LITTER DECOMPOSITION ON FOREST ROADS VERSUS INSIDE TROPICAL RAINFORESTS IN SABAH, MALAYSIA

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Forest roads constructed by bulldozers change the physical environment within the forests. A litter-bag experiment using three substrates (wood blocks, and *Shorea* and *Macaranga* leaf litter) was performed to clarify the effects of forest roads on initial litter decomposition in tropical rainforests. The results showed that the wood blocks and leaf litter had different decomposition rates between locations (on the path vs. inside the forest). The wood blocks decomposed more slowly on the path than inside the forest, whereas *Shorea* leaf litter decomposed more quickly on the path than inside the forest. The lower moisture content of both *Shorea* and *Macaranga* leaf litter indicated a more pronounced drought condition on the path. The surface area of leaf litter decreased more in *Macaranga* than in *Shorea*, whereas the leaf mass per area showed the opposite trend. This findings suggested that *Macaranga* leaf litter mainly decomposed by fragmentation, whereas *Shorea* leaf litter mainly decomposed by microbial degradation and leaching, in addition to fragmentation. The results indicated that road disturbance changed the balance between fragmentation and other degradation processes. The findings also highlighted that assessing the loss of surface area and leaf mass per area is appropriate for evaluating the influence of different types of leaf litter decomposition.

Keywords: Leaf area, leaf mass per area, litter bags, road disturbance, skid trails

INTRODUCTION

Forest roads (e.g., logging roads and skid trails constructed by bulldozers) are linear disturbances that separate continuous forests into smaller fragments, and change their physical environments (Laurance et al. 2009). The use of bulldozers increases soil compaction, which in turn, decreases infiltrability and root penetrability resulting in soil erosion of the running surface after rainfall (Malmer & Grip 1990, Sidle et al. 2004, Makineci et al. 2007). In tropical rainforests, soil erosion on roads is severe because of high rainfall intensities (Wallin & Harden 1996, Laurance et al. 2009). These environmental conditions on forest roads limit the recovery of plants and ground-dwelling invertebrate communities (Guariguata & Dupuy 1997, Pinard et al. 2000, Vasconcelos et al. 2000).

These impacts of forest roads also affect litter decomposition, which is controlled by macro- and microclimate, decomposing organisms, and litter quality (Coûteaux et al. 1995). Road disturbances cause a decline in the contents of soil organic matter and nutrients and result in an increase in temperature and a decrease in microbial activity on and around roads (Uhl et al. 1982, Ilstedt et al. 2006, Delgado et al. 2007, Makineci et al. 2007). These abiotic and biotic changes result in slower litter decomposition (Barlow et al. 2007). In tropical forests, in addition to microorganisms, litter-feeding invertebrates, including termites and isopods, also play a major role in litter

decomposition (Yamashita & Takeda 1998, González & Seastedt 2001). Road disturbance likely alters how these invertebrates affect litter decomposition by changing their community composition.

Fragmentation by litter-feeding invertebrates and abiotic processes, such as drying, wetting and surface water flow on the ground, decrease the surface area of leaf litter (Anderson 1973, Swift et al. 1979). In contrast, the surface area is maintained during degradation by microorganisms and the leaching of soluble substrates in the early stages of litter decomposition. Osono et al. (2009) evaluated the differences in the decomposition processes in a tropical forest between sun-bleached portions that were colonized by fungi and non-bleached portions of leaf litter by measuring the leaf mass per area. Therefore, the proportion of remaining leaf litter surface area and leaf mass per area are useful indices for roughly separating the types of decomposer functioning in the early stages of litter decomposition.

This study aimed to clarify the effects of forest roads on initial litter decomposition in tropical rainforests. A litter-bag experiment was conducted using the leaf litter of *Shorea* and *Macaranga*, which are the dominant and pioneer tree genera in the study region (Slik et al. 2003, Imai et al. 2012), as well as commercial wood material. It was predicted that (1) wood blocks and leaf litter would decompose more slowly on forest roads (bulldozer paths) than inside the forest; and (2) *Shorea* and *Macaranga* leaf litter would have different decomposition rates, because these genera are known to differ in their physical and chemical characteristics (Hirobe et al. 2004).

