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短 報 (Short communication)

Effects of distance from devastated forests and topography on dung beetle assemblages in burned forests of East Kalimantan, Indonesia

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Abstract

To evaluate the effects of distance from human living area and topography on dung beetle assemblages in burned natural forests, we set baited pitfall traps on 3 valleys and 3 ridges in a protected but burned forest along with the transect beginning from the border of the protected forest in East Kalimantan. Species richness and the logarithm of the number of beetles collected significantly decreased as sites approached the border. The Morisita' s indices of similarity (C_λ) between each site and the control site set in the artificially devastated forest with fire outside the border significantly increased as sites approached the border. Thsese results suggest that more severe fire near human living areas degrades dung beetle diversity more significantly. All valley sites were considered as remnants of previous fires but the similarity index to the another control site set in the large unburned natural forest was apparently low at two valley sites near the border suggesting that the dung beetle diversity separated from the large unburned forest by burned ridges was severely degraded even if the forests were unburned.

Key words : baited pitfall trap, Borneo Island, forest fire, ridge, Scarabaeidae, Sungai Wain Protection Forest, valley

1. Introduction

Dung beetles (Coprophagous group of Scarabaeoidea: Bolboceratidae, Hybosoridae, and parts of Scarabaeidae (Scarabaeinae and Aphodiinae) in the present study) are superior indicators of habitat quality and environmental change in tropical regions (McGeoch et al. 2002, Aguilar-Amuchastegui and Henebry 2007, Gardner et al. 2008, Nichols and Gardner 2011). These beetles also serve important ecological functions, such as promoting the rapid decomposition of dung and carcasses that affects nutrient cycling, bioturbation, plant growth enhancement, secondary seed dispersal, and maggot control (Davis 1996, Andressen 2003, Larsen et al. 2005, Slade et al. 2007, 2011, Nichols et al. 2008). Thus, a higher diversity of beetles indicates a more active, complicated forest ecosystem.

Forest fire in primary forests have degraded tropical biodiversity especially for arthropods in Asia (Gibson et al. 2011). In East Kalimantan, Indonesia, a vast forest fire occurred in 1983 and 1998 (Taylor et al. 1999, Yamaguchi and Tsuyuki 2001). Yamaguchi and Tsuyuki (2001) showed that the intensity of fire damage was higher on ridges than in valleys and decreased in accordance with the distance from human living areas because forests near human living areas were not only burned naturally but also artificially.

In past studies carried out in East Kalimantan, studies comparing butterfly assemblages between burned and unburned forests have shown that fire may reduce species richness and/or changed the community structure (Cleary 2003, Cleary and Genner 2004, 2006, Cleary and Grill 2004, Cleary and Mooers 2004, Cleary et al. 2004, Hirowatari et al. 2007). Fire may also reduce genetic diversity of forest butterfly species because of the habitat loss (Cleary et al. 2006, Fauvelot et al. 2006a); however, on the other hand, fire may increase genetic diversity of other forest butterfly species dispersing among habitats (Fauvelot et al. 2006b). Fire may also reduce both species richness and number of individuals of braconid parasitic wasps (Maeto et al. 2009), and species richness of ground beetles and bark and ambrosia beetles (Makihara et al. 2000). On odonates and longicorn beetles, fire generally does not affect species richness but may change community structure (Cleary et al. 2004, Makihara 2013). Also, with regard to soil animals and floor invertebrates, fire does not often affect species richness (Yajima 1988). However, few past studies have taken into account topography and distance from human living areas that affected the burning level in

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East Kalimantan (Yamaguchi and Tsuyuki 2001). Moreover, no studies to date have evaluated the effect of forest fire on dung beetle assemblages in tropical Asia.

In the case of a protected forest area surrounded by artificially devastated forest, such as often occurs for agricultural land and grassland after slash-and-burn agriculture, the distance from where humans live is represented by the distance from the border of the protected forest area since the most artificial effects are typically protected at the border if the protected forest is fenced off from the devastated forest. The purpose of this study was to evaluate the effects of the distance from the border of a protected forest area, as well as topography, on dung beetle communities in the protected but burned natural forest of East Kalimantan.

