Can Cattle Grazing in Mature Oil Palm Increase Biodiversity and Ecosystem Service Provision?*

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How to maximise biodiversity within oil palm plantation habitats, and the role this biodiversity plays in ecosystem functioning and crop production are key areas of research. Increasingly, cattle are being grazed under mature oil palm as a source of income for local communities, and to control the understory vegetation.

Dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) play a pivotal and easily quantifiable role both in tropical forests and agricultural grasslands by providing key ecosystem functions and services, such as nutrient recycling, bioturbation, fly and disease control, and mediating greenhouse gas fluxes. However, dung beetle diversity, composition, and the role they play in ecosystem service provision in oil palm landscapes are largely unknown.

Dung beetle communities and dung removal rates were studied in 36 blocks of oil palm, half of which were cattle grazed, as part of a larger project investigating the importance of biodiversity for crop production in oil palm plantations. Nineteen species of dung beetles were recorded across all the sites. Dung beetle abundance, but not species richness, was higher in cattle grazed oil palm. In particular the large nocturnal tunnelling species, Catharsius renaudpauliani *Ochi & Kon, which is in one of the most functionally important genera in South East Asia, was found in high abundances only in the cattle grazed oil palm. Dung removal rates were significantly higher in plots that were grazed compared to in plots that were ungrazed. Plots grazed by cattle had average removal rates in 48 hours of 80 per cent (±6%), similar to those recorded in old growth forests, compared to only 11 per cent (±3%) in ungrazed plots. Thus, dung beetle abundance, and hence removal rates, appear to be determined by the presence of large mammals, rather than the level of habitat degradation or complexity* per se.

The results suggest that cattle grazing may also help to increase biodiversity and maintain soil ecosystem functioning. The increase in dung beetles through cattle grazing is predicted to help restore soil ecosystem functioning, for example by having a positive impact on soil hydrological properties and fertility.

***Keywords**: Biodiversity, cattle integration, dung beetle, ecosystem function, soils.*

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Cattle integration in oil palm in Indonesia

There is inadequate production of animal protein throughout South East Asia, with supplies unable to meet current and projected future demands. Integrating tree crops, such as oil palm, with ruminant production systems is one solution, but this is currently under-valued and inadequately researched (Latif & Mamat, 2002; Gabdo & Abdlatif, 2013).

Studies have shown that cattle integration into oil palm systems is possible once trees are mature (>7 years old) and when grass and fern cover is high (around 60-70%). In mature oil palm the understory produces around 500 kg per hectare per year of dry matter; enough to support a cow every 3 ha. Thus, a mature oil palm plantation can easily sustain 300-600 heads of cattle (Latif & Mamat, 2002).

Cattle breeds used in many plantations in Peninsular Malaysia and Sabah are non-native Yellow cattle from China, while Brahman cattle and the indigenous Bali cattle are more common in Indonesia (Martojo, 2003; Tohiran *et al.,* 2008). In Malaysia fencing of the cattle and rotation through the plantation is more common, while in Indonesia free roaming cattle managed by the local communities are often grazed under mature stands (Latif & Mamat, 2002; Martojo, 2003).

Studies in Malaysia have shown both financial and biological benefits to cattle grazing under oil palm. The cattle require little maintenance and so only two workers can manage a herd, with large savings in terms of weeding and labour costs. Weeding can be reduced by 17-70 per cent (a saving of IR 76-223,000/ha/yr) (Ayob & Kabul, 2012), while beef production can generate IR109 million per year, an internal rate of return (IRR) of 19-50 per cent (Latif & Mamat, 2002; Devendra, 2011). Moreover, cattle integration supports local livelihoods, and sustainable beef and dairy production, reducing reliance on imports. Several studies also cite improved biological and agro-ecosystem impacts as benefits of cattle integration, although most of these perceived benefits have not been investigated in any detail (Tohiran *et al.,* 2008; Ayob & Kabul, 2012). However, case studies show increases in yields of 0.49-3.52 mt per FFB per hectare per year (~14% increase) under cattle integrated systems (Devendra, 2011; Gabdo & Abdlatif, 2013), and reduced fertiliser use by up to 69 per cent in cattle-coconut systems (Devendra, 2011).