MATERIALS AND METHODS

Study sites

The study was conducted in Deramakot Forest Reserve and the neighboring Tangkulap Forest Reserve, Sabah, Malaysia (5° 14'–5° 30 'N, 117° 11'–117° 36' E), which are subject to different forest management practices. This region has an equatorial tropical humid climate. The annual rainfall at this site averages approximately 3,100 mm, and the mean annual air temperature is 25 °C, based on data from 2008 to 2010. Both Deramakot (551 km²) and Tangkulap (275 km²)

are composed of lowland mixed dipterocarp tropical rainforests that were selectively logged from the 1950s to the 1980s (Lagan et al. 2007, Ong et al. 2013).

The study areas have three forest types: pristine (5° 22' N, 117° 25' E), reduced-impact logged (RIL) (5° 21' N, 117° 25' E), and conventionally logged (CL) forests (5° 24' N, 117° 18' E). The pristine forest had some evidence of mild logging activities (e.g. old bulldozer paths and old stumps) in the past before they were conserved in the 1980s. The RIL is a kind of selective logging that requires detailed tree inventories, such as locations, species names and size (biomass) of the trees, and it reduces soil damage through well-planned construction of logging roads and skid trails (Bertault & Sist 1997, Putz et al. 2008). The section of RIL forest that was used in this study was conventionally logged once between the 1950s and the 1980s, and then by reduced-impact logging once in 1995. The CL forest was harvested by unregulated selective logging at least twice before 2001 (Langner et al. 2013). For details of the study sites and forest management practices, see Lagan et al. (2007) and Ong et al. (2013).

Several skid trails were constructed by bulldozers or crawler tractors in the late 1980s in the pristine forest and in the 1990s in each section of the RIL and CL forests. Skid trails are generally used as corridors to transport cut logs from the points of felling to log landings or logging roads during active logging (Buckley et al. 2003, Sidle et al. 2004). These bulldozer paths in the three forests were narrow (2.5–4.0 m wide), and the canopies above the paths were closed by the elongation of branches from the edges of path after road construction. There was much fallen litter on the paths, but the soil was compacted by the machinery.

Litter-bag experiment

Litter bags (20 cm × 20 cm) made of nylon netting with a 4 mm × 2 mm diamond-shaped mesh was used. Naturally senesced leaves of *Shorea macroptera* and *Macaranga* sp. were collected under the canopy of each tree species in March 2006. Dried wood blocks (2 cm × 3 cm × 4 cm) of *Magnolia hypoleuca* were also used, purchased in Japan. These substrates were air-dried until their weights stopped decreasing further in the laboratory and the initial weight was measured

to the nearest 0.01 g. The initial weight of *Shorea* and *Macaranga* leaf litter ranged from 0.51–1.58 g, 1.10–4.59 g and 3.42–6.34 g, respectively. The three types of materials (*Shorea* leaf, *Macaranga* leaf, wood block) were separated into three litter bags. To clarify the effects of fragmentation by litter-feeding invertebrates and abiotic processes, the surface area of each leaf was measured using Image J v. 1.37, based on a digital image of the leaf (Rasband 2007).

Two quadrats (2 m × 2 m) were established in a pristine and RIL forest in Deramakot, and a CL forest in Tangkulap. One quadrat was established on a bulldozer path and the other was established inside the forest (20 m from the edge of the path). In March 2006, 10 litter bags each of *S. macroptera* leaf litter, *Macaranga* sp. leaf litter and wood blocks were placed in each quadrat of each forest. All the litter bags were retrieved in September 2006 (6 months later). The leaf litter and wood blocks in the bags were weighed before (wet mass) and after air-drying (dry mass), and the surface area of the leaf litter samples was also measured. Moisture content (%) of leaf litter was calculated gravimetrically as follows: moisture content = [(wet mass - dry mass)/dry mass] × 100.

