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RESEARCH ARTICLE

Targeted cattle grazing as an alternative to herbicides for controlling weeds in bird-friendly oil palm plantations

Kamil A. Tohiran[1,2] · **Frisco Nobilly**[3] · **Raja Zulkifli**[1] · **Thomas Maxwell**[4] · **Ramle Moslim**[5] · **Badrul Azhar**[2,6]

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Abstract The use of agrochemicals is expected to increase with the global expansion of oil palm plantations. In line with environmentally sustainable palm oil certification, targeted grazing can minimize the dependency on herbicides for controlling weeds in plantations. Here, we show for the first time that targeted grazing would control weeds and improve biodiversity of desired animal species. We sampled birds at 45 oil palm plantations in Peninsular Malaysia that were systematically grazed, non-systematically grazed, or herbicide-controlled plantations without cattle grazing. We found that bird species richness increased with size of grazing area, but decreased with number of cattle. Bird abundance was higher in the systematic grazing system, but negatively related to number of cattle. These factors explained 18.41 and 25.34% of the observed variations in bird species richness and abundance, respectively. Our findings suggest that targeted cattle grazing can be instrumental for transforming conventional oil palm agriculture into more biodiversity-friendly agroecosystems. Targeted grazing is likely to be practical under field conditions in major palm oil producing countries. In addition, the use of targeted grazing as a biological control method for weeds would be welcomed by palm oil consumers and encouraged by sustainable palm oil certification bodies such as the Roundtable on Sustainable Palm Oil (RSPO).

Keywords Biodiversity-friendly agroecosystems · Biological control · Bird abundance · Cattle grazing · Oil palm · Species richness

1 Introduction

Global palm oil production area has increased rapidly from 11.7 million ha in 2003 to 17 million ha in 2013 due to increasing demand for palm oil (FAO 2016). Indonesia and Malaysia altogether produce 82% of the world's palm oil, amounting to more than 267 million tonnes in 2013 (FAO 2016). This has increased the input of agrochemicals in oil palm producing countries. For example, the use of herbicides in Malaysia increased from 30,427 tonnes in 2006 to 36,132 tonnes in 2010 (FAO 2016). Because oil palm growth can be reduced by competition with weeds, herbicides such as paraquat, glufosinate ammonium, and glyphosate are consistently used to control weeds (Mattsson et al. 2000; Wibawa et al. 2010). A typical oil palm plantation may use up to 90% of its overall pesticide input as herbicides (Page and Lord 2006). However, some herbicides are a source of contamination to water resources and could pose a threat to the natural ecosystem as well as causing health problems to the operator (Wibawa et al. 2007; Salman and Hameed 2010; Schiesari and Grillitsch 2011). The use of hazardous herbicides has been

✉ Badrul Azhar
b_azhar@upm.edu.my

[1] Crop and Livestock Integration Unit , Integration Research and Extension Division, Malaysian Palm Oil Board, 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia

[2] Department of Forest Management, Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

[3] Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

[4] Department of Agricultural Sciences, Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, Canterbury 7647, New Zealand

[5] Entomology Unit, Biology Division, Malaysian Palm Oil Board, 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia

[6] Biodiversity Unit, Institute of Bioscience, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

banned in some palm oil producing countries but the use of chemical herbicides is still prevalent in oil palm plantations (Wibawa et al. 2007). The negative consequence for bird diversity of herbicide use in agriculture has been highlighted by several researchers (Parsons et al. 2010; Chiron et al. 2014; Gill and Garg 2014). A decline in shrub birds has been described in studies of wildlife impacts from herbicides (Stoleson et al. 2011).

Livestock such as cattle, buffaloes, and goats are being integrated with oil palm plantations that have reached mature age (i.e., more than 5 years) in Malaysia (Md. Said and Man 2014). This agricultural practice is encouraged by the government to meet the local market demand for red meat and to control oil palm weeds (Devendra 2007). Moreover, livestock grazing can reduce the dependency on herbicides which may indirectly help maintain farmland biodiversity (Rinella and Hileman 2009; García et al. 2012; Jambari et al. 2012; Slade et al. 2014). Despite the benefits, the integration of livestock and oil palm agriculture has not been widely adopted by major oil palm plantation companies due to lack of relevant technical expertise (e.g., animal husbandry) and other outstanding problems (e.g., theft and property intrusion by livestock). In contrast, targeted grazing has been widely practiced in agricultural lands (e.g., vineyards and fruit orchards) in developed countries for controlling weeds and maintaining biodiversity (Launchbaugh et al. 2006; Isselstein et al. 2007; Wallace et al. 2008; Frost et al. 2012). Targeted grazing is the introduction of a particular kind of grazing animal at a specified season, duration, and intensity to accomplish specific vegetation management goals (Frost et al. 2012). The successful practice of targeted grazing requires site-specific knowledge of plant growth, animal nutrition and grazing behavior, understanding the relationship between biodiversity and ecosystem function, and public relations (Macon 2014).

