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Diversity and community structure of dung beetles (Coleoptera: Scarabaeidae) across a habitat disturbance gradient in Lore Lindu National Park, Central Sulawesi

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ABSTRACT

Shahabuddin (2010) Diversity and community structure of dung beetles (Coleoptera: Scarabaeidae) across habitat disturbance gradient in Lore Lindu National Park, Central Sulawesi. Biodiversitas 11: 29-33. Dung beetles are important component of most terrestrial ecosystems and used to assess the effects of habitat disturbance and deforestation. This study aimed at comparing dung beetle assemblages among several habitat types ranging from natural tropical forest and agroforestry systems to open cultivated areas at the margin of Lore Lindu National Park (LLNP), Central Sulawesi (one of Indonesia's biodiversity hotspots). Therefore, 10 pitfall traps baited with cattle dung were exposed at each habitat type (n = 4 replicate sites per habitat type) to collect the dung beetles. The results showed that species richness of dung beetles declined significantly from natural forest to open area. However cacao agroforestry systems seemed to be capable of maintaining a high portion of dung beetle species inhabiting at forest sites. The closer relationship between dung beetle assemblages recorded at forest and agroforestry sites reflects the high similarity of some measured habitat parameters (e.g. vegetation structure and microclimate) between both habitat types, while species assemblages at open areas differed significantly from both other habitat groups. These results indicated that habitat type has importance effect on determining the species richness and community structure of dung beetles at the margin of LLNP.

Key words: forest conversion, diversity, habitat selection, dung beetles marker.

INTRODUCTION

The deforestation of tropical forests and their subsequent conversion to human-dominated land-use systems, such as agricultural land, is one of the most significant causes of biodiversity loss. This also occurs in Sulawesi where the deforestation rate has reached nearly 190,000 ha/year (Holmes 2000), and almost all lowland forests below 400 m asl. have been lost (FWI and GWF 2002). Dung beetles (Coleoptera: Scarabaeidae) are ecologically important since their dung burial activity could maintain soil fertility (Omaliko 1984), increase plant yields (Miranda et al. 2001) and dung-seed dispersal activity promotes plant regeneration (Andresen 2002, 2003). However, they have proved to be sensitive to habitat perturbation, such as canopy forest loss (Davis and Sutton 1998) and human habitat modification (Shahabuddin et al. 2005). Therefore, they widely used as biological indicators for evaluating the effects of habitat disturbance driven by human activities.

Lore Lindu National Park (LLNP) in Central Sulawesi is one of the core areas for the protection of the biodiversity of Wallacea (Myers et al. 2000). Generally, forest habitats in the interior of LLNP are still relatively undisturbed while the margins of the park are characterized by a mosaic of near-primary forests, degraded forests, forest gardens and plantations of cacao, coffee, maize and paddy rice as the most important crops. Although the forest conversion has strong negative effects on biodiversity (Lawton et al. 1998), some agroecosystems including traditional agroforestry systems, such as cacao and coffee cultivations established under the diverse layers of forest trees, can maintain a relatively high portion of tropical biodiversity (Harvey et al. 2006). Therefore, there is an increasing recognition that biodiversity conservation should also include efforts to a sustainable management of human-modified ecosystems outside of the protected areas, which are capable to maintaining at least a certain fraction of tropical biodiversity (Mendoza et al. 2005; Tscharntke et al. 2005; Bos et al. 2007).

Studies on dung beetles have been conducted in some islands of Indonesia, such as in North Sulawesi (Hanski and Niemela 1990; Hanski and Krikken 1991), Sumatra (Gillison et al. 1996), and West Java (Noerdjito 2003), and Shahabuddin et al. (2005, 2007). More attention has to be paid to Sulawesi Island since with its unique geographical history (Whitten et al. 2002), about 75% of dung beetles species inhabited in Sulawesi are most likely endemic species (Hanski and Krikken 1991). However, most of those studies only focused on forest sites and did not take into account the relative contribution of land-use activities such as agroforestry on dung beetles diversity.

This study aims to address the following research questions: (i) How forest conversion to land-use systems at the margin of LLNP affects the species richness and community structure of dung beetle and whether the species richness of dung beetles inhabiting natural forest is significantly higher than those in land-use system (agroforestry systems or annual cultures). (ii) How significant the contribution of agroecosystems to the total (regional) species richness of dung beetles is. (iii) What habitat variables will be the best predictors for explaining differences in dung beetle communities between land-use type.