Despite the well documented economic and financial benefits of cattle integration, many oil palm plantations oppose cattle integration due to perceived negative impacts, such as soil compaction, decreases in yield, increased greenhouse gas emissions, increased fly and parasite populations, and the potential spread of *Ganoderma* fungus (Devendra, 2011). However, there are few studies that address any of these negative impacts quantifiably, and those that do have found that compaction, loss of soil nutrients and decreased yields are generally not a problem with proficient management of the cattle (Tohiran *et al.,* 2008).

The role of dung beetles in oil palm ecosystems

It is already established that forest conversion to oil palm plantation has severe impacts on biodiversity. However, little research has focussed on methods that can be employed to maximise biodiversity within plantation habitats, nor the role this biodiversity plays in ecosystem functioning and crop production (Foster *et al.,* 2011; Turner *et al.,* 2011).

Cattle grazing may help to increase biodiversity through increasing habitat heterogeneity, and providing new habitat and food for invertebrates (such as beetles, flies, worms), which then are prey for larger animals (such as birds, bats, frogs and mammals). Most dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) rely on mammal dung for food and nesting, Thus, a healthy mammal population is necessary to sustain a strong population of dung beetles, and they can be useful as indicators of mammal abundance (Nichols *et al.,* 2009; Viljanen *et al.*, 2010). Throughout the world dung beetles are in decline through habitat loss, changes in agricultural and farming practises, and loss of large mammals (Nichols *et al.,* 2007). In Borneo, dung beetles show sharp declines in abundance and number of species as forests are lost to oil palm plantations (Edwards *et al.,* 2013; Gray *et al.,* 2014). Importantly, these declines have been recorded in young oil palm without cattle grazing, and it is therefore predicted that dung beetles may show positive responses to cattle introductions into oil palm plantations.

Dung beetles are an ideal group for monitoring the effects of cattle integration systems on biodiversity. Studies have shown that they are a cost-effective indictor for monitoring, as they have high ecological and biodiversity indictor values (and so can act as surrogates for overall biodiversity), and low survey costs (Gardner *et al.,* 2008). Importantly, through burying the dung into the soil, dung beetles play a pivotal and easily quantifiable role both in tropical forests and agricultural grasslands by providing key ecosystem functions and services, such as nutrient recycling, bioturbation, fly and disease control (Nichols *et al.,* 2008). Ecosystem services mediated by dung beetles have great economic importance, and were valued as $380M per year in the USA alone (Losey & Vaughan, 2006). On a forest floor in Borneo, a dung pat can disappear within 24 hours (Slade *et al.*, 2011).

Within oil palm plantations, dung beetles may help to reduce any negative impacts of cattle, by removing livestock (and human) dung, which in turn supresses parasite and fly populations (Nichols & Gomez, 2013), and reduces greenhouse gas emissions from the dung (Penttilä *et al.,* 2013). Furthermore, they may help reduce compaction of the soil and improve soil hydrological properties, by increasing infiltration and moisture in the soil, improving aeration, and bringing subsoil to the surface (Brown *et al.,* 2010). By enhancing the soil structure, they may improve nutrient cycling and carbon storage in the soil, thus increasing soil fertility and plant growth, and decreasing the need for chemical fertilisers. Importantly, they may reduce nitrogen and phosphorus loss and leaching of nutrients into waterways, thus improving the sustainability of the oil palm plantation. Grazing cattle under mature oil palm therefore has the potential to provide significant economic benefits to plantation owners through providing an alternative product, reducing the need for costly weed control and enriching the soil, while also benefitting dung beetle and wider biodiversity in plantation ecosystems.

