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EFFECTIVENESS OF DUNG BEETLES AS BIOINDICATORS OF ENVIRONMENTAL CHANGES IN LAND-USE GRADIENT IN SULAWESI, INDONESIA

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ABSTRACT

Bioindicators have been widely accepted as useful tools for monitoring and detecting changes in the environment or habitat condition. By using bioindicators, it is possible to assess the impact of human activities on the biota, instead of examining the entire biota. In this paper we analyzed diversity of dung beetles (Coleoptera: Scarabaeidae) across land use gradient in Central Sulawesi and tested the suitability of dung beetles as bioindicators for environmental changes. Ninety baited pitfall traps were placed and several habitat parameters were measured at five land-use types ranging from natural forest to cacao agroforestry systems to open areas in 2009 and 2012. The effectiveness of dung beetles as bioindicators of environmental changes was evaluated by the *IndVal* method, a method combining the specificity and fidelity of certain species with particular types of habitat or environmental conditions. Surprisingly, the results showed that the diversity of dung beetles in two types of cacao plantations were similar to the forest sites and were significantly higher than the open cultivated area. Of the 16 dung beetles species analyzed only four species could be suggested as indicator (characteristic) species while the majority of collected species were categorized as detector species. Two of them (*Copris saundersi* and *Onthophagus forsteni*) were associated with natural forest and cacao agroforestry system, thus were suggested as the indicator of shaded and cooler habitats whereas *O. limbatus* and *O. trituber* can be suggested as indicator of unshaded and warmer habitats (bare land area).

Keywords: bioindicators, diversity, Scarabaeidae, habitat preferences, *IndVal*.

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INTRODUCTION

The conversion of natural habitat to other land uses and its consequences on environmental changes has been acknowledged as the main driver of biodiversity loss at the Southeast Asia and global scales (Sodhi *et al.* 2004) and by 2100 the impact of land use changes on biodiversity is likely to be more significant than that of climate change, nitrogen deposition, species introductions and changing atmospheric concentrations (Sala *et al.* 2000; Young 2009). Therefore, detecting environmental changes due to land-use change is needed in order to avoid the continuous loss of biodiversity.

Bioindicators have been proven to be useful tools for monitoring and detecting changes in the environment. Species have different ecological requirements and their reactions to environmental variation are different from one another. Therefore, some species are better indicators than others (Dufrêne & Legendre 1997). Some species are generalists occurring in a wide range of habitats (ubiquitous), while others are more specialized, requiring certain habitat characteristics (*stenotopic*).

A bioindicator can be defined as a species or a species group that reflects the abiotic or biotic state of the environment (*environmental indicator*), represents the impact of environmental change on a habitat, community or ecosystems (*ecological indicator*), or indicates the diversity of other species (*biodiversity indicator*) (McGeoch 1998). One of the reasons for using bioindicators is their cost-effectiveness. By using bioindicators it is possible to assess the impact of human activities on the biota, instead of examining the entire biota. Especially useful are species that provide early warning of change (Spellerberg 1993).

Environmental changes can cause different kinds of effects in the indicator, including physiological changes or changes in species number or abundance. The response of the species can be seen within the organism (e.g. heavy-metal concentrations), at the species level (species number and abundance) or at the community level (relations between species, e.g. pest/predator). Increase or decrease or abundance of species number might be directly caused by change in abiotic and/or biotic factors or indirectly by change of species assemblage of other species (Davis *et al.* 2001; Rainio & Niemela 2003; Hambler *et al.* 2011; Gerlach *et al.* 2013).

A good bioindicator must fulfill several criteria. It has to be well-known taxonomically and ecologically, be distributed over a broad geographic area, have specialization to certain habitat requirements, provide early warning of change, be easy and cost-effective to survey, be relatively independent of sample size. Its response should reflect the response of other species, one should be able to differentiate between natural cycles or trends and those induced by anthropogenic stress, and it should be of potential economic importance (e.g. Noss 1990; Pearson & Cassola 1992). However, it is difficult to find species or species groups which would have all of these criteria (Noss 1990; Pearson & Cassola 1992). Requirements needed depend on the goal of the survey and the sensitivity to the anthropogenic disturbance is the most important criteria for monitoring environmental changes (Kremen *et al.* 1993).