2. Methods

2.1 Study sites

A burned area of Sungai Wain Protection Forest (SWPF), located 24 km north of Balikpapan in the lowlands of East Kalimantan, Indonesia, was selected as study area (Fig. 1). The east part of SWPF was burned in 1983 and 1998 (Taylor et al. 1999) and the fire produced banded structures of ground cover that were made by burned forests on ridges and remnant forests in valleys (Yamaguchi and Tsuyuki 2001) (Fig. 1).

We established a 1000 m main transect beginning at the fenced border of SWPF and which crossed through the SWPF, covering three valleys and three ridges in the study area (from S1°03'53", E116°54'04"to S1°04'21", E116°53'38") (Fig. 1 and Fig. 2-a). Six-secondary transects (trap transects) of about 90 m in lengh on the actual ground surface (not-horizontal length) were distributed on the main transect with the center points of the transects being located on the tips of ridges or the bottoms of valleys. These were named sites V1, V2, and V3 for valley transects and sites R1, R2, and R3 for ridge transects in relation to the distance from the border of SWPF (Fig. 1 and Fig. 2-a). As one exception, site V3 was set vertically to the main transect (Fig. 1) for two reasons. First, we could not set

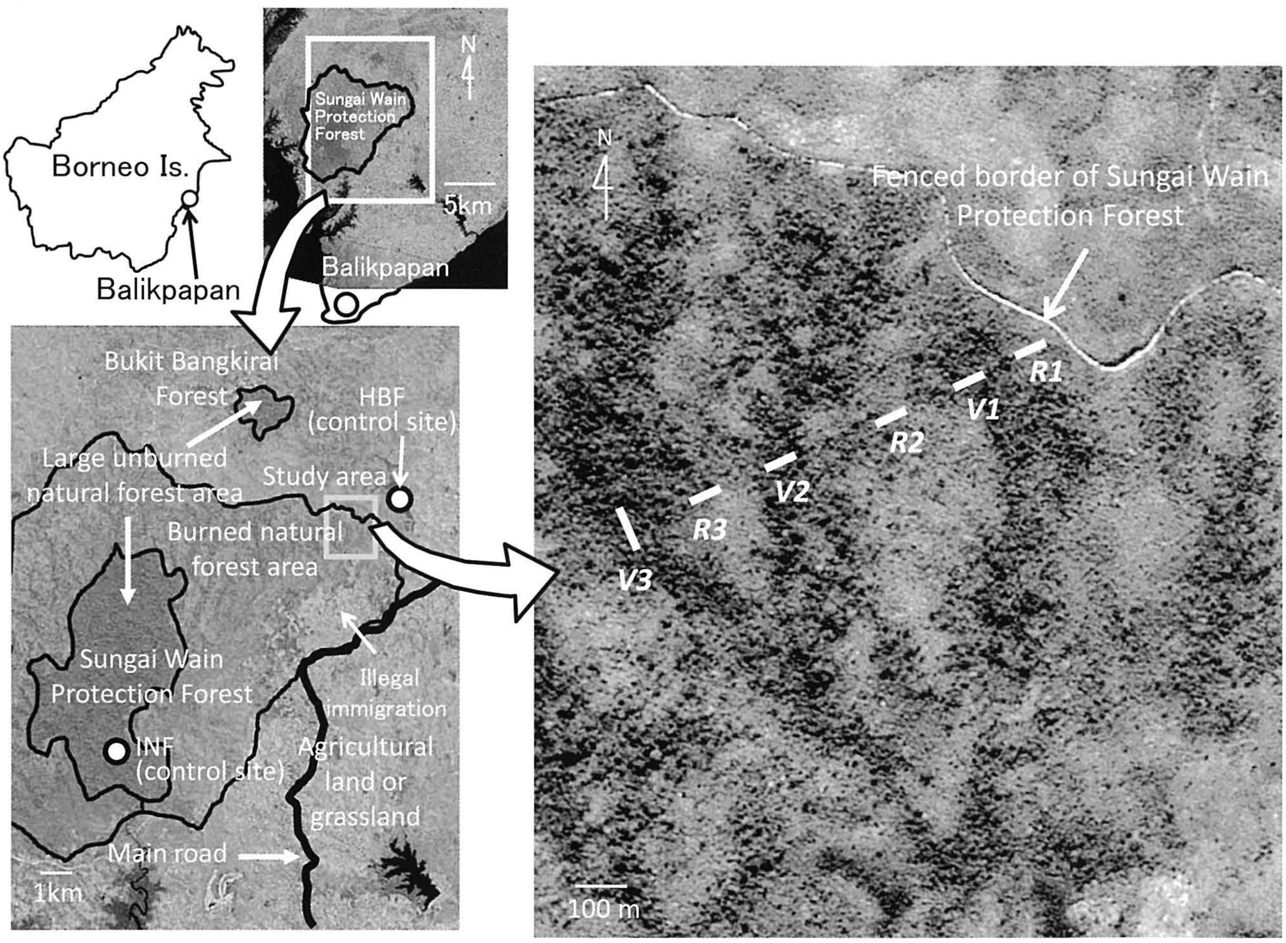

Fig. 1. Location of study area and transect sites
Locations of transect sites and their names are indicated by thick lines and bold italic characters. Locations of the cotrol sites (site HBF in the artificailly destructed forest and site INF in the large unburned natural forest) are indicated by open circles. The 'SPOTS5' satellite took this picture at 2:27:04 (GMT) on 19 June, 2005.

traps on the slope of the west side of the valley for site V3 since the slope was too steep. Second, we wanted to ensure there was no trap interference. Larsen and Forsyth (2005) recommended that baited pitfall traps should be kept at least 50 m apart in order to minimize interference among traps. If site V3 was set along the main transect, the distance between sites R3 and V3 became shorter than 50 m, and thus site V3 had to be set vertically to the main transect. The center of V1 was shifted 15 m outer from the bottom of valley since the slope of the west side was too steep to set traps (Fig 2-a).