OBJECTIVES

i) To assess whether cattle grazing can increase biodiversity in mature oil palm plantations, by comparing dung beetle abundance, species richness and community composition in cattle grazed and ungrazed areas.
ii) To assess whether cattle grazing can enhance ecosystem service provision by comparing the ecosystem service of dung removal in cattle grazed and ungrazed areas.

MATERIALS AND METHODS

Study site

The study was conducted within oil palm plantations owned and managed by SMART Research Institute (SMARTRI), in Riau Province, Sumatra, Indonesia (N0 55.559, E101 11.619). These consist of lowland mature oil palm plantations (age of oil palm approx. 26 years). Ungrazed plots were situated in the Unjung Tanjung and Kandista Estates within plots established as part of the Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Project (see www. oilpalm biodiversity.com), and cattle grazed plots were situated in the Libo and Rokan Estates. The design followed the BEFTA plot design, whereby each estate has three blocks consisting of three plots in neighbouring compartments, so nine plots per estate (distance between each plot within a block is 150 m, distance between blocks within each estate is 1-4.5 km) (see Foster *et al.,* 2014 for further details).

Dung removal

Rates of dung removal were measured by monitoring standard-volume dung piles placed in the field during October 2013. Fresh cattle dung was collected from the Bali cattle roaming within the Libo and Rokan plantations. Dung was collected fresh, homogenised and frozen for 24 hours to kill any invertebrates. Seven hundred grammes piles were placed at the centre of each of the plots with a plate as a rain-shield. Leaves and debris were cleared, so that the dung was always placed directly onto the soil surface. The volume of dung used was the same as that used in previous experiments in Borneo, where it was the smallest amount that could be left out without total removal within 24 h (Slade *et al.*, 2011; Gray *et al.,* 2014). The dung was collected after 48 hours and re-weighed. Three moisture control piles of dung, from which all beetles were excluded using a fine mesh, were placed in each of the sites. This allowed the mass loss due to evaporation or mass gain due to excess rain to be accounted for. Differences in proportion of dung removed between the cattle grazing treatments were analysed with a linear mixed effects model (LME) with arcsine square-root transformed proportions. Blocks nested within estate were modelled as random effects. χ^2 and p-values for the effect of grazing were obtained by likelihood-ratio tests of the model with the fixed effect of 'grazing' included or excluded.

Dung beetle trapping

Dung beetles were trapped using a dung-baited pitfall trap placed at the centre of each of the plots 10 days after the dung removal experiment. This prevented interference between the two components of the study, but was close enough in time that the dung beetle assemblages caught during trapping would be similar to those present during the dung removal experiment. The traps were plastic containers, 14 cm deep by 13 cm diameter, part-filled with a mixture of water, salt, and detergent, and set flush with the soil surface. A muslin bag of 25 g human dung was suspended 5 cm above the trap. Each trap was protected from rain by a plastic plate held 20 cm above it. Beetles collected from the traps after 48 hours, stored in 75 per cent alcohol in a freezer, and identified to species level, at the Oxford University Museum of Natural History (OUMNH). Reference collections are held in the OUMNH and SMARTRI.

Differences in dung beetle abundance, biomass, species richness, and abundance of the largest beetle, *Catharsius renaudpauliani* Ochi & Kon, between the cattle grazing treatments were analysed with a linear mixed effects model (LME) for biomass, and generalised linear mixed models (GLMMs) with a poisson error structure, and corrected for overdispersion where necessary, for species richness, abundance and abundance of *C. renaudpauliani* individuals. Blocks nested within estate were modelled as random effects. Biomass was square-root transformed before analysis to meet the assumptions of normality. χ^2 and p-values of fixed effects were obtained by likelihood-ratio tests of the full model with the explanatory variable included or excluded. Linear models with arcsine square-root transformed proportions of dung removed were used to test whether overall dung beetle abundance, species richness, biomass, and the abundance of *C. renaudpauliani* individuals can predict the amount of dung removed. All analyses were carried out in R (R Development Core Team 2006) using the package *lme4* (Bates *et al.*, 2013).

