixed in 70% ethanol using the labeled plastic container.

Calculation of animal abundances and biomass

The number of individuals (abundance or density) of the extracted animals was calculated as follows (Meyer, 1996):

$$\frac{IS}{A} = I.cm^{-2}$$

IS = mean number of individuals per sample
A = surface area of the corer (cm^2) *)
I = number of individuals

*) Area of the corer = $r^2.\pi$ = (10 cm)^2 x 3.14= 314 cm^2. The value was then converted into m^2.

Biomass of the soil fauna was calculated based on their individual dry weight using different regression equations of body length-body weight.

Calculation of soil animal diversity

Diversity indices were calculated according to Shannon's diversity index (Ludwig and Reynolds, 1998). The equation for the Shannon function is as follow:

$$H' = \sum_{i=1}^{s}\left[(n_i/n)\ln(n_i/n)\right]$$

H' = Shannon's diversity index
n_i = the number of individuals belonging to the i^{th} of *s* species (or animal groups) in the sample
n = the total number of individuals in the sample.

The diversity index was calculated for both, number of soil animal groups and their biomass.

Grouping and identification

All samples were sorted and counted in the laboratory using a stereomicroscope. All animals were classified into taxonomic orders except for springtails, beetles, millipedes, centipedes and Oligochaeta. Springtails and beetles were classified into families. The individuals of the classes of millipedes, centipedes and Oligochaeta were not classified further. Identification was based on Borror *et al.* (1989) and Chu (1949). After the animals had been placed into orders, they were classified based on their body length according to the classification system of van der Drift (1951) (Table 1).

Table 1. Classification System of Soil Fauna Categories Based on Body Length

Categories	Body Length (*mm*)
Microfauna	<0.2
Mesofauna	0.2 – 2.0
Macrofauna	2.0 – 20.0
Megafauna	>20.0

RESULTS AND DISCUSSION

Soil Fauna in Different Ecosystems of the Region

In the assessment of soil fauna that was conducted during the dry season, the total soil fauna abundance was high in the teak forest (2 340 individuals m^{-2}) and home garden (2 940 individuals m^{-2}) and low in the fallow paddy field (1 790 individuals m^{-2}) (Table 2). The teak forest also showed the highest total soil fauna biomass (961 mg m^{-2}), followed by home garden (368 mg m^{-2}) and fallow paddy field (309 mg m^{-2}), respectively (Table 3). Nevertheless, due to the high variance of the data, the Student's *t*-test analysis on the log-transformed fauna data showed that the differences in total soil fauna abundance and biomass were not significant in the teak forest, home garden and fallow paddy field ecosystems.

Abundance and biomass

The mesofauna abundance was higher compared to that of the macrofauna, especially in the home garden and fallow paddy field. Mesofauna numbers in the home garden and paddy field were 2 130 and 1 450 individuals m^{-2} or 73% and 81% of the total number of soil animals, respectively. In general, the mesofauna abundance was dominated by Acari (mites) and Collembola (springtails). Their populations ranged between 20%-35% (mites) and 60%-80% (springtails) of the total mesofauna. According to Lavelle and Spain (2001), Collembola and Acari are generally dominant among mesofauna, both numerically and in terms of biomass. Although mesofauna numbers were high, their biomass was low, as they are small animals with body width ranging between 0.2 – 2.0 mm. Their biomass in the teak forest, home garden and paddy field accounted for only 5.3 mg, 9.0 mg and 10.5 mg m^{-2} or 0.6%, 2.4% and 3.4% of the total animal biomass, respectively.