MATERIALS AND METHODS

Study area

The study area is located on the northern margin of the Lore Lindu National Park in Central Sulawesi (LLNP)-Indonesia. The Lore Lindu National Park, a local biodiversity hotspot is covering an area of 229,000 ha and located southeast of Palu, the province capital of Central Sulawesi. All study sites were selected in Palolo Valley in the vicinity of the villages of Bobo (01^{o}07'10.2" S-119^{o}59'40.2" E) and situated at an altitude between 800 and 1000 m asl. Dung beetle communities were studied in four habitat types: - natural forest (NF), selectively logged forest (SF), agroforestry systems (cacao plantations with Gliricidia as shadow trees; AF) and annual cultures (maize fields, AC). For each habitat type three site replications were selected. Detailed description of each habitat type was shown in Table 1.

Table 1. Description of each habitat type studied.

Habitat type	Habitat description	Site codes
Natural Forest	Lower montane forest; big emergent trees and numerous medium-sized trees form a multi-layered canopy; height of upper canopy layer 20-30m with single big emergent trees up to 40m; well-developed understorey layer of small trees/scrubs, ginger and rattan up to 4-8m high; herb layer dominated by Rubiaceae species and ferns.	NF1-3
Selectively logged forest	Single emergent trees up to 30 m; closed canopy layer 15-20 m high; herb layer 0.5-2m high and dominated by ferns and Rubiaceae sp. Some selective logging activities took place in all sites, however, the plots are so far just slightly affected.	SF1-3
Agroforestry system	Ca. 5 yrs old cacao plantations (ca. 1 ha) with *Gliricidia sepium* (Leguminosae) and *Musa* sp. as shaded trees; cacao trees up to 2-3 m high; *Gliricidia sepium* trees 7-9 high; some sites has herb layer with 20-30 cm high	CP1-3
Annual culture	Maize fields (0.5-1 ha).	AC1-3

Specimens collection

Dung beetles were sampled in 50m^2 plots at 12 sites all using baited pitfall traps as described in Shahabuddin, et al. (2005). On each site 10 traps were set up along a 50 m transect. Traps were baited and exposed synchronously to dung beetles three times during (May-July 2009). Traps were baited with ca. 20 g of fresh cattle (*Bos taurus*) dung collected from pasture land around the study sites. Trapped specimens were removed from the traps after two days and preserved in Scheerpelz solution as recommended by Krell (2007). Later on, samples were identified in the laboratory with available identification keys (e.g. Balthasar 1963). The reference collection of the Center for Biodiversity Research Tadulako University was used. Taxa, which could not be identified, were sorted to morphospecies.

Characterization of habitat type

Several habitat parameters (vegetation structure and microclimate) were measured and tested for their potential to predict changes in the diversity and community structure of dung beetles (Shahabuddin et al. 2005).: 1). air temperature and relative humidity at about 1 m above ground at start and end of the exposing period were measured by using a digital thermo-hygrometer (Corona^R Model: GL 99), 2). Canopy cover visually estimated at four locations per site for a corridor of ca. 10 m beside the transect lines, 3). number of trees (dbh ≥ 10 cm) measured at four of 5x5 m^2 plots beside each transect, one plot every 10 m changing between both sides of the transect, and 4). herb layer coverage was estimated at four plots of 2x2 m^2 randomly placed at ca. 5 m beside the transect line.

Data analysis

Species richness of dung beetles was estimated using the second-order jackknife extrapolation method (Colwell 2004), one of the best species richness predictor with respect to accuracy (e.g. Brose et al. 2003). As units for estimating the total species richness of individual sites, samples pooled for individual sample times ($n = 4$) were used). Effects of habitat type on species richness were tested using one-way ANOVA. Abundance data were log (n+1) transformed before analysis (Zar 1999). The Bray-Curtis similarity index was used to quantify between-site (beta) diversity of dung beetles (Krebs 1999). The similarity matrices resulted was used to compare the similarity of species composition of dung beetles between habitat type and to construct a two-dimensional ordination of all samples using multidimensional scaling (Clarke 1993). The program Statistica 6.0 (StatSoft ,2001) were used to perform all statistical analyses. Second-order jackknife calculations were computed with the program EstimateS Version 7.00 (Colwell 2004) by randomizing the ranking of samples 100 times.