RESULTS

Dung removal

Significantly more dung was removed in the cattle grazed plots (80% ±6%), where some plots experienced 100 per cent dung removal, than the ungrazed plots (11% ±3%) (χ^2_1=8.55, p=0.003) (*Figure 1*). Dung removal also varied among the estates. Unjung Tanjung had the lowest dung removal and Libo the highest (*Figure 1*).

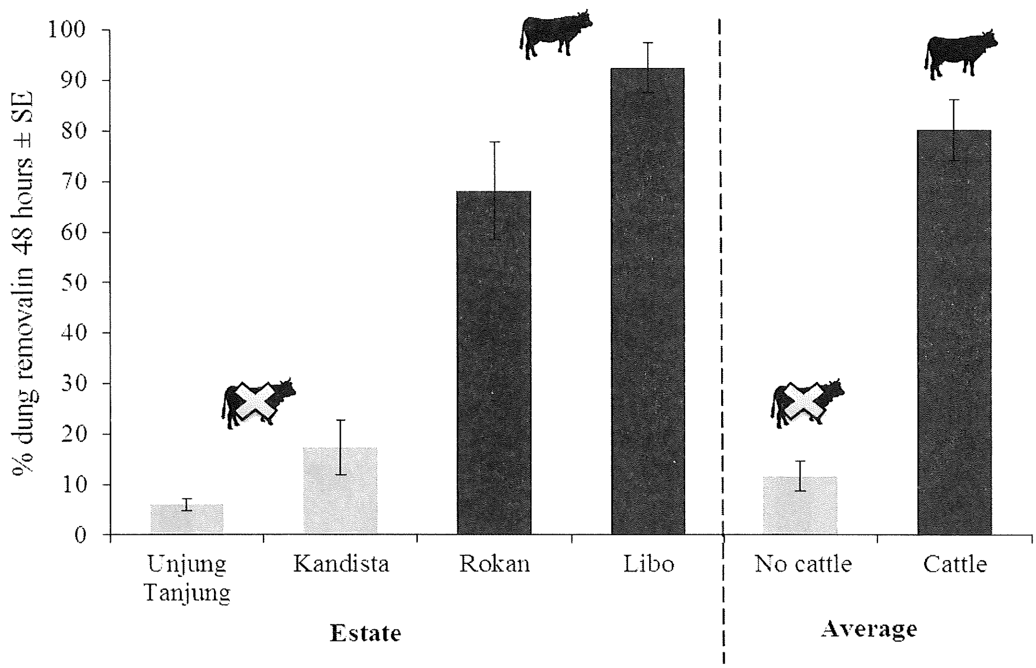

Figure 1 Dung removal (±SE) in the four estates (n = 9 for each estate), and on average for mature oil palm with cattle grazing versus *ungrazed oil palm*

Dung beetle communities

A total of 5,200 individuals of 19 species of dung beetle across all plots were captured. There was no significant difference in species richness between grazed and ungrazed plots (χ^2_1=0.63, p=0.43, *Figure 2a*), and most species occurred in both areas. Only five species were found in grazed plots and only two species were found in ungrazed plots (*Table 1*). All species were diurnal tunnellers, except for *Catharsius renaudpauliani* Ochi & Kon, which is a nocturnal tunneller.

Abundance was significantly higher in cattle grazed plots than ungrazed plots (χ^2_1=8.34, p=0.0039, *Figure 2b*). The most abundant species was a small diurnal tunnelling species, *Onthophagus* aff. *obscurior*. However, in terms of biomass the large nocturnal tunneller, *C. renaudpauliani*, dominated the assemblages, weighing on average 92 times more than an individual of *O.* aff. *obscurior* (*Table 1*). There were significantly more *C. renaudpauliani* individuals per trap in grazed than ungrazed areas (χ^2_1=10.75, p=0.001, *Figure 2d*), where up to 36 *C. renaudpauliani* burrows were found under a single pat. As biomass and