To investigate relationships between dung beetle diversity and forest condition, we measured and identified all trees that had diameters at breast height (DBH) larger than 5 cm in a 100 m^2 quadrat before we set traps. The quadrats were set around the center and at both ends of each trap transect (three quadrats per site) except for site V3 where the quadrat was set only the center of the transect.

So as to collect the control data from artificially devastated forest areas, we also made a 90 m trap transect at 800 m outside from the border of SWPF (site HBF: S1°03'34", E116°54'10") (Fig. 1). The forest condition was also measured there using the same methods as for the burned forest sites, except that the transect for forest condition was located about 80 m south from the one used for trapping.

We also made a 90 m control trap transect at 1 km inside of the large unburned natural forest area of SWPF (site INF: S1°06'50", E116°49'40") (Fig. 1) to compare the similarities of beetle assemblages between the burned forest sites and a site in the large unburned area. Bukit Bangkirai Forest (BBF) was the nearest unburned natural forest from the study area but a vast artificially degraded area lay between BBF and the study area (Fig. 1), suggesting that the forest dung beetle populations were divided between BBF and the study area. Since the unburned area of SWPF and the study area were connected by the burned natural forests without artifificial disturbances (Fig. 1), suggesting that the unburned area of SWPF can provide forest dung beetles for the study area, we made the control trap transect in the unburned forest area of SWPF, althuough the forest condition was not measured there.