In this study dung beetles (Coleoptera: Scarabaeidae) was selected as a bioindicator group because it has been widely known as one of the best bioindicator groups (e.g. Halffter & Favila 1993; McGeoch *et al.* 2002). Dung beetles have been proven to be very suitable to assess effects of disturbances on tropical ecosystems (Nichols *et al.* 2007; Shahabuddin 2010) and human habitat modification (Shahabuddin *et al.* 2010; Harvey *et al.* 2006) due to their abundance, highly varied with respect to species traits, and rapid responses to environmental change (Slade *et al.* 2011; Shahabuddin *et al.* 2005 & 2010; Spector 2006; Slade *et al.* 2011). Another advantage is their relatively complete species inventories and their data on the abundance of individual species can be achieved rapidly with standardized methods (Larsen & Forsyth, 2005). Recently, dung beetles have been identified as one of the most cost-effective group for biodiversity survey in tropical forests (Kessler *et al.* 2011) and contributors in improving the level of soil carbon stocks (Kessler *et al.* 2012).

One method used to quantify the 'bioindicator value' of a range of taxa is the indicator value (*IndVal*) method developed by Dufrene and Legendre (1997). This method combines measurements of the degree of specificity of a species to an ecological state, for example a habitat type, and its fidelity within that state (Dufrene & Legendre 1997). Species with a high specificity and high fidelity within a habitat will have a high indicator value. High fidelity (frequency of occurrence) of a species across sample sites is generally associated with large abundance of individuals. Both characteristics facilitate sampling and monitoring, which are important requirements for a useful bioindicator (Kremen *et al.* 1994; McGeoch *et al.* 2002).

The indicator value method is important to conservation biology because it is conceptually straightforward and allows researchers to identify bioindicators for any combination of habitat types or areas of interest, e.g. existing conservation areas, or groups of sites based on the outcome of a classification procedure (McGeoch & Chown 1998). Accordingly, *IndVal* method has become the most robust and popular method used to measure indicator species analysis (McGeoch *et al.* 2002; Aydin & Kazak 2010; Negro *et al.* 2011).

In Central Sulawesi, forest habitats especially in the interior of Lore Lindu National Park (LLNP) are still relatively undisturbed while the margins of the park are characterized by a mosaic land-use type such as near-primary forests, secondary forests, forest gardens and plantations of cacao, maize and paddy rice fields (Gerold *et al.* 2004). This study aimed to evaluate the effectiveness of dung beetles as bioindicator of environmental changes across land-use gradient in the margins of LLNP.

MATERIALS AND METHODS

Study Area

This study was carried out at the northern margin of the LLNP in Central Sulawesi, Indonesia. The Park, a local biodiversity hot spot covers an area of 229,000 ha and is located southeast of Palu, the capital of Central Sulawesi Province. All study sites were selected at the surrounding of the Palolo Valley in the vicinity of the villages of Bobo

(01°07'0.46" S - 119°59'702" E) and were situated at an altitude between 790 and 985 m asl. Dung beetle communities were studied in five land-use types: natural forest (NF); secondary forest (SF); cacao agroforestry systems (cacao cultivated under natural shade tree at the forest margin (AC); Cacao plantation under monospecific shade tree dominated by *Gliricidia sepium* (CP); and open area (OA), cultivated either by *Zea mays* or *Morus alba*. Three replications sites for each land-use type were selected with distance at least 50 m from each other.

Specimens Collection

Dung beetles were sampled in 2500 m² plots at 15 sites all using baited pitfall traps as described in Shahabuddin *et al.* (2010). Six traps were set up at the centre of each plot and placed with an interval of 10 m. The traps were baited with ca. 30 g of fresh cattle (*Bos taurus*) dung and exposed six times from April to July in 2009 and March to June in 2012. Cattle dung has been widely used as bait for dung beetles, aside from human faeces (e.g. Erroizi *et al.* 2004; Andresen 2005; Mendoza *et al.* 2005). Our previous study also showed that at the same weight of bait (ca. 30 g) cattle dung attracts the dung beetles with similar species composition found in the dung of anoa (*Bubalus deppresicornis*), an endemic herbivore of Sulawesi (Shahabuddin *et al.* 2010).

The trapped specimens were removed after two days and preserved in Scheerpelz solution (Krell 2007). Later on, the samples were identified in the laboratory using available identification keys (e.g. Balthasar 1963) and by comparing to the reference collection of the Center for Biodiversity Research Tadulako University. Species which could not be identified, were sorted to morphospecies.

Environmental Variables Measured

Several habitat parameters (i.e. vegetation structure and microclimate) affecting the dung beetles diversity (see Davis *et al.* 2001; Shahabuddin 2010) were measured to characterize the land-use types including air temperature, relative humidity, canopy cover, and herb layer coverage. The relative humidity at the start and end of the exposure period were measured using a digital thermo-hygrometer (Corona[®] Model: GL 99) 1 m above ground while the canopy cover was visually estimated at four locations per site for a corridor of ca. 10 m inside the plot. The herb coverage was estimated at four plots of 2x2 m² randomly placed at ca. 5 m inside the plot. Based on the environmental variables measured all land-use types were then grouped using a two-dimensional scaling (Clarke 1993; StatSoft 2001).