RESULTS AND DISCUSSION

Diversity of dung beetles

A total of 1696 dung beetles were collected during study period. They belonged to 3 genera (dominated by *Onthophagus*) and 24 species. The five most predominant species were *Onthophagus wallacei*, *O. fuscostriatus*, *O. limbatus*, *Copris macacus*, and *O. ribbei* (Table 2).

Table 2. Number of collected specimens of individual dung beetle species in the four different habitat types. Species are ranked according to their total number of collected specimens. Species most likely endemic to Sulawesi according to Balthasar (1963) are indicated with an asterisk

Species	Habitat				Number of
	NF	SF	CP	AC	specimens
Onthophagus wallacei Harold*	70	23	62	433	588
O. fuscostriatus Boucomont*	223	198	4	0	425
O. limbatus (Herbst)	0	3	1	144	148
Copris macacus Lansberge*	64	18	24	0	106
O. ribbei Boucomont	53	33	8	1	95
Onthophagus. sp. 2	28	25	14	5	72
O. trituber Wiedemann	0	0	5	65	70
Onthophagus sp. 6	26	3	4	8	41
Onthophagus sp. 5	0	1	1	31	33
Aphodius sp. 1	2	0	0	26	28
O. rudis Sharp	1	3	11	10	25
Camponotus saundersi Harold	21	3	0	0	24
O. holosericeus Harold*	1	1	11	0	13
C. punctulatus Wiedemann	2	0	5	4	11
Onthophagus sp. 3	0	0	4	0	4
Aphodius sp. 2	1	0	0	2	3
O. rectecormutus Lansberge	0	0	0	2	2
O. forsteni Lansberge	0	0	2	0	2
O. aureopilosus Boucomont*	0	1	0	0	1
Onthophagus sp. 9	1	0	0	0	1
Onthophagus sp. 8	1	0	0	0	1
Onthophagus sp. 7	0	1	0	0	1
Onthophagus sp. 4	1	0	0	0	1
Onthophagus sp. 2	1	0	0	0	1

Changes natural forest to other land-use type has significantly affect on species richness (ANOVA: F(3,8) = 7.46, p < 0.05, Figure 1a) but not on the abundance of dung beetles (Figure 1b). Although species richness was decreased from natural forest to open cultivated area, this study only detected a significant reduction of species richness on open cultivated area. Species richness at the natural forest, disturb forest and cacao agroforestry were nearly similar (Figure 1b).

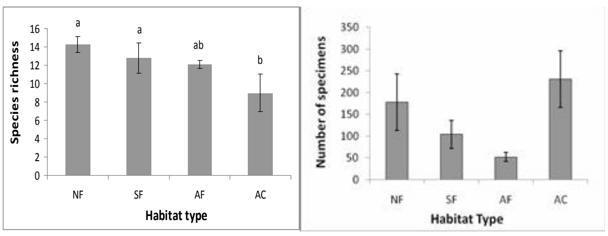

Figure 1. Species richness (left) and abundance (right) of dung beetles in relation to habitat type. (NF = natural forest, SF = selectively logged forest, AF = agroforestry system, AC = annual culture). Arithmetic means ± SD are given. Different letters on top of the bars indicate significant differences between habitats

Further analysis to show species level response to habitat changes revealed that six of the seven most abundant dung beetles species (total of ≥70 collected specimens) recorded in all habitats significantly respond to habitat type. Three of those species were significantly highest in the natural forest (Figure 2 a-c), while the rest was highest in annual culture (Figure 2 d-f).