2.2 Collection of dung beetles

Baited and flight intercepting pitfall traps were used to collect the beetles because they catch a larger number of dung beetle species than normal baited pitfall traps (Ueda et al. 2015). A plastic cup (8.4 cm in open diameter, 5.6 cm in minimum diameter, and 12.2-cm high) was driven into the ground to set up each trap with its opening level with the ground surface. Two B5-size transparent plastic sheets that crossed each other were then laid over the cup, upon which a plastic bowl (ceiling: 20 cm in diameter and 5-cm high) was placed upside down. Each trap contained a 50-ml glass bottle (4.3 cm in diameter and 8.0-cm high) with a perforated lid (having six holes, each 5 mm in diameter), and was baited to attract beetles. Fresh human excrement (10 g) and raw jack fish (30 g) were used as bait because these baits attract large number of species and individuals of dung beetles (Ueda et al. 2015). A cut nylon net (with a 0.5-mm mesh) was placed between the lid and bottle to prevent small beetles from entering. The traps also contained a 30% solution of propylene glycol to kill and preserve the beetles collected. All traps in the burned area and site INF were set in the morning on 14 December 2007 and 15 December 2007, respectively, with all captured insects being collected five days after trap installation. In general, five days of trapping is enough to assess the beetle community using the traps baited with human excrement and raw fish (Ueda et al. 2015). For site HBF, we were oblidged to use the trapping data obtained in 2006, since the staff of SWPF reccomended that we did not conduct research outside of the SWPF in December 2007 due to the potential dangers associated with people engaged in illegal logging and coal mine: indeed, all trees outside the border, including the HBF site, were logged illegally in 2008. Traps in the HBF site were set for five days from 18 December 2006 with the same methods as in 2007.

Because of the short period provided to carry out this research, we installed the intensive trap catch system in order to collect as many beetles as possible; that is, 10 traps were distributed along a 90-m transect at intervals of 10 m for each site, with human excrement and raw fish used alternately as the attractant. Total numbers of species and individuals from the ten traps were pooled in one data set.

2.3 Identification and storage of specimen

All beetles captured in the present study were dried on absorbent cotton and identified using a binocular (Nikon Nature Scope). Some beetles were pinned and sent to Japan to ensure their identity. Females of two *Catharsius* species (*C. dayacus* Lansberge and *C. renaudpauliani* Ochi et Kon) were difficult to distinguish from each other; however, since all of 15 *Catharsius* males collected in SWPF, that is, the burned forests sites and site INF, were *C. dayacus*, all of 12 *Catharsius* females were treated as *C. dayacus*. On the contrary, since all of 6 *Catharsius* males collected in site HBF were *C. renaudpauliani*, all of 6 *Catharsius* females were treated as *C. renaudpauliani*.

