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Effect of land use change on ecosystem function of dung beetles: experimental evidence from Wallacea Region in Sulawesi, Indonesia

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ABSTRACT

Shahabuddin (2011) Effect of land use change on ecosystem function of dung beetles: experimental evidence from Wallacea Region in Sulawesi, Indonesia. Biodiversitas 12: 177-181. The deforestation of tropical forests and their subsequent conversion to human-dominated land-use systems is one of the most significant causes of biodiversity loss. However clear understanding of the links between ecological functions and biodiversity is needed to evaluate and predict the true environmental consequences of human activities. This study provided experimental evidence comparing ecosystem function of dung beetles across a land use gradient ranging from natural tropical forest and agroforestry systems to open cultivated areas in Central Sulawesi. Therefore, standardized dung pats were exposed at each land-use type to assess dung removal and parasite suppression activity by dung beetles. The results showed that ecosystem function of dung beetles especially dung burial activity was remarkably disrupted by land use changes from natural forest to open agricultural area. Dung beetles presence enhanced about 53% of the total dung removed and reduced about 83% and 63% of fly population and species number respectively, indicating a pronounce contribution of dung beetles in our ecosystem.

Key words: land use change, ecosystem function, dung beetles.

INTRODUCTION

Dung beetles in the sub family Scarabaeinae (Coleoptera: Scarabaeidae) have important ecological roles related to nutrient cycling. Removing and burying dung, either for adult feeding or for oviposition and subsequent feeding of the larvae (Hanski and Cambefort 1991) has important ecological consequences in terms of ecosystem functions such as soil fertilization and aeration (Mittal 1993; Wilson 1998), increased rates and efficiency of nutrient cycling as well as plant nutrient uptake and yield (Wilson 1998; Miranda et al. 2000), and secondary seed dispersal of seeds defecated by frugivorous vertebrates (Andresen 2002, 2003).

Dung burial is the initial step to most of the beneficial functions of tropical dung beetles and such activity, the removal of resources for competitors, therefore is also a mechanism by which dung breeding fly numbers may be reduced (Ridsdill-Smith et al. 1988). Fresh mammal dung is an important resource for a variety of dung-breeding flies as well as dung beetles. Several pestiferous, dung-dwelling fly species (principally *Musca autumnalis, M. vetustissima, Haematobia thirouxi potans, H. irritans exigua and H. irritans irritans*) have followed the introduction of livestock globally. Fly infestations has been reported reduce the livestock productivity (Guglielmone et al. 1999) and represent an enormous financial burden to livestock producers (Byford et al. 1992). Recently, Losey and Vaughan (2006) estimated that the annual value of ecological services provided by native insects in the United States to be more than $ 57 billion including $ 0.38 billion through dung burial activity by dung beetles. A series of ecosystem function of dung beetles has been comprehensively reviewed by Nichols et al. (2008).

Studies on dung beetles have been conducted in Indonesia (Hanski and Krikken 1991; Gillison et al. 1996; Shahabuddin et al. 2005, 2007, 2010; Shahabuddin 2010). However, that study more emphasized on diversity and community structure of dung beetles and not pays much attention on ecological function of dung beetles across a habitat disturbance gradient, including in Sulawesi.

As a key landmass within the Wallacea biogeographic region, one of the world's biodiversity and endemism hotspots, Sulawesi has extremely valuable in terms of conservation (Cannon et al. 2007; Myers et al. 2000). The loss of forest habitat and forest degradation on this equatorial island (Cannon et al. 2007) reflect the situation found in several countries of Southeast Asia: deforestation is still happening, possibly even at increasing rates (Sodhi et al. 2004; Koh 2007), with new forms of land-use gaining ground.

While several studies have been reported that conversion of natural habitats such as tropical forests to land-use systems is responsible for the decline of diversity of most taxonomic groups including insects (Lawton et al. 1998; Schulze et al. 2004; Shahabuddin et al. 2005, 2010), effect of land-use change on ecosystem function of the studied taxa is rarely investigated (but see Andresen 2003; Horgan 2005; Slade et al. 2007). Most of those studies focused on direct first-order effects i.e. on diversity and abundance of selected taxa but did not emphasized to the second-order effects of land-use change related to the ecological roles of the studied taxa. Additionally, of few comparative field studies from the tropical area recorded ecosystem function of dung beetles (i.e., Klein 1989; Andresen 2003; Slade et al. 2007) those study do not covering arrange of habitat type from natural forest to agricultural area.

The present study, conducted in Lore Lindu National Park, Central Sulawesi, aimed to analyze effects of forest conversion to land-use systems on ecosystem function of dung beetles mainly on dung removal activity and suppression the population of parasitic flies inhabited in herbivore dung.