Data analysis

The degree of decomposition was expressed as the proportion (%) of the final to the initial leaf litter and wood-block mass, leaf surface area and leaf mass per area that was lost after 6 months. The degree of drought condition is also expressed by the moisture content of leaf litter at the sampling time (6 months later). Generalised linear mixed models (GLMMs) with Gaussian error distributions were used to clarify the effects of location (on the path vs. inside the forest) and tree species (*Shorea* vs. *Macaranga* leaf litter) on the proportions of remaining mass and surface area of leaf litter after logit transformation (Warton & Hui 2011). When the proportion of the remaining leaf surface area exceeded 1, the value was assumed to be 1, and the logit transformation was conducted after adding the minimum value of the proportion in the treatment. Because leaf mass per area and leaf moisture content could exceed 100%, logit transformation was not used for these values. The proportions of leaf mass and area, leaf mass per area and leaf moisture content were

used as response variables, location and tree species as the explanatory variables, and the study forests as a random effect. The GLMMs was also used to clarify the effects of location on the proportion of remaining mass of wood blocks after logit transformation. The lmer function within the lme4 package in R v.3.1.3 was used (R Development Core Team 2017). Model comparisons were conducted based on Akaike's information criterion (AIC) values. Models with the lowest AIC values were considered as the best fit in each analysis.

RESULTS

The AIC values of both the final mass (g) and surface area (cm^2) of leaf litter were the lowest in the species × location interaction between the path and inside the forest (Table 1). The final leaf mass and surface area of *Shorea* was smaller on the path than inside the forest, while those of *Macaranga* were not different between locations (Figure 1a, b, Table 1). The AIC value of the final leaf mass per area (g cm^{-2}) was the lowest in the model using species as an explanatory variable (Table 1), and thus the leaf mass per area decreased more in *Shorea* than in *Macaranga* (Figure 1c). The moisture content of leaf litter was lower on the path (*Shorea*, 147.5%; *Macaranga*, 57.1%) than inside the forest (*Shorea*, 252.5%; *Macaranga*, 182.1%) (Table 1, Figure 2). The AIC values of final mass (g) of wood block were the lowest for location (GLMM, AIC: null model = 121, location = 113), and the mean remaining mass of wood blocks was higher on the path (79.2%) than inside the forest (64.7%) (Figure 3).
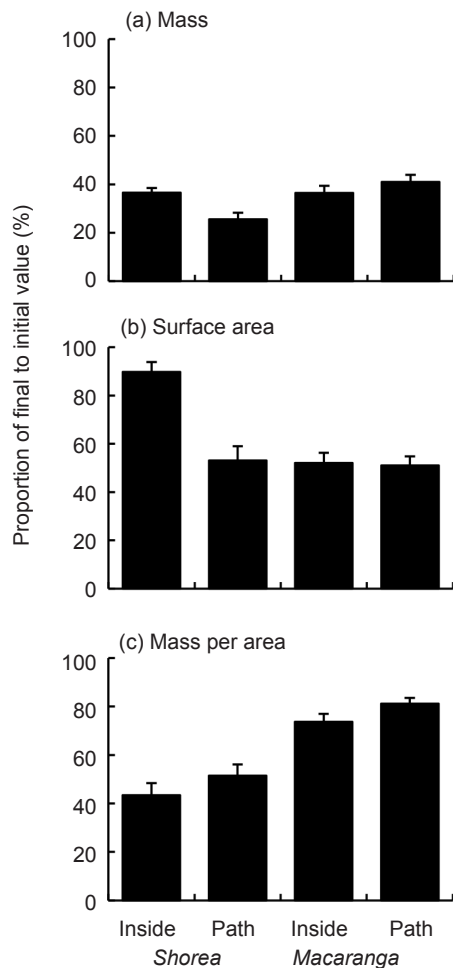
DISCUSSION

The three substrates (wood blocks, and leaf litter of *Shorea* and *Macaranga*) had different decomposition patterns at different locations in the early stage of decomposition. The wood blocks decomposed more slowly on the path than inside the forest, whereas *Shorea* leaf litter decomposed more rapidly on the path than inside the forest, and *Macaranga* leaf litter had similar decomposition rates at both these locations. The lower moisture content of both *Shorea* and *Macaranga* leaf litter indicated a more pronounced drought condition on the path and lower activity of microorganisms. Ilstedt et
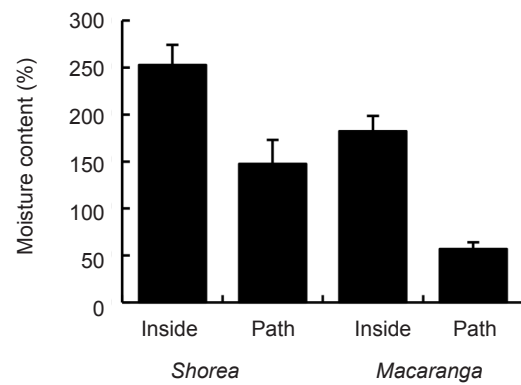
Table 1   Comparison of delta AIC values and coefficients (coef.) among the models for remaining proportions of the mass (g), surface area (cm^2), mass per area (g cm^{-2}) and moisture content (%) of leaf litter using species (*Shorea* and *Macaranga*), location (inside the forest and on the path), and their interactions as explanatory variables