Data Analysis

The three most widely used measures of species diversity were species richness, Shannon-Wiener Index and Simpson Index ($S_i = \sum p_i^2$) (Lande 1996). 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 land-use type, samples from all traps and replicates were pooled for individual sample

times ($n = 6$) due to the close proximity between each trap and site. Effects of habitat type on diversity were tested using one-way ANOVA. Abundance data were transformed by $\log(n+1)$ before analysis (Zar 1999). StatSoft 6.0 software (2001) was used to perform all statistical analyses. All diversities measured were computed with EstimateS Version 7.00 program (Colwell 2004) by randomizing the ranking of samples 50 times. Only species sampled in both sample periods (2009 and 2012) were analyzed.

The effectiveness of each dung beetles species as bioindicators were identified for each habitat type using the indicator value (*IndVal*) method (Dufrene & Legendre 1997). This method combines measures of specificity and fidelity and provides an *indicator value* for each species, as a percentage (Dufrene & Legendre 1997). Specificity measure: $A_j = N_{individuals_j} / N_{individuals}$, where $N_{individuals_j}$ is the mean number of species i across sites of group j , and $N_{individuals}$ is the sum of the mean numbers of individuals of species i over all groups. Fidelity measure: $B_{ij} = N_{sites_j} / N_{sites}$, where N_{sites_j} is the number of sites in cluster (habitat) j where species i is present, and N_{sites} is the total number of sites in that cluster. The percentage indicator value for species i in cluster (habitat) j is then: $IndVal_{ij} = A_j \times B_{ij} \times 100$. The indicator values are the highest (100) when all individuals of a species are found in a single habitat (high specificity) and when the species occurs in all samples of that habitat (high fidelity). Species with *IndVal* between 50% to less than 70% is categorized as the detector or generalist species while those species with significant *IndVal* of greater than 70% were regarded as characteristic indicator species for the particular habitat type (McGeoch *et al.* 2002).

RESULTS AND DISCUSSIONS

Diversity of Dung Beetles

A total of 1996 dung beetles specimens were collected during the study period. They belong to four genera (dominated by *Onthophagus*) and 28 species (for complete species list see Shahabuddin 2013). However, only 16 species were recorded in both sample periods (2009 and 2012). The diversity of dung beetles changed from natural forest, to agroforestry cacao and to open area. Interestingly, the diversity of dung beetles in both forest types and the two types of cacao plantations tend to be similar but significantly higher than that in open cultivated area (Table 1). Hence, this study showed that secondary forest and agroforestry system may support a high portion of tropical dung beetles species than in the bare land and thereby in line with the findings by Nichols *et al.* (2007) and our previous study (Shahabuddin *et al.* 2010).

The fact that agroforestry system has high potency for conserving high biodiversity supported by previous study (e.g. McNely & Scroth 2006; Schulze *et al.* 2010). However, the results may also be related with the spatial distribution of our study sites. The agroforestry cacao sites were closer to the natural and secondary forest than to the open area and has a high opportunity to be colonized by dung beetles coming from the forest sites. Therefore, the high diversity of dung beetles at the cacao agroforestry system is also related to their close proximity to the forest sites. It has

Table 1. Diversity of dung beetles at five habitat type. NF = Natural Forest; SF = Secondary Forest; AC = Cacao agroforestry system ; CP = Cacao plantation; OA = open area

Land-use type	Estimated species richness (Jack-2) ($F_{4,10}=6.27, P < 0.05$)	Number of species recorded $F_{4,10} = 3.60, P < 0.005$	H'	Simpson
NF	14.3a	9ab	1.6	4.2
SF	14.4a	10.7ab	1.7	4.2
AC	15a	11a	1.7	4.3
CP	13.6a	10ab	1.7	4.5
OA	8.7b	6.3b	1.3	3.1

been reported that neighboring forest or isolation from forest may determine insect communities in tropical land-use systems (Tschardt *et al.* 2005; Klein *et al.* 2006). Agroforestry systems can be part of the habitat for many forest species using it for foraging, but they may also harbour largely independent populations.