Table 2: Abundances of Soil Fauna in Different Ecosystems of the Region (soil depth 0-15 cm; averages over five replications)

No.	Taxa	Teak Forest		Home Garden		Fallow Paddy	
		Mean	SD	Mean	SD	Mean	SD
				(Individual m^{-2})			
	Mesofauna						
1	Acari: Oribatida (Oribatid mites)	166	233	134	82	229	114
	Tetranychidae (Spider mites)	38	52	166	198	0	0
	Others	57	65	140	80	57	128
	Total Acari	**261a**	**250**	**440a**	**188**	**287a**	**154**
2	Collembola: Isotomidae	140	129	1 100	590	446	449
	Poduridae	83	77	471	476	0	0
	Hypogastruridae	0	0	32	39	0	0
	Entomobryidae	26	42	19	17	6	14
	Neelidae	13	29	38	35		14
	Onychiuridae	229	289	6	14	701	1 160
	Sminthuridae	0	0	6	14	0	0
	Total Collembola	**490a**	**440**	**1 680a**	**514**	**1 160a**	**1 470**
3	Protura	6	14	0	0	0	0
4	Symphyla	13	17	13	17		0
	Total Mesofauna	**771a**	**609**	**2 130b**	**572**	**1 450ab**	**1 500**
	Macrofauna						
5	Aranae (Spiders)	32	39	32	39	0	0
6	Coleoptera: Carabidae	13	17	0	0	38	86
	Others ad.	6	14	32	55	198	184
	Others la.	0	0	13	17	83	58
7	Chilopoda (Centipedes)	13	17	0	0	6	14
8	Diplopoda (Millipedes) juvenile	19	29	57	79	0	0
9	Diplura: Japygidae	0	0	217	120	0	0
	Anajapygidae	0	0	6	14	0	0
10	Diptera	0	0	0	0	6	14
11	Hymenoptera:						
	Formicidae (Ants)	1 190	1 670	414	717	6	14
	Others	0	0	19	43	6	14
12	Isopoda	6	14	0	0	0	0
13	Isoptera (Termites)	268	581	0	0	0	0
14	Lepidoptera (larvae)	6	14	13	17	0	0
15	Pseudoscorpiones	13	17	0	0	0	0
	Total Macrofauna	**1 560ab**	**1 580**	**803b**	**604**	**344ac**	**277**
	Oligochaeta:						
16	Earthworms	6	14	0	0	0	0
17	Enchytraeids	0	0	13	29	0	0
	Total Oligochaeta	**6**	**14**	**13**	**29**	**0**	**0**
	Number of Individual m^{-2}	**2 340a**	**1 830**	**2 940a**	**1 050**	**1 790a**	**1 460**
	Number of Taxa m^{-2}	**21**		**21**		**13**	
	Shannon's Diversity Index	**1.82**		**2.06**		**1.67**	

In a row, means followed by a common letter are not significantly different at the 5% level (Student's *t*- test on log-transformed fauna data).

Table 3: Biomass of Soil Fauna in Different Ecosystem of the Region (averages over five replications)