MATERIALS AND METHODS

Study area

The study area is located on the northern margin of the Lore Lindu National Park (LLNP) in Central Sulawesi, 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 Bobo villages (01^{o}07'10.2" S - 119^{o}59'40.2" E) and situated at an altitude between 800 and 1000 m asl.

Fields study was conducted from June to August 2010 in four land-use types: natural forest (NF), selectively logged forest (SF), agroforestry systems (cacao plantations with Gliricidia as shadow trees; CP) and open cultivated area (OC). For each habitat type three site replications were selected. Detailed description of each land-use type was shown in Table 1.

Table 1. Description of each land-use type studied

Land-use type	Land-use type description
Natural Forest (NF)	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 under storey layer of small trees/scrubs, ginger and rattan up to 4-8m high; herb layer dominated by Rubiaceae and ferns.
Selectively logged forest (SF)	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. Some selective logging activities took place in all sites, however, the plots are so far just slightly affected.
Cacao agroforestry system (CP)	Ca. 5 yrs old cacao plantations (ca. 1 ha) with *Gliricidia sepium* (Leguminoceae) and *Musa* sp. as shaded trees; cacao trees up to 2-3 m high; *G. sepium* trees 7-9 m high; some sites has herb layer with 20-30 cm high
Open cultivated area (OC)	Two of study sites were maize fields. The rest was a pasture land (ca. 0.5 ha.)

Dung beetles and dung removal activity

Dung removal activity was studied by expose four experimental dung pats from fresh cow dung (fitting in 300 ml plastic containers) with a mean fresh weight of ca. 258 ± 15.3 g at all study sites. Two of the baits were wrapped in 2 mm insect screening that excluded dung beetles to utilize the dung, a further 2 baits were open (unprotected from beetles). Baits were randomly placed on the soil surface at each site and were collected after 18 days where more than 50% of the dung pat has been buried by dung beetles (Shahabuddin 2007). The collected dung pats were stored separately in plastic bags. In the laboratory, they were dried at 100^{o}C for 96 hours and weighed using an analytical balance (Sartorius MC 410 S) (Sanchez et al. 2004). The mean dry weight of 10 fresh dung pats not exposed in the field was used as a control (ca. 55.2 ± 7.1 g). The percentage of dung removed was estimated by the differences between control and remaining dung pats (after exposure).

Dung beetle and fly activity

Fly abundance and richness were monitored using the similar standardized bait used in the dung removal study as described above. Six baits were set out at each site, three of the baits were wrapped in 2 mm insect screening that excluded dung beetles but allowed flies to lay eggs into the dung, a further three baits were open (unprotected from beetles). Baits were randomly placed on the soil surface at each site and one of each bait type (open and beetle-exclusion) was collected each day for 3 days. The baits were placed on dry sand in individual plastic containers covered with muslin and held for 3 weeks in an insectary to allow flies to emerge, after which time the baits were dissected to remove all remaining fly larvae and pupae. Flies were identified to family level by using Borror et al. (1996) and counted.

Data analysis

Data were tested for normal distribution by Shapiro-Wilk's test and apply appropriate transformation before performed data analysis (Zar 1999). The effects of bait type (beetle presence/absence) and habitat type on dung removal and flies suppression activity of dung beetles were analyzed using a two-way ANOVA. Results from both habitat types were pooled since habitat had no significant effect on fly-parameters in the experiment. Most of statistical analysis was performed by using STATISTICA software (Statsoft 2004).

RESULTS AND DISCUSSION

Effect of land-use and bait type on dung decomposition

Percentage of dung decomposed or removed differed significantly between habitat types and bait type (land-use, $F_{3,16}$ = 5.58, $p < 0.05$; presence/absence of beetles, $F_{1,16}$ = 123.15, $p < 0.001$; interaction, $F_{3,16}$ = 1.37, $p > 0.05$). Additionally, protecting bait from dung beetles access significantly reduced the amount of removed dung (Figure 1) and presence of dung beetles could be increased about 53% of the total removed dung.

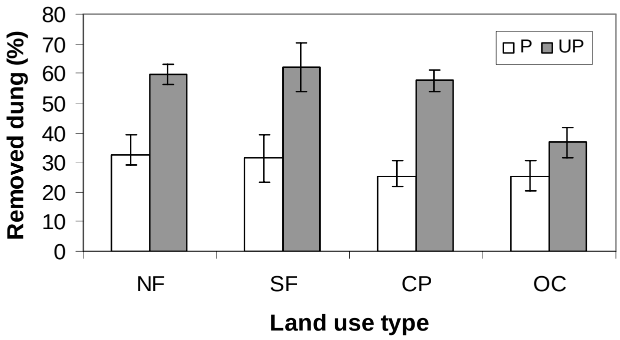

Figure 1. Percentage of removed dung (± SD) from unprotected (UP) and protected (P) bait in relation to land-use type

The present study showed a significant contribution of dung beetles to dung removal. However this ecological function was disrupted by land-use change from natural forest to agricultural area. Although percentage of removed dung was decreased from natural forest to open cultivated area, this study only detected a significant reduction of buried dung on open cultivated area. Percentage of removed dung at the natural forest, disturb forest and cacao agroforestry were nearly similar. This results was in line with previous study conducted at similar study sites found that diversity of dung beetles at forest sites has no significant different with those of cacao agroforestry but remarkably higher than that of open area (Shahabuddin 2010).