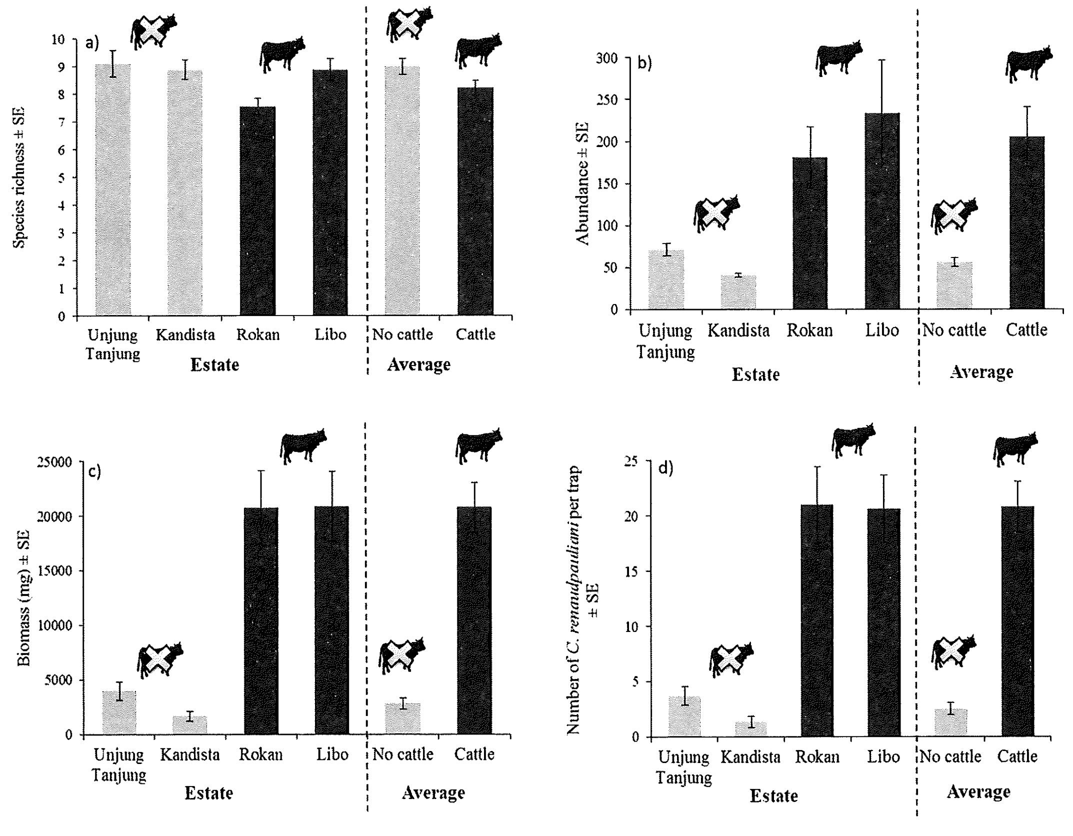

Figure 2 Species richness (a), Abundance (b), Biomass (c) and number of individuals of C. renaudpauliani *per trap (d) (±SE), in the four estates (n = 9 for each estate) and the average removal for mature oil palm with cattle grazing* versus *ungrazed oil palm*