All beetles were stored in the insect specimen room

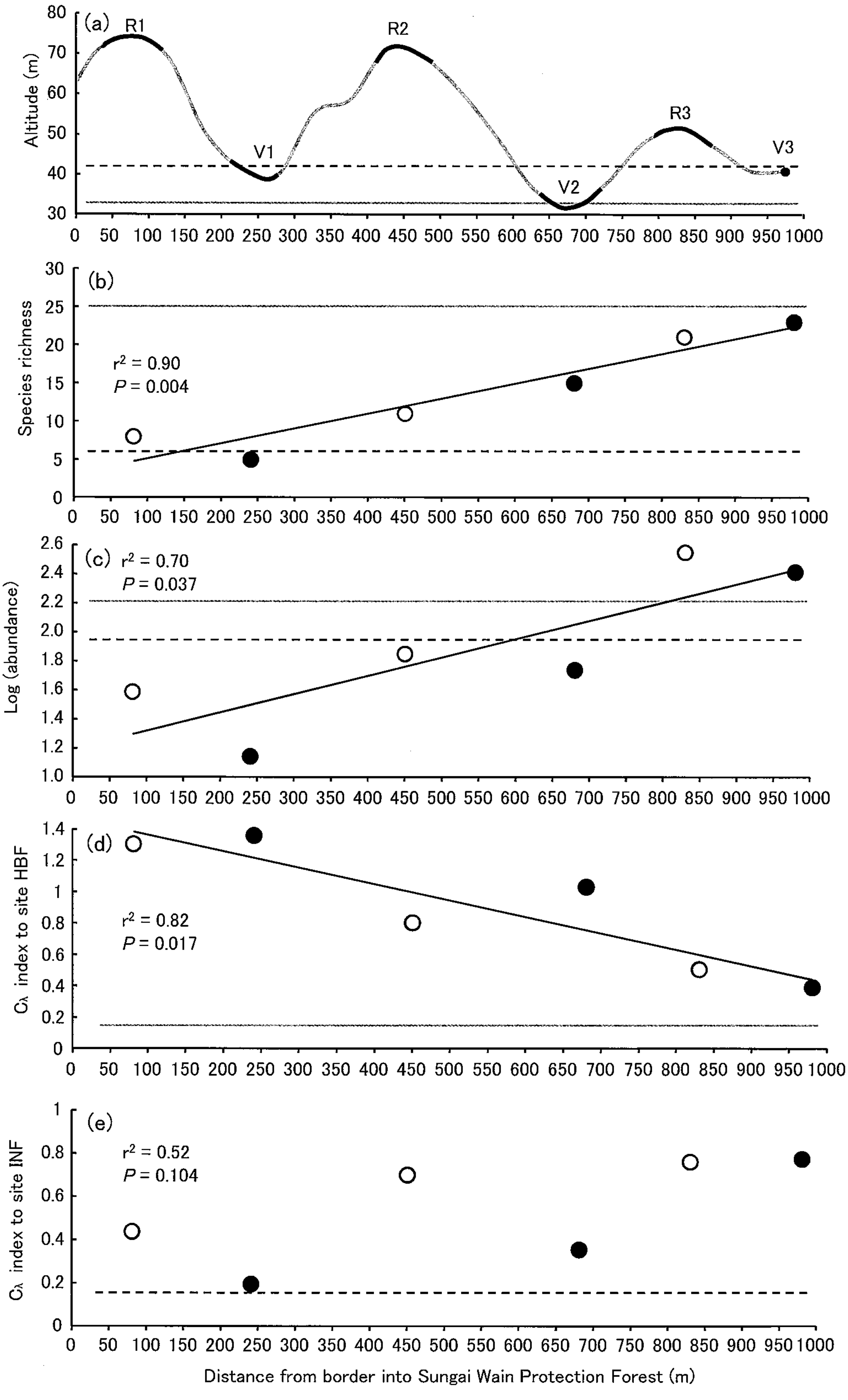

Fig. 2. Topography on the transect set in the study area (a) and species richness (b), the logarithm of abundance (number of beetle collected) (c), the Morisita's index of similarity (C_λ) to site HBF (d), and the Morisita' s index of similarity (C_λ) to site INF (e) of the dung beetles collected at each site

Topographies of trap transects were indicated with black lines in figure a. Data on control sites HBF and INF are shown as the dotted horizontal lines and the gray horizontal lines, respectively in figures. Closed circles and open circles indicate data in valley sites and data on ridge sites, respectively, and black lines in figures b, c, and d indicate data linear regression lines. Results of linear regression analyses are shown in figures b, c, d, and e.

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2.4 Reliability of data

Studies have shown that dung beetle communities can be effectively assessed using data from a single baited trap over several days or from several baited traps for one day (Nichols and Gardner 2011). Carrion beetle communities are also efficiently and accurately assessed with data from one baited trap (Ueda 2015). In the present study we used 5 traps per bait per site installed for a 5 days period. Our intensive trap catch system should thus be reliable for analyses despite the relatively short research period. Our research, however, was performed only in December, and it is likely that longer studies would be needed in order to assess full beetle community. Annual data of the dung beetle catch in tropical regions with no severe dry season showed little variation in species richness and/or abundance (Peck and Forsyth 1982, Hanski and Krikken 1991). In tropical regions with severe dry season, beetles are most often captured during the wet season, whereas relatively few species are collected during the dry season (Janzen 1983, Andressen 2005, Neves et al. 2010). Mean monthly rainfall in the Bukit Soeharto Grand Forest Park (BSGFP) that is located about 20 km northwest from the study area is between 120 mm in August and 220 mm in December (Toma et al. 2000). This indicates that our research area is in a tropical region with no severe dry season and the dung beetle catch should have little seasonal variation. Moreover, our study was carried out in December, which has the largest rainfall of the year in BSGFP, suggesting that the large species richness and abundance of dung beetles are most likely to occur during the wet season. Because there was no severe dry season and copious rain in December in our study area, our data from December should be adequate for comparative studies of communities of the dung beetles.