With the inception of the Roundtable on Sustainable Palm Oil (RSPO) certification in 2008, certified oil palm growers need to comply with certain environmental standards. Currently, considerable emphasis in certification schemes is given to the protection of high-value conservation areas such as forest patches and riparian habitat areas (Azhar et al. 2015). Less attention is given to the potential value of agricultural practices such as controlling competing plants using targeted grazing. Reducing pesticide impacts on the environment has become one of the criteria for sustainable palm oil certification. One of the Principles and Criteria of RSPO encourages oil palm growers to use biological agents to control pest organisms instead of herbicides (RSPO 2017).

Continuous application of herbicides in agriculture areas can harm both the environment (e.g., soil, water, and biodiversity) and human health (González-Tokman et al. 2016; Wang et al. 2016). Weeds may become more resistant towards herbicides with time and increased use of herbicides may result (Green 2014; Heap 2014). In response to this issue, oil palm growers need to develop "green" management practices that can control oil palm weeds and maintain farmland biodiversity. To date, there is a lack of research that focuses on the ecological aspects of integrating cattle farming and oil palm agriculture. This study will shed new light on how to reconcile oil palm production and biodiversity conservation by replacing conventional weeding methods with livestock grazing (Fig. 1).

Previous studies (Azhar et al. 2011, 2013) did not detect significant effects of cattle grazing on bird biodiversity, as data collected were only limited to the presence or absence of cattle in oil palm plantations. In this study, we compared vegetation structure attributes in relation to understory vegetation and stocking density (i.e., grazing area per animal unit) as well as chemical weeding costs between different grazing systems (i.e., systematic grazing, non-systematic grazing, and control). We predicted that vegetation structure attributes and weeding costs were significantly different between distinct grazing systems. We also investigated the effects of targeted cattle grazing on bird biodiversity and vegetation structure of weeds by gathering specific details with respect to grazing management. We hypothesized that managed cattle integration with oil palm plantations would increase bird species richness and abundance and be simultaneously effective in controlling weeds.

2 Material and methods

2.1 Study area

This study was conducted on 45 plantations located in the provinces of Johor, Pahang, and Negeri Sembilan in Peninsular Malaysia, encompassing 79,351 ha total (Fig. 2). Initially, we requested permission to conduct research from 60 plantations but 15 plantations declined to be surveyed. The plantations were planted with oil palms that have a 25-year productive cycle of yielding oil palm fruit bunches, during which herbicides are typically applied three times annually.

2.2 Cattle grazing management

To estimate stocking density and number of days spent grazing at each plantation, we recorded the number of cattle allowed to graze at a particular plantation. To differentiate between grazed and non-grazed plantations, we classified grazed plantations as those with a cattle integration scheme (permitted by plantation management and managed systematically) and without or the minimum use of herbicide application, whereas we classified non-grazed plantations as those without a cattle integration scheme and where herbicides were commonly used to control unwanted weeds. Glyphosate (1.7 L per ha) and paraquat (3.2 L per ha) herbicides were commonly used in non-grazed plantations.

Fig. 1 Integration of cattle farming with oil palm cultivation may provide positive outcomes in terms of environmental sustainability and agricultural productivity