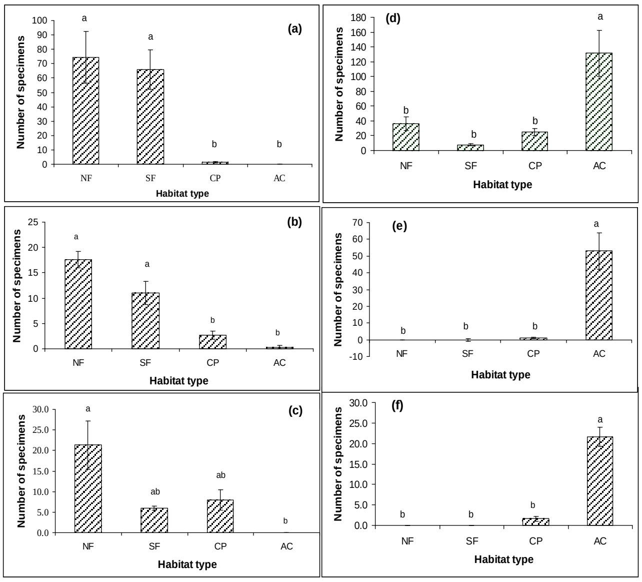

Figure 2. Mean number of dung beetles in each of the four habitat types, given for the six most abundant species. a: *Onthophagus fuscostriatus* (ANOVA $F_{3,8}$=9.47, p<0.05), b: *Onthophagus* ribbei ($F_{3,8}$=22.31, p<0.05), c: *Copris macacus* ($F_{3,8}$=5.99, p<0.05), d: *O. wallacei* ($F_{3,8}$=8.70, p<0.05), e: *Onthophagus limbatus* ($F_{3,8}$=1.04, p<0.01), f: *Onthophagus trituber* ($F_{3,8}$=59.31, p<0.01). Different letters on top of the bars indicate significant differences between habitats.

This study documented that the conversion of natural forest to secondary forests and land use systems had a negative effect on dung beetle diversity. A decline of insect diversity related to forest disturbance and conversion of forests or forest plantations to agricultural habitats has been also shown for other taxonomic groups (e.g. Schulze 2004; Shahabuddin et al. 2007; Susilo et al. 2009). Although the structure of dung beetle communities changed between natural forest, selectively logged forests and the two land-use systems. Each of the tree habitat types following destruction of natural forest supported about 70% of the species richness found in the natural forest, thereby indicating a surprisingly little reduced diversity despite the great human-induced habitat transformation.

Davis et al. (2001) reported a significant decrease of dung beetle diversity across a gradient of forest disturbance ranging from primary to logged and plantation forest in Northern Borneo. Recent analysis shows a strong and negative response of by tropical forest dwelling dung beetle communities to increasing modification of tropical forest and declining fragment size (Nichols et al. 2007). However, in general, the damage caused by logging and forest conversion seems to depend on the intensity of the logging and land-use. High intensity logging is known to have a negative effect on coprophagous beetles and other insect groups (Hill 1995; Davis et al. 2001) but a reduced-impact logging system has better preserved the coprophagous beetles assemblage of primary forest than conventional logging techniques (Davis 2000). This result could be explained by using *intermediate disturbance hypothesis* (reviewed by Collins and Glenns 1997) predicts that diversity will be highest in communities with intermediate levels of disturbance. If disturbances are too rare, the competitive dominants will eliminate other species and reduce diversity as equilibrium conditions develop. If disturbances are too frequent, most species will go locally extinct, which lowers diversity, because they can not tolerate repeated disturbances. Under intermediate levels of disturbance, diversity is maximized because disturbance-tolerant species and competitively dominant species coexist.

Species composition of dung beetles

Change of habitat types has a tremendous effect on species composition. An ordination technique aimed to compare dung beetles community at habitat studied showed a higher distance between open area and natural forest, agroforestry cacao and annual culture compared to the distance among those three latter habitats (Figure 3). This result indicated that the structure of dung beetle communities differed between forest habitats and land-use systems. However, the dung beetle species did not appear to be restricted to only one habitat type causing a high overlap of the species composition between all sites (similar to the results from the community analysis using Sørensen indices). Of the 20 species recorded at forest sites, 60% (= 12 species) were also found at the cacao plantations. Although four of *Onthophagus* sp. and one of *Aphodius* sp. were only recorded at forest site they all could not be categorized as "*forest-dependent species*" since their abundance were very low (1 specimen per species) and those species could be collected in other land-use type if the sampling period was longer. Moreover, if the singleton was excludes about 90% of the species recorded at forest sites were also occurs at the cacao plantation. This species distribution indicating the high potential of agroforestry system for supporting the dung beetles diversity at the landscape level. Nevertheless, the contribution of agroforestry to the dung beetles (and overall) diversity depend on some factors such us management of shaded tree and the distance to the nearby forest (Bos et al. 2007; Clough et al. 2009).