TABLE 1
ABUNDANCE AND MASS OF DUNG BEETLE SPECIES CAPTURED IN CATTLE GRAZED AND UNGRAZED AREAS

Species	*†Mass (mg)*	*Abundance ungrazed*	*Abundance cattle grazed*
Catharsius renaudpauliani Ochi & Kon	914.65	45	354
Liatongus femoratus Illiger	23.86	0	2
Onthophagus (Onthophagus) orientalis Harold	20.66	178	485
Onthophagus (Serrophorus) rectecornutus Lansberge	17.33	1	4
Onthophagus (Onthophagus) waterstradi Boucomont	14.61	98	0
Oniticellus tesselatus Harold	11.74	0	1
Pharaphodius aff. *marginellus* Fabricius	10.06	0	3
Onthophagus (Gibbonthophagus) aff. *obscurior* Boucomont	9.92	123	1891
Onthophagus (Gibbonthophagus) aff. *ventralis* Lansberge	8.17	115	30
Onthophagus aff. foedus Boucomont	8.17	1	0
Onthophagus (Micronthophagus) vigilans Boucomont	6.51	25	28
Onthophagus (Gibbonthophagus) aff. *limbatus* Herbst	6.51	2	23
Onthophagus (Paraphanaeromorphus) trituber Wiedemann	5.62	31	33
Onthophagus (Onthophagiellus) crassicollis Boucomont	5.24	253	1199
Onthophagus (Micronthophagus) aff. *echinus* Boucomont	4.52	68	48
Onthophagus (Gibbonthophagus) luridipennis Boheman	4.27	1	2
Onthophagus (Furconthophagus) aff. *liliputanus* Lansberge	2.31	0	1
Eodrepanus aff. *striatulus* Paulian	2.12	0	6
Caccobius unicornis Fabricius	1.18	61	88
Total		1002	4198

† taken from similar species in Slade *et al.* (2011) and Gray *et al.* (2014)

C. renaudpauliani abundance were positively correlated (Pearson's correlation coefficient = 0.997) there was also significantly higher overall biomass in grazed plots (χ^2_1=13.48, p=0.0002, *Figure 2c*).

Greater overall dung beetle abundance and biomass, and abundance of *C. renaudpauliani* individuals all significantly predicted increases in dung removal (p<0.001 in all cases, the relationship for number of *C. renaudpauliani* individuals is shown in *Figure 3*. Similar relationships were observed for overall dung beetle abundance and biomass). However, species richness did not predict removal (p=0.26).

DISCUSSION

Rates of dung removal in the mature oil palm with cattle grazing were similar to those

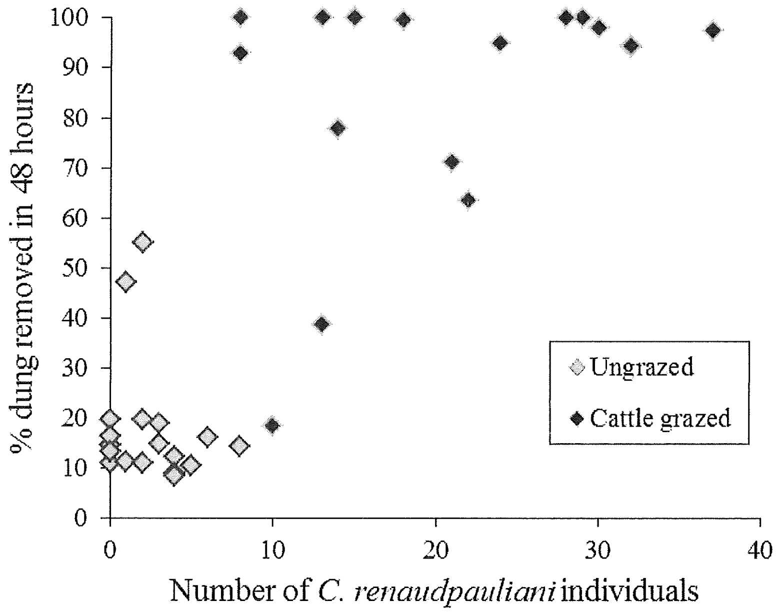

Figure 3 *Number of* C. renaudpauliani *individuals significantly predicts dung removal. Similar relationships were observed for overall dung beetle abundance and biomass*

recorded for undisturbed forests in Borneo, and higher than in logged forest and young (6-15-year-old) oil palm with no cattle grazing in Borneo (Slade *et al.*, 2011; Gray *et al.*, 2014). Interestingly, the rates of dung removal in the mature oil palm without cattle were similar to those recorded in young ungrazed oil palm in Borneo (Gray *et al.*, 2014), suggesting that it is not the age of the oil palm but the presence of a continuous dung source which is important.