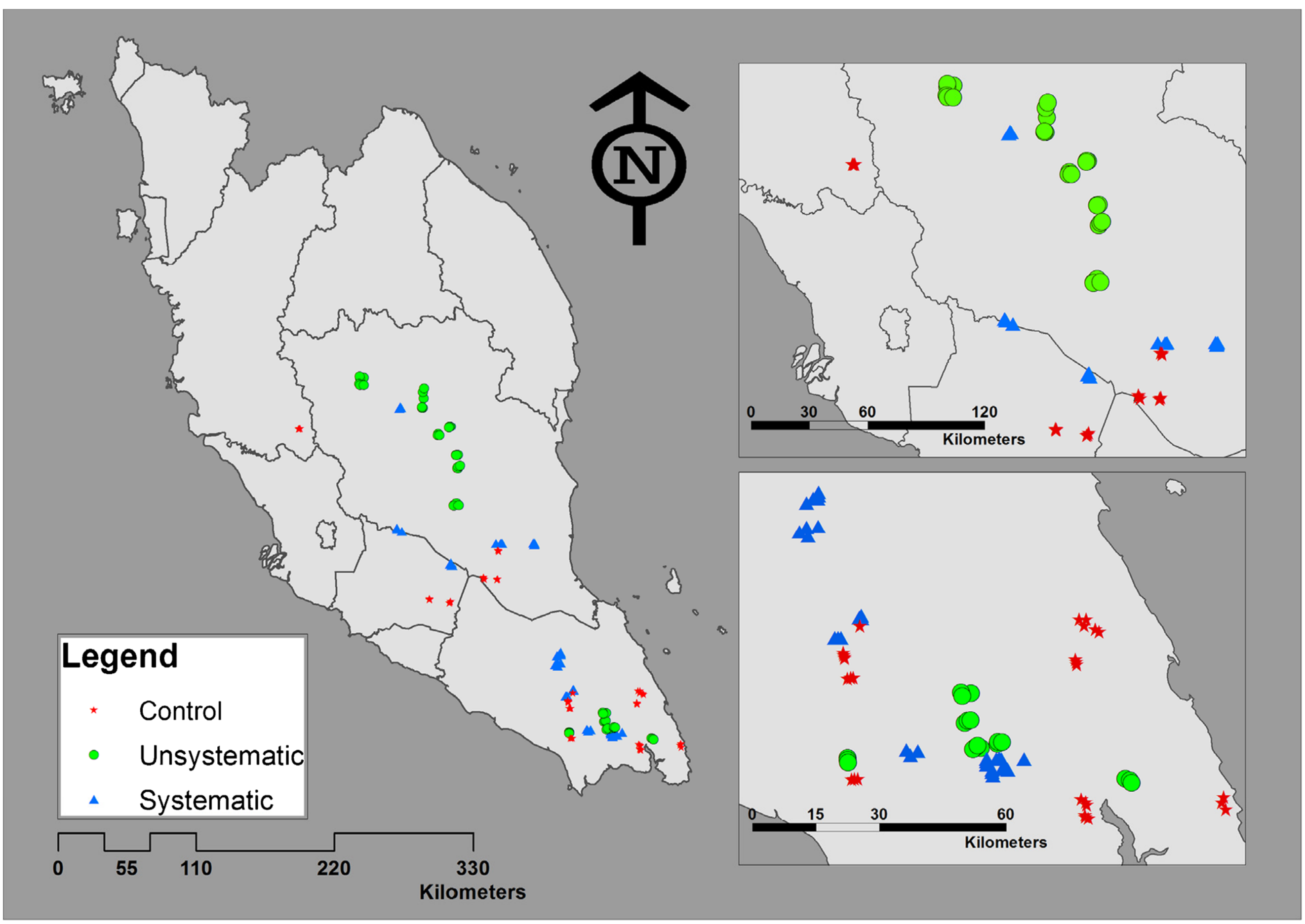

Fig. 2 Map of study areas encompassing 135 sampling points within 45 oil palm plantations in Peninsular Malaysia

Grazed plantations were further categorized into systematic and non-systematic grazing systems. The systematically grazed plantations were characterized by mobile electric fencing facilities, well-coordinated grazing (i.e., grazing was concentrated into small areas of less than 5 ha for short durations of 2–3 days depending the number of cattle, with electric fence being moved to corral the cattle into a new area), and sprayed with herbicides once a year (1.4 L of glyphosate per ha and 2.5 L of paraquat per ha). In contrast, the non-systematically grazed plantations were characterized by a free-ranging system driven by ad hoc grazing decisions made by the owners and sprayed with herbicides more frequently (2.1 L of glyphosate per ha and 3.8 L of paraquat per ha). In both systems, cattle were left day and night within oil palm plantations during the study period.

Targeted grazing treatments were non-systematically grazed (mean plantation area ± SE = 1364 ± 170.5 ha; mean number of cattle ± SE = 862 ± 183 animal units), systematically grazed (mean plantation area ± SE = 1922 ± 297.6 ha; mean number of cattle ± SE = 493.3 ± 73.50 animal units), and a control group of non-grazed plantations (mean plantation area ± SE = 2003 ± 261.1 ha), applied to a group of 15 surveyed plantations for each of the three grazing treatments. Each plantation was located at least 1 km apart. The total number of cattle reared in systematic and non-systematic grazed plantations categories was 20,329 head. The cattle breed used for integration with oil palm farming at our study areas was a Kedah-Kelantan cross, which is native to Peninsular Malaysia.