Nonetheless, this study suggests that the preservation of environmental heterogeneity should be encouraged for conserving dung beetles in the LLNP, Central Sulawesi. This is important because high diversity of dung beetles in tropical land-use will enhance its ecosystem function and this ecological services will be diminished by increasing human dominated land-use (Shahabuddin 2011; Slade *et al.* 2011; Kudavidanage *et al.* 2012). In more natural and heterogeneous habitats, such as natural forest and agroforestry system, dung removal, biological control and seed dispersal activities of dung beetles were higher than in homogenous or disturbed habitats (Slade *et al.* 2007; Nichols *et al.* 2008; Shahabuddin 2011; Slade *et al.* 2011).

Indicator Species

Because the dung beetles diversity at the forest sites (natural forest and secondary forest) and the cacao plantation sites (agroforestry cacao and cacao plantation) were similar to each other but significantly higher than in the open area (Table 1), the indicator species analysis land-use type is only classified into three groups, *i.e.*: forest, agroforestry cacao and open area. The high similarity of environmental parameter measured among these three groups of land-use types was supported by ANOVA showing that temperature and herb coverage decreased from the natural and secondary forest to the open area while canopy and humidity showed a reverse pattern. However, a highly significant difference of environmental parameter measured was only recorded in the open area (Fig. 1). This land-use type grouping was also supported by the ordination technique using multidimensional scaling (Fig. 2).

Based on *IndVal* analysis of 16 dung beetles species collected in two sampling years (2009 and 2012), this study recorded four species having *IndVal* less than 70% and therefore, can be used as indicator (characteristic) species that are: *Copris saundersi* at forest sites, *Onthophagus forsteni* at cacao plantation, as well as *O. trituber* and *O. limbatus* at open area (Table 2). *Copris saundersi* and *Onthophagus forsteni* are suggested to be used as indicators of cooler and shaded habitats such as forest sites and cacao agroforestry

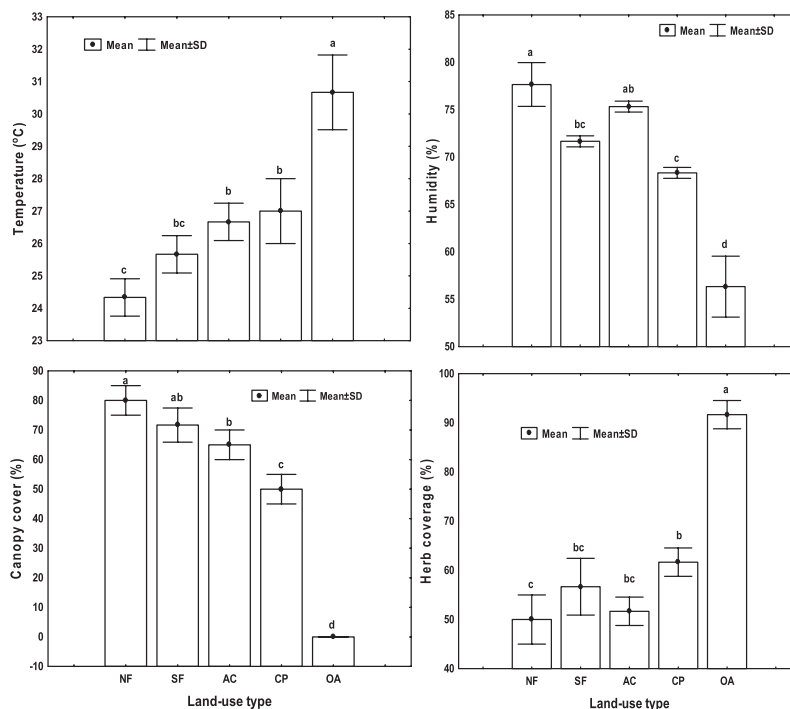


Figure 1. The effects of land use change on a) Temperature (ANOVA: $F(4, 10)=25.15, p<0.01$), b) Relative humidity (ANOVA: $F(4,10)=62.88, p<0.01$), c) Canopy cover (ANOVA: $F(4,10)=139.81, p<0.01$), and d) Herb layer coverage (ANOVA: $F(4, 14)=52.15, p<0.01$). All variables were averaged per land-use type. NF= Natural Forest; SF= Secondary Forest; AC= Agroforestry cacao; CP= Cacao plantation; OA= open area. Significant differences between habitat types were indicated by different letters over the standard error (based on Tukey's HSD post-hoc test)

system, while *O. trituber* and *O. limbatus* most likely indicate warmer and unshaded habitats (e.g. open cultivated area). These characteristic species (*IndVal* of $> 70\%$) are unlikely to move from their requisite to other habitat types, even under changing conditions within this habitat. Accordingly, populations of these species need only to be monitored within the specific habitat.