2.5 Data analysis

To compare the degradation and conservation levels of the dung beetle communities in the burned area, the Morisita's indices of similarity (C_λ) between site HBT and each site in the burned area and between site INF and each site in the burned area were calculated, respectively. To evaluate the distance from the border and the effect of forest condition on the beetle communities, the relations between the distance from the border, indices of the beetle communities, and indices of forest condition were analyzed using linear regression. JMP 8 (SAS Institute 2009) was used for the linear regression analyses to test whether the distance from the border significantly related to the indices of beetle communities that were species richness, abundance (total number of beetles collected), C_λ values to sites HBF and INF, and the indices of forest condition that were mean DBH, maximum DBH, tree density, total basal area of all tree and of both *Macaranga* species and *Vernonia arborea*, and the basal area ratio of *Macaranga* species and *V. arborea* to all trees. Most of *Macaranga* species in East Kalimantan were pioneer tree species and they are superior indicators of forest condition degraded by fire (Slik et al. 2003). *V. arborea* is also a pioneer tree species on the severely burned area in East Kalimantan (Yassir et al. 2010) and was also abundant in the present study. JMP 8 (SAS Institute 2009) was also used for the linear regression analyses to test the significances of relationships between the indices of beetle communities and the indices of forest conditions. Prior to these analysis, abundances of the beetles were converted by using a logarithm so as to reduce their discrepancies.

3. Results

A total of 39 species and 1,047 individuals of dung beetles were collected (Appendix table 1). Species richness was highest at INF and it significantly increased in accordance with distance from the border in the burned area (Fig. 2-b). Abundance was highest at R3 and its logarithm significantly increased with the distance from the border, with higher values occurring at ridge sites than at valley sites (Fig. 2-c). The C_λ value to HBF was highest at V1 and significantly decreased with the distance from the border (Fig. 2-d). The C_λ value to INF was highest at V3 and tended to increase with the distance from the border, with higher values occuring at ridge sites than at valley sites (Fig. 2-e).

There were no significant relations between the distance from the border and indices of forest conditions ($P > 0.05$). However, the mean DBHs, tree densities, and basal areas of trees tended to increase with the distance from the border, with higher values occurring at valley sites than at ridge sites (Table 1). The basal area ratios of *Macaranga* species and *V. arborea* to all trees were apparently higher at ridge sites than those at valley sites, and for the ridge sites, the ratios tended to decrease with the distance from the border (Table 1). There were no significant relations between indices of the beetle communities and indices of forest conditions ($P > 0.05$).

4. Discussion

In the present study, forest fire appeared to reduce the dung beetle diversity as species richness was highest at site INF. This same trend has been observed for butterflies, braconids, ground beetles and bark and ambrosia beetles (Makihara et al. 2000, Cleary 2003, Cleary and Grill 2004, Cleary and Mooers

Table 1. Forest condition of each site

Site	Mean DBH (cm)	Maxi-mum DBH (cm)	Mean tree density (Number of trees per ha)	Mean basal area (BA) of trees (m^2/ha)	BA of *Macaranga* spp. and *Vernonia arborea* (m^2/ha)	BA ratio (%) of *Macaranga* spp. and *V. arborea* to all trees	Most dominant tree species on BA
HBF	7.1	15.2	1067	6.0	3.7	59.5	*Vernonia arborea*
R1	8.8	27.3	1067	9.3	5.7	62.0	*Vernonia arborea*
V1	10.2	40.5	1000	12.0	0.2	1.5	*Alseodaphne falcata*
R2	8.2	15.8	833	5.1	2.9	57.3	*Macaranga trichocarpa*
V2	11.1	47.3	1133	18.4	3.0	16.2	*Artocarpus glaucus*
R3	10.0	25.1	1333	13.3	7.3	54.8	*Glochidion rubrum*
V3	11.0	25.8	2100	26.1	0.0	0.0	*Madhuca kingiana*

100 m^2 quadrats were set around the center and both ends of each site (three quadrats per site) except for site V3 where the quadrat was set only on the center of the site. Trees more than 5 cm in their DBH (diameter of breast height) were measured.