2.3 Survey design and bird sampling

Point transect sampling was used to record birds within a radius of 100 m. Using a nested experimental design, three sampling points were randomly established at each plantation. A total of 135 sampling points was surveyed twice (total spatial replicates = 3 points per plantation × 45 plantations = 135 points) (Fig. 2). To ensure independence of observation, each point was located at least 500 m apart. We conducted daily bird surveys from 7 a.m. to 11 a.m., spending 10 min at each point to identify all birds either visually or acoustically. Sampling was conducted during non-rainy days. The number of individuals of each bird species was recorded. We identified bird species based on morphological characteristics according to Robson (2008). A handheld GPS was used to geo-reference each point (latitude and longitude). Sampling was conducted between November 2014 and March 2016.

2.4 Habitat quality and landscape metric measurements

At each sampling point, the following data were collected from within four 1-m^2 quadrats on harvesting paths or around the sampling point: (1) visually estimated percentage of understory vegetation coverage (grass and non-grass species), (2) average height of understory vegetation, (3) average height of three oil palms using a laser rangefinder, (4) percentage of canopy cover using a GRS densitometer, (5) proximity to nearby forest using the circular shape function in Google Earth Pro, and (6) altitude. In contrast to planting inter-rows, cut oil palm fronds did not occupy harvesting paths and thus encouraged weed growth. This enticed cattle to graze more on harvesting paths than inter-rows. As with bird sampling, vegetation structure measurements were taken twice. We gathered additional information related to livestock management, mature oil palm area and age, and weed management (e.g., herbicide cost and the number of selective and circular herbicide sprayings) from plantation managers. We reported the season we conducted sampling in as either wet or dry. Visitations to sampling points were divided into first survey and second survey times.

2.5 Data analysis

A one-way ANOVA was conducted to compare vegetation structure attributes and chemical weeding costs between the three treatment levels (i.e., non-systematically grazed, systematically grazed, and control plantations). Arcsine transformations were performed on percentage data such as bare ground, litter coverage, and understory vegetation coverage, while a log transformation was performed on understory vegetation height data to improve linearity. We conducted post hoc analysis using Tukey's test for each vegetation attribute to determine differences between treatment groups. In addition, we performed *t* tests to compare the distribution of cattle stocking density data between unsystematically grazed and systematically grazed plantations.

We used generalized linear models (GLMs) to examine the relationship between bird biodiversity and weed management type, plus other habitat quality (e.g., canopy cover, understory vegetation height and coverage, oil palm height, litter coverage, bare ground, grazing system), landscape (e.g., proximity to forest, percentage of mature oil palm area, grazing area), and geographical (e.g., altitude, dry or wet season) attributes. We developed two predictive models: a bird species richness model and an individual bird abundance model. We used a Poisson distribution with a log-link function to fit a regression model with multiple explanatory variables. We conducted correlation tests to check for multi-collinearity among 13 predictor variables in global models. We excluded predictor variables such as bare ground and age of oil palm stands as these were strongly correlated ($|r| > 0.7$) and their inclusion would have distorted model estimations (Dormann et al. 2007). We used all possible subsets of regression (i.e., fitted the model with all subsets of the explanatory variables) to determine the final model. Because GLMs have a fixed dispersion (e.g., Poisson distribution), the probabilities were obtained by treating the Wald statistics as chi-square statistics (Payne 2008). The Wald statistics were computed based on weighted sums of squares. The advantage of Wald statistics is that the model does not have to be refitted (excluding each predictor variable) to compute the information. The Wald statistics thus provide a much more efficient method of assessing the model than F statistic. We reported the coefficient of determination, R^2 of the final model. All statistical analyses were conducted in GenStat version 15 (VSNI, Hemel Hempstead, UK).

3 Results and discussion

3.1 General pattern of bird biodiversity

From observations within oil palm plantations, we recorded 2603 individual birds from 36 species and 22 families including 14 forest species based on Robson (2008) (Table 1). Passerines constituted more than 55% of the bird community within oil palm plantations. All species were classified as "least concern" by the IUCN Red list.

3.2 Vegetation structure, cattle stocking density, and chemical weeding cost

Our results showed that understory vegetation height (df = 1, $F = 25.61$, $P < 0.001$), understory vegetation coverage (df = 1, $F = 15.68$, $P < 0.001$), litter coverage (df = 1, $F = 3.39$, $P = 0.035$), and bare ground (df = 1, $F = 15.36$, $P < 0.001$) differed significantly between the three targeted grazing-weed control treatments in oil palm plantations. The way systematically grazed, non-systematically grazed, and control treatments affected vegetation structure was not the same (Fig. 3).