Beside indicator species, this study has recorded several generalist or moderate species with *IndVal* between 50% to less than 70%. These species were therefore, not characteristic species, as they do not have high *IndVal* of more than 70% for any particular habitat. Species meeting these criteria are unlikely to respond very rapidly to changing habitat conditions. They can invade either close canopy or moist habitat e.g. natural forest, cacao agroforestry or cacao plantation but also open or warmer environment such as open area. Furthermore, these species are less likely to become more vulnerable than indicator species, because a variety of habitats or ecological states, rather than only a single one, provide suitable resources for them and accordingly this group of species will be useful for longer-term monitoring.

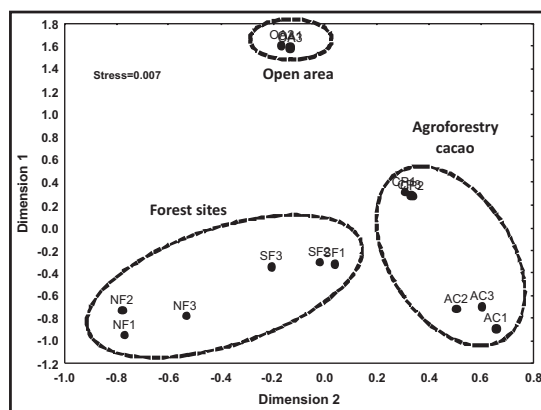


Figure 2. Multidimensional scaling (MDS) placing the five land-use type studied in three groups based on several habitat parameters measured. NF= Natural Forest; SF= Secondary Forest; AC= Agroforestry cacao; OA= open area

Table 2. Indicator values (*IndVal* percentage) for dung beetle species recorded in three group of habitats. Species with *IndVal* > 70 % is categorized as a characteristic species (C) while species with *IndVal* 50 ≤ 70 % is a detector species (D) of certain habitat type

Species*	Forest Sites		Agroforestry cacao		Open area		Species category
	2009	2012	2009	2012	2009	2012	
<i>Copris macacus</i>	67.4	13.3	22.6	20.0	0.0	0.0	-
<i>Copris punctulatus</i>	12.1	22.2	30.3	44.4	24.2	0.0	-
<i>Copris saundersi</i>	95.8	91.7	0.0	0.0	0.0	0.0	C
<i>Onthophagus cf. wallacei</i>	22.4	41.5	10.5	41.5	67.0	1.5	-
<i>Onthophagus forsteni</i>	0.0	3.7	33.3	74.1	0.0	0.0	C
<i>Onthophagus fulvus</i>	0.0	16.7	53.6	61.8	7.1	21.5	D
<i>Onthophagus recticornutus</i>	0.0	0.0	0.0	33.3	66.7	0.0	-
<i>Onthophagus ribbei</i>	60.5	32.4	8.4	37.1	0.4	1.0	D
<i>Onthophagus rudis</i>	5.3	39.5	29.3	51.2	13.3	9.3	D
<i>Onthophagus scrutator</i>	1.3	37.5	67.8	57.1	5.8	0.0	D
<i>Onthophagus</i> sp.1	63.6	62.8	19.4	30.2	6.9	4.7	D
<i>Onthophagus</i> sp.2	33.3	0.0	0.0	33.3	0.0	0.0	-
<i>Onthophagus</i> sp.3	0.0	46.9	66.7	38.6	0.0	14.5	D
<i>Onthophagus trituber</i>	0.0	4.2	7.1	4.2	92.9	75.0	C
<i>Phaechrous emarginatus</i>	58.3	35.7	0.0	41.9	0.0	22.4	-
<i>Onthophagus limbatus</i>	0.7	0.3	0.2	19.6	97.3	77.3	C

* Only species recorded in both sample years (2009 and 2012) were included in the *IndVal* analyses

CONCLUSIONS

The fact that diversity of dung beetles at secondary forest and agroforestry system has no significant differences with natural forest has important implications on landscape management aiming at maintaining a high biodiversity. Besides natural forest sites, certain agroecosystems like cacao agroforestry also have potency to maintain a high local diversity. Dung beetles have high potency to be used as bioindicator (i.e. ecological indicator) in relation with their fidelity and specificity to a particular type of habitat. *Copris saundersi* and *Onthophagus forsteni* can be suggested as indicator (characteristic) species of cooler and shaded habitats (e.g. forest sites and cacao agroforestry system), while *O. trituber* and *O. limbatus* can be suggested as indicator of warmer and unshaded habitats (e.g. open cultivated area). The remaining dung beetles species found across the land-use types in the margin of LLNP, Central Sulawesi are better to be categorized as detector or moderate species.

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