|	Mass	Coef.	Area	Coef.	Mass per area	Coef.	Moisture content	Coef.
Null	7		47		33		51	
Species	5		29		**0**	-0.30	38	
Location	9		35		36		18	
Species + location	6		15		3		**0**	0.80 (species) -1.17 (location)
Species × location	**0**	0.04 (species) 0.16 (location) -0.87 (interaction)	**0**	2.55 (species) -0.10 (location) -2.24 (interaction)	8		2	

Lowest AIC values are set to 0; coefficients were added to the lowest AIC model; positive or negative coefficient values for species and location indicate higher levels of each variables for *Shorea* (on the path) or *Macaranga* (inside the forest), respectively

Figure 2   Moisture content (%) of *Shorea macroptera* and *Macaranga* sp. leaf litter on the path and inside the forests in the study area at the sampling time (6 months later); values represent means ± standard errors

Figure 1   Proportion (%) of initial to final value of (a) the mass (g), (b) surface area (cm^2) and (c) mass per area (g cm^{-2}) of *Shorea macroptera* and *Macaranga* sp. leaf litter on the path and inside the forests in the study area after 6 months; values represent means ± standard errors
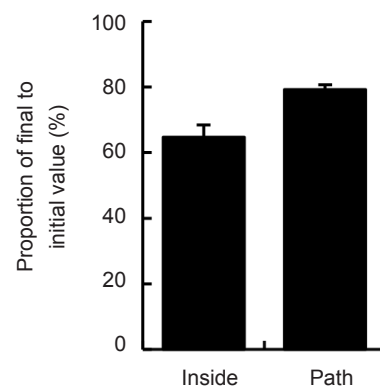
Figure 3   Proportion (%) of final to initial value of the mass (g) of wood blocks on the path and inside the forests in the study area after 6 months; values represent means ± standard errors

al. (2006) reported decreased microbial activity on skid trails. In contrast to the wood blocks, the greater decomposition rates of *Shorea* leaf litter on the path could be attributed to greater fragmentation by biotic and abiotic processes on the path. Several studies have reported that isopods are abundant in open lands and disturbed environments (Tsukamoto & Sabang 2005, Hassall et al. 2006, Hasegawa et al. 2014). Such litter-feeding invertebrates might be more abundant on paths created with bulldozers, resulting in greater decomposition of *Shorea* leaf litter. On the path, which maintained lower moisture conditions, leaf litter might also be subject to more frequent drying-and-wetting cycles, causing leaf litter to crack and split more than that inside the forest (Anderson 1973).

The decrease in the surface area of leaf litter was greater in *Macaranga* than in *Shorea*, whereas the leaf mass per area showed the opposite trend. Thus, *Macaranga* leaf litter was probably mainly decomposed by fragmentation, whereas *Shorea* leaf litter was primarily broken down by degradation processes attributed to microorganisms and leaching, in addition to fragmentation. In a tropical forest in Sarawak, a litter-bag experiment by Hirobe et al. (2004) showed that the leaf litter of three *Macaranga* species decomposed more rapidly than that of three *Shorea* species, due to the high litter quality (high phosphorus concentration and low acid-insoluble residue). Thus, the high quality of *Macaranga* leaf litter in the study sites had a greater effect on the preference of litter-feeding invertebrates than that of microorganisms.

CONCLUSIONS

In conclusion, the results indicated that road disturbance changed the balance between fragmentation and other degradation processes. The findings also highlighted that, in addition to measuring the loss of mass and chemical characteristics of leaf litter, assessing the loss of surface area and leaf mass per area was required to evaluate how different types of degradation processes impact leaf litter decomposition, as well as differences in litter decomposition among treatments.

ACKNOWLEDGEMENTS

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