The likelihood that the dung pats was still removed in a smaller rate in the absence of dung beetles indicating that other organisms were also involved on dung removed. Termites and earthworms were known has capacity to create tunnels and redistribute soil. Herrick and Lal (1996) found the contribution of termites on dung buried and soil removed. While several studies have demonstrated that some earthworms are efficient dung removers in Europe (Holter 1979), Australia and New Zealand (Baker 1994), their dung related contribution to bioturbation in areas with a higher diversity of Scarabaeinae dung beetles is unknown.

Dung burial activity by dung beetles reported has important roles in increasing soil fertility. Shahabuddin et al. (2008) found that removal dung by dung beetles significantly increase of the total content of N, P and K. Also Omaliko (1984) reported that dung decomposition increased concentrations of nitrogen, potassium, phosphor, magnesium and calcium of soil up to 42-56 days after dung exposure. Furthers, dung burial activity altered environmental conditions, reduce pH of dung, speeds it incorporation into the soil and greatly reducing loss of Nitrogen as ammonia gas (NH_3) (Yokohama et al. 1991).

Many factors including the traits and community structure of dung beetles influenced dung burial activity. Although species diversity has a strong correlation with dung burial rate (Larsen et al. 2005), effect of biomass (Horgan 2005) and functional group diversity (Slade et al. 2007) on dung removal proved to more importance compared with species diversity. A laboratory experiments noted that dung beetles size and biomass were the best predictors for the amount of removed dung, while the number of species involved was just of minor importance (Shahabuddin et al. 2008). While large beetle species are functionally more efficient than smaller ones on dung removal activity (Shahabuddin et al. 2008), large-bodied beetle species tended to be more prone to land-use change from natural forest to human dominated land use type (Shahabuddin et al. 2007). Therefore the loss of those large species due to changes of land use may cause a significant decrease in ecosystem function.

Dung burial activity proved to be not only important for maintaining or increasing soil fertility but also has several other advantages such as enhancing total nitrogen and phosphorus of plants as well as its yield, improving plant regeneration through dung-seed dispersal activity, and increasing plant palatability by reducing plants fouled with dung (see Nichols et al. 2008). Therefore, in natural ecosystems the reduction of dung beetle populations most likely has cascading and long-term effects throughout the ecosystem (Klein 1989; Larsen et al. 2005).

Effect of land-use and bait type on flies population

A total of 438 flies (323 imago and 115 larvas) were collected during study period. The most predominant families were Sphaeroceridae, Tachinidae, and Muscidae. They comprise about 73.1% of the total fly specimens (Table 2).

Table 2. Number of specimens of each fly family emerged from unprotected (UP) and protected (P) bait from dung beetles access.

Family	Bait type		Total
	UP	P	
Sphaeroceridae	0	98	98
Tachinidae	11	62	73
Muscidae	9	56	65
Hippoboscidae	1	34	35
Stratiomyidae	0	21	21
Bombyliidae	0	15	15
Calliphoridae	0	13	13
Scatopsidae	0	3	3
Larvae	17	98	115
Total	38	400	438

Majority of the specimens (82.8%) were emerged from unprotected bait and only three of eight families (37.5%) were collected from colonized bait by dung beetles (Table 2). These results indicated a tremendous effect of dung beetles presence on reducing flies population. However land-use type has no significant effect on the number fly family collected (Number of specimens; land-use type, $F_{3,19} = 0.67$, $P = 0.58$; presence/absence of beetles $F_{1,19} = 19.85$, $P < 0.001$. Number of family; land-use type, $F_{3,19} = 1.86$, $P = 0.17$; presence/absence of beetles $F_{1,19} = 33.01$, $P < 0.001$).