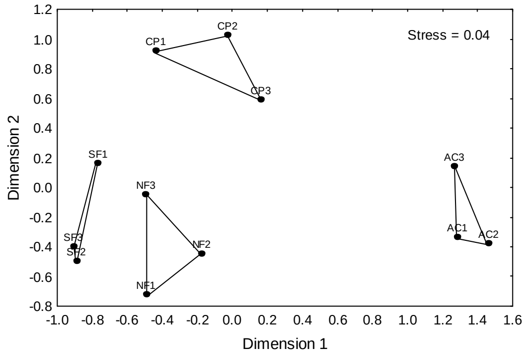

Figure 3. Two-dimensional scaling plot based on Bray-Curtis indices quantifying similarity of dung beetle communities sampled at 12 sites belonging to four different habitat types. Lines connect sampling sites belonging to the same habitat.

Relation with habitat parameter

Changes of dung beetles diversity and composition may relate to some habitat parameters measured. Air temperature and herbs coverage increased from natural forest to annual culture, while humidity, canopy cover and number of tree showed a reverse pattern (Table 3). This result was concordance with previous study showed that some species of dung beetles response differently to changes of land-use type in Central Sulawesi (Shahabuddin et al. 2005).

Table 3. Habitat characteristic at four habitat type studied in Lore Lindu National Park (NF=natural forest, SF= selectively logged forest, AF= agroforestry system, AC= annual culture)

Habitat parameters	Habitat type			
	NF	SF	AF	AC
Canopy cover (%)	85.0 (5.0)	63.3 (2.9)	45.0 (5.0)	0.0 (0)
Number of tree	7.7 (1.2)	6.0 (1.0)	5.7 (0.6)	0.0 (0)
Herb coverage (%)	56.7 (5.8)	66.7 (5.8)	63.3 (2.9)	73.3 (2.9)
Temperature (^{o}C)	25.4 (1.3)	25.2 (1.2)	27.1 (2.3)	27.2 (1.7)
Humidity (%)	76.3 (5.5)	70.7 (1.2)	69.3 (0.6)	68.3 (3.1)

Besides effects of an uneven distribution of food among habitats and the influence of soil type (Hanski and Cambefort 1991), microclimate conditions have a critical effect on habitat selection by coprophagous beetles (Barbero et al. 1999). Therefore, changes in microclimate following the alterations of vegetation structure at four studied land-use type may also affect coprophagous beetle populations. It is known that thermoregulation strategies and the ability to maintaining an optimal body temperature may restrict coprophagous beetles to a certain range of microclimatic conditions (Verdu et al. 2004, 2006).

Closed canopy cover, lower temperature most likely suitable for *O. ribbei*, *O. fuscostriatus*, and *Copris macacus* because they more abundance in forest sites and cacao agroforestry system (see Figure 2 a-c). On the contrary *O. wallacei*, *O. limbatus*, and *O. trituber* were prefer to inhabit in drier habitat or sites with low canopy cover such as open cultivated area (see Figure 2 d-f). This is partly in line with previous study in Napu situated at southern part of Lore Lindu National Park. In that area *O. ribbei*, *O. fuscostriatus*, and *Copris macacus* were more abundance in cooler and shaded habitat (e.g. natural forest and cacao agroforestry) (Shahabuddin et al. 2005). In South Africa, dung beetles fauna were also showed a habitat preferences and grouped by Davis et al. (2002) as 'shaded species" and "unshaded species".

CONCLUSION

Species richness and species composition of dung beetles changed following the conversion of natural forest to others land-use types at the margin of Lore Lindu National Park. Species richness of dung beetles tended to decrease with increasing of land-use intensity indicating a pronounced negative effect of land-use changes on the dung beetle fauna. However, contrasting to the open areas, cacao agroforestry systems with vegetation structure more resembling natural forest proved inhabited by a dung beetle fauna which was similar to the one found at forest sites. Although species richness of dung beetles at natural forest was higher compared to all others land-use types, agroforestry sites contributed a high level (at least 60%) to the diversity of dung beetle communities recorded at Palolo region. Although few species showed a high association with certain habitat type most of them were not restricted to certain habitat but seems to occupy a wide range of habitats indicating that majority of dung beetles in Central Sulawesi are generalist and do not have strongly pronounced habitat requirements.

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