No.	Taxa	Teak Forest		Home Garden		Fallow Paddy	
		Mean	SD	Mean	SD	Mean	SD
	Mesofauna			(*mg m*$^{-2}$)			
1	Acari: Oribatida (Oribatid mites)	0.18	0.26	0.15	0.09	0.25	0.12
	Tetranychidae (Spider mites)	0.17	0.24	0.75	0.89	0.00	0.00
	Others	0.26	0.29	0.63	0.36	0.26	0.58
	Total Acari	**0.61a**	**0.48**	**1.52bc**	**0.77**	**0.51ac**	**0.57**
2	Collembola : Isotomidae	0.62	0.57	4.85	2.60	1.96	1.97
	Poduridae	0.19	0.18	1.08	1.10	0.00	0.00
	Hypogastruridae	0.00	0.00	0.18	0.22	0.00	0.00
	Entomobryidae	0.21	0.35	0.16	0.15	0.05	0.12
	Neelidae	0.03	0.07	0.09	0.08	0.01	0.03
	Onychiuridae	2.61	3.29	0.07	0.16	7.99	13.27
	Sminthuridae	0.00	0.00	0.01	0.03	0.00	0.00
	Total Collembola	**3.66a**	**3.66**	**6.45a**	**2.27**	**10.00a**	**14.50**
3	Protura	0.01	0.01	0.00	0.00	0.00	0.00
4	Symphyla	1.02	1.40	1.02	1.40	0.00	0.00
	Total Mesofauna	**5.30a**	**5.07**	**8.99a**	**3.08**	**10.50°**	**14.40**
	Macrofauna						
5	Aranae (Spiders)	18.20	22.30	18.20	22.30	0.00	0.00
6	Coleoptera: Carabidae	11.66	15.90	0.00	0.00	34.90	78.00
	Others ad.	5.53	12.40	27.70	47.90	172.00	159.00
	Others la.	0.00	0.00	12.60	17.30	81.90	57.00
7	Chilopoda (Centipedes)	0.66	0.91	0.00	0.00	0.33	0.74
8	Diplopoda (Millipedes) juvenile	17.00	26.80	53.90	74.60	0.00	0.00
9	Diplura: Japygidae	0.00	0.00	4.33	2.40	0.00	0.00
	Anajapygidae	0.00	0.00	0.13	0.28	0.00	0.00
10	Diptera	0.00	0.00	0.00	0.00	2.86	6.39
11	Hymenoptera:						
	Formicidae (Ants)	592.00	836.00	207.00	359.00	3.19	7.12
	Others	0.00	0.00	9.55	21.40	3.19	7.12
12	Isopoda	0.72	1.61	0.00	0.00	0.00	0.00
13	Isoptera (Termites)	161.00	348.00	0.00	0.00	0.00	0.00
14	Lepidoptera (larvae)	12.60	28.20	25.22	34.50	0.00	0.00
15	Pseudoscorpiones	2.02	2.77	0.00	0.00	0.00	0.00
	Total Macrofauna	**822.00a**	**781.00**	**359.00a**	**322.00**	**298.00a**	**238.00**
	Oligochaeta:						
16	Earthworms	134.00	299.00	0.00	0.00	0.00	0.00
17	Enchytraeids	0.00	0.00	0.41	0.91	0.00	0.00
	Total Oligochaeta	**134.00**	**299.00**	**0.41**	**0.91**	**0.00**	**0.00**
	Biomass Total	**961.00a**	**933.00**	**368.00a**	**289.00**	**309.00a**	**235.00**
	Shannon's Diversity Index	**1.22**		**1.53**		**1.21**	

In a row, means followed by a common letter are not significantly different at the 5% level (Student's *t*- test on log-transformed animal data).

In general, the individual macrofauna numbers were lower than those of the mesofauna, except in the teak forest, accounting for less than 30% of the total number of soil fauna. Nevertheless, their biomass was very high and reached more than 90% of the total biomass (Table 3). Although the macrofauna abundance was higher in the teak forest than in the home garden and fallow paddy field, the Student's *t*-test analysis showed no significant difference between macrofauna in those ecosystems. The macrofauna abundance, however, was significantly higher in the home garden than in the rainfed paddy field (Table 2). The most numerous macrofauna groups found in the teak forest ecosystem were Formicidae (ants) and Isoptera (termites), while Diplura and Coleoptera (beetles) dominated in the home garden and fallow paddy field, respectively. Oligochaeta occurred only in the home garden and teak forest, and their abundance was very low, attaining less than 1.0% of the total number of soil animals. In the teak forest, however, the biomass of Oligochaeta was high, attaining 134 mg m^{-2} or 14.0% of the total biomass.

Diversity

In the teak-forest and home-garden ecosystem, there were more taxa than in the fallow paddy field. The teak forest and home garden had 21 taxa, whereas in the paddy field only 13 taxa were found. Although the teak forest and the home garden contained the same number of taxa, the diversity, calculated according to Shannon's diversity index (Ludwig and Reynolds, 1988), was higher in the home garden (2.06) than in the teak forest (1.82), while the fallow paddy field had the lowest animal diversity (1.67).