Although, the fly population emerged was reduced with dung age in both bait type, they showed a similar pattern, the number of flies was lower from the protected bait. There is no interaction between dung age and bait type (dung age, $F_{2,18} = 10.41$, $P < 0.001$; presence/absence of beetles $F_{1,18} = 39.27$, $P < 0.001$; interaction, $F_{2,18} = 2.21$, $P = 0.14$). While the number of collected family decreased with dung age, they all were lower at the unprotected bait. Dung age was interact with presence/absence of beetles on determine the number of family collected because the

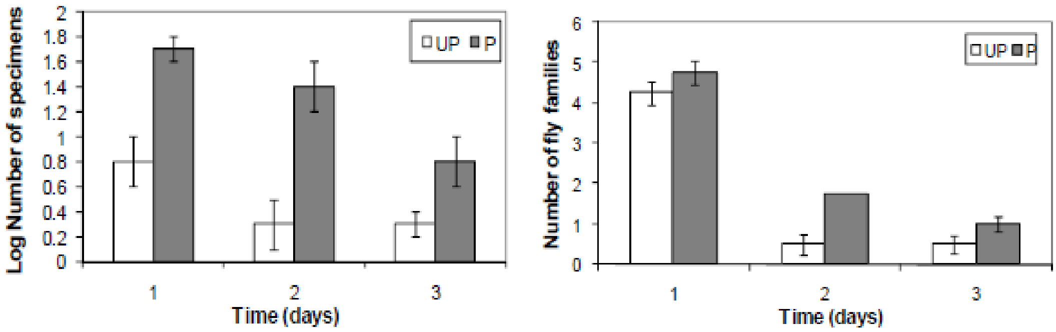

Figure 2. The effects of beetle exclusion on fly numbers and the number of flies family (±SD) emerging from 300 ml cow dung baits. UP=unprotected bait, P=protected bait (beetle exclusion).

collected family were nearly similar on both bait type on first day but significantly decreased at next day (dung age, $F_{2,18}$ = 8.49, P < 0.005; presence/absence of beetles $F_{1,18}$ = 39.79, P < 0.001; interaction $F_{2,18}$ = 8.77, P < 0.005) (Figure 2).

When and where dung beetles and dung flies co-occur, fly survival tends to decline as a consequence of asymmetrical competition for dung resources, mechanical damage of eggs by beetles, and fly predation by mites phoretic on dung beetles. A series of experimental manipulations of dung beetle and fly densities in artificial dung pats report elevated fly mortality in the presence of Scarabaeinae beetles, both in the laboratory and field (Wallace and Tyndale-Biscoe 1983; Ridsdill-Smith and Matthiessen 1988; Ridsdill-Smith and Hayles 1990; Bishop et al. 2005). Shortly, fly mortality caused by dung beetle activity is a combined consequence of (i) direct mechanical damage to fly eggs and early instars caused during adult beetle feeding (ii) unfavorable microclimates for fly eggs and larvae caused by dung disturbance and (iii) resource competition with older larvae, primarily from removal of dung for brood balls (reviewed by Nichols et al. 2008).

This is the first study in Sulawesi, a hearts of Wallacea region and probably in Indonesia known as megadiversity country documented effect of forest modification to human dominated land-use type on ecosystem function of dung beetles. Land use changes from natural forest to agricultural area proved to has detrimental effect on ecosystem function of dung beetles especially dung burial activity.

The likelihood that habitat disturbance due to land-use changes has pronounced effect on both diversity and ecosystem function of dung beetles (and other insect groups such as native bees, Kremen et al. 2004) indicating that effect of forest disturbance and land-use changes should not be only focus on it is direct effect to diversity of taxa studied but to ecological role of those taxa as well. This is particularly relevant with some hypothesis explain the biodiversity-ecosystem function relationships (see Schwartz et al. 2000; Giller and Donovan 2002).

As with most ecosystem services, before dung beetle services can be properly integrated with conservation planning or practice, additional research on dung beetle biodiversity ecosystem function (BEF) relationships and links between ecosystem functions and services will be required. A research agenda suggested by Kremen (2005) provides a near perfect fit to this task, suggesting future work that would identify: (i) the key species or traits providing ecosystem functions, (ii) the relationships between ecosystem function and community assembly and disassembly processes, (iii) the environmental factors influencing the production of ecosystem functions, and (iv) the spatio-temporal scales relevant to both providers and their functions (Kremen 2005). The most recent dung beetle BEF work has begun to advance our understanding of points 1-3, by identifying the specific-specific and community traits responsible for both ecological function (effect of traits) and sensitivity or resistance to environmental change (response traits) (Horgan 2005; Larsen et al. 2005; Slade et al. 2007; Shahabuddin et al. 2005, 2010; Shahabuddin 2008, 2010).

CONCLUSION

Dung beetles has a important role on dung burial activities and suppressing the fly population and these ecosystem function especially dung burial activity were remarkably disrupted by land use changes from natural forest to open agricultural area. Dung beetle presence elevated about 53% of the total dung removed and reduced about 83% and 63% of fly population and richness, respectively.

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