2004, Cleary et al. 2004, Cleary and Genner 2006, Hirowatari et al. 2007, Maeto et al. 2009). The trend of decreases in basal area ratios of *Macaranga* species and *V. arborea* to all trees at ridge sites with the distance from the border of SWPF (Table 1) suggests that fire damage decreases with the distance from the border. This coinsides with Yamaguchi and Tsuyuki (2001) who showed that the intensity of fire damage decreased in accordance with the distance from human living areas. Decreases in both species richness and the logarithm of abundance and increases in C_λ values to site HBF as sites approached the border (Fig. 2) suggest that more severe fire near human living areas (Yamaguchi and Tsuyuki 2001) degrades the dung beetle diversity more acutely.

It is considered that all valley sites were remnants from fire because of the low ratio of *Macaranga* species and *V. arborea* (Table 1). This coincides with Yamaguchi and Tsuyuki (2001) who showed that the intensity of fire damage was higher on ridges than in valleys. However, the fire damage changing with topography did not coincide with the changes of the dung beetle diversity. C_λ value to site INF was lower at sites V1 and V2 compared with sites R1 and R2 although the distance from the border was greater at site V1 than at site R1 and site V2 than at site R2, respectively (Fig. 2). This suggests that dung beetle diversity was severely degraded in valleys that were near to human living areas and separated from unburned forests even if the valleys were not ever previously burned. Higher C_λ values to site INF on ridge sites might be derived from the high abundance of the beetles that made feasible to collect more species increasing the opportunity to collect the species in unburned forests (Fig. 2). Doi (1988) observed that large herbivorous mammals, which provide dung and carcases to dung beetles, were abundant in burned forests compared with unburned forests in East Kalimantan. Although no studies compared the abundance of herbivorous mammals between ridge and valley in burned forests, higher diversities of the beetles on the burned ridges may be associated with the higher abundance of wildlife. Bedick et al. (2004) observed that the carrion-baited pitfall traps placed on the ridges attracted significant more burying beetles than the traps placed in the valleys, and discussed that greater trap captures on ridges may have resulted from greater movement of odors from baits or warmer temperatures on ridges compared with in valleys, or from the beetles flying over intervending ridges between valleys. These predictions concerning with the flight activities of beetles are also plausible to the higher diversities of dung beetles on ridges in the present study. However, it is difficult to clear the reason why the diversities of dung beetles were higher on ridge compared with in valleys in the present study. Results of our study were from one study area. Future studies concerning with the higher diversities of dung beetles on ridges are needed to investigate the dung beetle communities on another study areas including several valleys and ridges in the burned forests of East Kalimantan.

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Appendix table 1. Dung beetles collected at each aite in this study