In the teak forest, Hill's number (Ludwig and Reynolds, 1988), a number indicating an abundant taxa (N1) was 6.2, while the number of very abundant taxa (N2) was 3.7. In fact, four taxa, namely Formicidae (Hymenoptera), Isoptera, Onychiuridae (Collembola) and Oribatida (Acari) accounted for 79% of the total abundance. The number of abundant taxa in the home garden was higher (8 taxa) than in the other ecosystems, with five of them very abundant (N2) and accounting for 80% of the total abundance, namely Isotomidae and Poduridae (Collembola), Tetranychidae (Acari), Japygidae (Diplura), and Formicidae (Hymenoptera). Meanwhile, in the fallow paddy field, five taxa were found to be abundant, with four of them most numerous (88% of the total abundance), i.e. Onychiuridae and Isotomidae (Collembola), Oribatida (Acari), and Coleoptera (Table 2).

For the three ecosystems, namely teak forest, home garden and fallow paddy field, two groups of animals, i.e. Collembola and Acari, were the dominant taxa in terms of individual numbers. They were not only the most numerous animal groups, especially in the home garden and paddy field, but also always occurred in those ecosystems. Actually, ants were the most abundant animal group in the teak forest; however, they were not dominant in the other two ecosystems, and were rare in the fallow paddy field. Due to the high variance of the data, the high number of ants in the teak forest did not significantly differ from the number of ants in the home garden and paddy field.

The diversity index calculated from soil fauna biomass was higher in the home garden (1.53) than that in the teak forest (1.22) and fallow paddy field (1.21). Three groups of animals dominated the soil fauna biomass in the teak forest, namely Formicidae (ants), Isoptera (termites), and earthworms, making up for more than 90% of the total soil fauna biomass. Ant biomass was high in the teak forest and low in the paddy field. Ants also dominated soil fauna biomass in the home garden, along with Diplopoda and Coleoptera, accounting for 78% of the total soil fauna biomass. Their biomass was significantly higher in the home garden than in the paddy field and did not differ from that in the teak forest. In the fallow paddy field, Coleoptera, both larvae and adults, dominated the soil fauna biomass, accounting for more than 90% of the total in this ecosystem. The number of adults was significantly higher here than in the teak forest and home garden (Table 3).

General Discussion

Land use can alter soil conditions and the soil community of meso- and macro-organisms (Lavelle *et al.*, 1997; UNEP, 2001). For example, in the ecosystem comparison, the teak forest and home garden had a higher soil fauna abundance and biomass than the fallow paddy field. The teak forest and home garden had also a greater soil fauna variety, with at least three taxa dominating the soil fauna biomass in the teak forest, namely ants, termites and earthworms. Ants were also a dominant group in the home garden, whereas termites and earthworms did not occur in the soil samples of the fallow paddy field.

Poor vegetation cover and lack of plant litter covering the soil surface tend to reduce the abundance of soil fauna in the fallow paddy field, whereas some crops, like cassava, papaya and sweet potatoes, still found in the home garden during the dry season, protected the soil surface from direct sunshine. Likewise, in the teak forest, teak trees, shrubs and grasses as well as litter on the forest floor shaded the soil surface from direct sun and maintained soil moisture. This condition presumably provided a more favorable habitat for soil fauna (Saetre *et al.*, 1999), and accounted for the higher numbers of their population and diversity in the home garden and teak forest than in the fallow paddy field. Thus, vegetation cover appears important to maintain soil moisture and soil living-organisms.

CONCLUSIONS

In the fauna survey during the dry season, soil fauna in the .home garden and teak forest showed a higher abundance and diversity compared to the fallow paddy field, and their biomass was also higher in the teak forest and home garden than in paddy field. In these three ecosystems, two groups of animals, i.e. Collembola and Acari, were the dominant animals in terms of individual numbers. They were not only the most numerous groups, but also always occurred in those ecosystems.

Less vegetation cover tend to reduce the abundance, biomass and diversity of soil fauna in the fallow paddy field, whereas vegetation and litter found in the home garden and teak forest protected the soil surface from direct sunshine and maintained soil moisture. This condition presumably provided a more favorable habitat for soil fauna. Thus, vegetation cover appears important to maintain soil moisture and soil living-organisms.

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