The large nocturnal tunneller, *C. renaudpauliani,* was responsible for the large amounts of dung removal in cattle grazed areas. The genus, *Catharsius*, has been shown to be particularly important for dung removal in tropical forests within Borneo, where two sympatric species, *C. renaudpauliani* and *Catharsius dayacus* Lansberge, co-occur. When species in this genus are absent dung removal has been shown to greatly decrease (Slade *et al.,* 2007; Slade *et al.*, 2011). Thus, the low rates of dung removal in oil palm in Borneo are thought to be due to the small numbers of *Catharsius* species found within oil palm plantations there (Edwards *et al.,* 2013; Gray *et al.,* 2014). This follows the generally held view that the largest, forest-dependent species go extinct first, with consequences for ecosystem functioning (Larsen *et al.*, 2005; Larsen *et al.*, 2008; Senior *et al.,* 2013). However, our results show that dung beetle abundance, the abundance of the large functionally important *C. renaudpauliani*, and hence dung removal rates, appear to be determined by the presence of large mammals, rather than the level of habitat degradation or complexity *per se*. Thus, if the system is restored (in this case through replacing forest-dwelling large mammals with cattle) large-bodied species may still persist within degraded landscapes, and while oil palm will never be as diverse as forested areas, with careful management some restoration of ecosystem functionality to levels similar to those of forested habitats may be possible.

Although abundance and biomass were higher in cattle grazed plots, species richness was not significantly different from ungrazed areas, and most species occurred in both grazed and ungrazed plots. This suggests that there are still sufficient numbers of mammals within ungrazed oil palm to support substantial populations of dung beetles. However, the majority of the species occurring at high abundances in the ungrazed plots were small bodied and diurnal. The size of beetles captured in an area is correlated with the size of mammals present within that area. Thus, the more larger bodied mammals present, the more larger bodied dung beetles will be found (Viljanen *et al.*, 2010). Our results therefore suggest that no large mammals were using the oil palm, and that the beetles were probably utilising the dung of small-bodied mammals, such as leopard cats, civets and humans.

Many of the perceived negative impacts of cattle grazing, such as soil compaction, decreases in yield, increased greenhouse gas emissions, and increased fly and parasite populations (Devendra, 2011) are likely to be mitigated through the ecosystem services provided by dung beetles in oil palm plantations where cattle are integrated. For example, increases in soil nutrient content, enhanced soil structure and hydrological properties (such as increased water infiltration, porosity, and soil moisture), reductions in erosion, and increases in soil fauna have the potential to both save money and increase the sustainability of plantations, through reduced fertiliser application, improved soil conditions, and increased yield and productivity of the palms. Moreover, removal of dung may also reduce fecal helminth parasite transmission in both livestock and humans (Nichols & Gomez, 2013). These ecosystem functions and services provided by dung beetles in oil palm plantations deserve further consideration. However, one of the major concerns raised by smallholders and oil palm managers is that *Ganoderma* infection may be increased in oil palm where cattle are grazed, and that dung beetles could act as disease vectors. This is an extremely important issue, which has not been studied in any depth, and thus deserves urgent attention.

CONCLUSIONS

Cattle grazing led to a high abundance of the large-bodied tunnellers, *C. renaudpauliani*. These beetles are responsible for high levels of dung removal, with the potential to mediate other important ecosystem functions, such as nutrient recycling, enhanced soil structure and soil hydrological properties, and increased plant growth. These additional benefits of cattle grazing need further exploration. Our results also suggest that cattle grazing in oil palm plantations may enhance biodiversity, in terms of increasing the abundance and biomass of dung beetles, although dung beetle species richness was not any higher in cattle grazed areas. We predict that cattle grazing may also provide additional resources and habitats for other species of invertebrates, such as earthworms, flies and other beetles, and in turn these may increase insect-feeding birds, bats and small mammals. Although the impacts of cattle grazing in oil palm require further research, this study indicates that cattle grazing under mature oil palm may provide an opportunity to enhance both productivity and biodiversity within oil palm habitats.

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