	HBF	R1	V1	R2	V2	R3	V3	INF
Bolbochromus catenatus (Lansberge)	0	4	0	0	0	0	0	0
Phaeochrous emarginatus Castelnau	0	0	0	0	1	0	0	2
Phaeocroops sp.	0	0	0	0	0	0	0	6
Ochicanton simboroni Ochi et Kon	0	0	0	0	1	0	0	0
Ochicanton woroae Ochi et Kon	0	0	0	0	0	1	0	0
Panelus sp.	3	0	0	0	0	0	0	2
Paragymnopleurus maurus (Sharp)	0	9	1	30	3	170	114	41
Sisyphus thoracicus Sharp	0	0	0	3	1	17	13	29
Synapsis cambeforti Krikken	0	0	0	0	0	0	0	2
Catharsius dayacus Lansberge (male)	0	1	0	3	0	5	4	2
Catharsius renaudpauliani Ochi et Kon (male)	6	0	0	0	0	0	0	0
Catharsius spp. (female: *dayacus* or *renaudpauliani*)	6	2	0	1	0	3	2	4
Copris gibbulus Lansberge	0	0	0	0	0	0	0	1
Microcopris fujiokai Ochi et Kon	0	0	0	0	0	0	0	1
Caccobius unicornis (Fabricius)	9	0	0	0	0	0	0	0
Caccobius binodulus Harold	0	0	0	0	0	0	0	1
Onthophagus (Parascatonomus) dux Sharp	0	2	2	5	8	35	4	16
Onthophagus (Parascatonomus) rudis Sharp	1	0	0	2	1	1	9	0
Onthophagus (Parascatonomus) aurifex Harold	0	0	0	0	4	2	1	0
Onthophagus (Parascatonomus) semiaureus Lansberge	0	0	1	3	10	3	2	0
Onthophagus (Parascatonomus) semicupreus Harold	4	1	0	0	6	6	4	4
Onthophagus (Proagoderus) schwaneri Lansberge	65	17	9	19	13	61	30	6
Onthophagus (Gibbonthophagus) fujiii Ochi et Kon	0	2	0	2	2	2	1	1
Onthophagus (Gibbonthophagus) obscurior Boucomont	4	0	0	0	0	1	4	0
Onthophagus (Gibbonthophagus) cervicapra Boucomont	0	0	0	0	0	4	11	4
Onthophagus (Serrophorus) laevis Harold	0	0	0	0	0	13	9	3
Onthophagus (Indachorius) woroae Ochi et Kon	0	0	0	0	0	3	2	0
Onthophagus (Pseudophanaeomophus) chandrai Ochi	0	0	0	0	0	0	0	2
Onthophagus (Onthophagus) aphodioides Lansberge	0	0	0	1	0	0	5	1
Onthophagus (Onthophagus) vulpes Harold	0	1	0	1	2	16	14	10
Onthophagus (Onthophagus) incisus Harold	0	0	0	1	0	4	17	1
Onthophagus (Onthophagus) infucatus Harold	0	0	1	0	0	1	1	0
Onthophagus (Onthophagus) pastillatus Boucomont	0	0	0	0	0	0	2	12
Onthophagus (Onthophagus) simboroni Ochi et Kon	0	0	0	0	1	0	1	3
Onthophagus (Onthophagus) waterstradti Boucomont	0	0	0	0	1	3	5	0
Onthophagus (Onthophagus) bonorae Zunino	0	0	0	0	0	0	0	1
Onthophagus (Onthophagus) borneensis Harold	0	0	0	0	0	0	0	3
Onthophagus (Onthophagus) pacificus Lansberge	0	0	0	0	1	1	1	0
Onthophagus (Onthophagus) semipacificus Ochi et Kon	0	0	0	0	0	1	2	0
Onthophagus (Onthophagus) sp.	0	0	0	0	0	0	0	1

インドネシア共和国東カリマンタン州の山火事林内の糞虫群集における荒廃林からの距離および地形の影響

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要旨

山火事天然林内の糞虫群集における人の生活圏からの距離および地形の効果を評価するために、東カリマンタン州の保護林内の山火事エリアにおいて保護林の境界から始まるトランセクト上の３つの谷と３つの尾根に落とし穴式ベイトトラップを設置した。種数と捕獲数の対数は境界に近づくにつれ有意に減少した。境界外の人為的荒廃林に設けた対照区との森下の類似度指数は、境界に近づくにつれ有意に増加した。これらの結果から、人の生活圏に近い火災が激しかった場所ほどより糞虫の多様性が劣化していると考えられた。谷の調査地は全て火事を免れたと考えられたが、大きな非山火事天然林内に設けたもうひとつの対照区との類似度指数が境界に近い２つの谷調査地で明確に低かったことから、森が火事に遭っていなくても尾根によって大きな非山火事林から隔てられると糞虫の多様性は大きく劣化すると考えられた。

キーワード：落とし穴式ベイトトラップ、ボルネオ島、森林火災、尾根、コガネムシ科、スンガイワイン保護林、谷

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