Average cattle stocking density in systematically grazed plantations was greater (4.985 ± 0.912 ha per animal unit) than non-systematically grazed plantations (2.755 ± 0.572 ha per animal unit). However, this difference was not significant ($t = 1.98$, $P = 0.068$).

Chemical weed control costs were lower in systematically grazed plantations (MYR107.9 ± 19.69 per ha) compared to those in control (MYR135.7 ± 24.67 per ha) and non-systematically grazed (MYR163.2 ± 14.19 per ha) plantations. However, this difference in weeding cost between grazing systems was not significant (df = 2, $F = 1.92$, $P = 0.159$).

3.3 Predicting bird species richness

We found that bird species richness was positively influenced by grazing area size (slope = 0.00006651, df = 1, Wald = 53.00, $P < 0.001$), understory vegetation height (slope = 0.00495, df = 1, Wald = 22.58, $P < 0.001$), number of selective herbicide sprayings per year (slope = 0.0452, df = 1, Wald = 7.45, $P = 0.006$), and litter coverage percentage (slope = 0.00320, df = 1, Wald = 7.53, $P = 0.006$) (Fig. 4). In contrast, the frequency of circular herbicide sprayings (slope = − 0.0768, df = 1, Wald = 23.03, $P < 0.001$), plantation canopy cover percentage (slope = − 0.001345, df = 1, Wald = 7.30, $p = 0.007$), cattle number (slope = − 0.0000499, df = 1, Wald = 4.71, $P = 0.030$), and distance from nearest forest (slope = − 0.00775, df = 1, Wald = 6.32, $P = 0.012$) adversely affected bird species richness (Fig. 4). Both wet season (slope = − 0.1938, df = 1, Wald = 116.72, $P < 0.001$) and time of visit (slope = − 0.1807, df = 1, Wald = 106.95, $P < 0.001$) significantly influenced bird species richness. Grazing system, height of oil palm stand, altitude, and weeding cost had no significant effect on bird species richness. The final model selected explained 18.41% of the variation in bird species richness.

3.4 Predicting bird abundance

Our results show that bird abundance was positively related with systematic grazing (slope = 0.2337, df = 2, Wald = 16.36, $P < 0.001$) and understory vegetation height (slope = 0.00584, df = 1, Wald = 5.32, $P = 0.021$) but negatively influenced with the percentage of mature oil palm stand (slope = − 0.00516, df = 1, Wald = 22.33, $P < 0.001$), height of oil palm stand (slope = − 0.01840, df = 1, Wald = 5.12, $P = 0.024$) and number of cattle (slope = − 0.0001517, df = 1, Wald = 7.93, $P = 0.005$) (Fig. 4). Bird abundance also was driven by wet season (slope = − 0.2026, df = 1, Wald = 23.16, $P < 0.001$) and visit (slope = 0.4394, df = 1, Wald = 114.51, $P < 0.001$). Bird abundance was not influenced by the percentage coverage of ground litter or palm canopy, herbicide spraying (circular or selective), grazing area, or elevation. The final model explained 25.34% of the variation in bird abundance.

3.5 Biological control agent for weeds

Chemical herbicides have been widely used to control understory vegetation by both large- and small-scale oil palm growers in producing countries. This conventional practice is not environmentally friendly and poses a threat to healthy ecosystems (Relyea 2012; Baker et al. 2013; Davis et al. 2013). Despite government policy to prohibit hazardous pesticides, the adverse effects of herbicides on wild flora and fauna persist. The overuse of herbicides causes the potential unintended effects on non-target species, including taxonomic groups that are of current conservation concern (Pereira et al. 2009; Power et al. 2013). We demonstrate that targeted grazing can be feasible to control understory vegetation without or minimum use of herbicides and maintain biodiversity.

Unlike chemical herbicides, targeted cattle grazing produced desirable results for weed control in oil palm agriculture by reducing understory vegetation coverage and height without exposing too much bare ground that would be erosion-

Table 1 Bird species recorded in systematically grazed, unsystematically grazed, and herbicide-controlled oil palm plantations across Peninsular Malaysia. Classification of bird species follows Robson (2008)

Family	Common name	Scientific name	Feeding gulids	Forest species	IUCN status	Passerine/non-passerine
Accipitridae	Black-winged kite	*Elanus caeruleus*	Carnivore, piscivore, insectivore	No	Least concern	Non-passerine
	Crested goshawk	*Accipiter trivirgatus*	Carnivore, piscivore, insectivore	Yes	Least concern	Non-passerine
	Crested serpent eagle	*Spilornis cheela*	Carnivore, piscivore, insectivore	Yes	Least concern	Passerine
Alcedinidae	Collared kingfisher	*Todiramphus chloris*	Piscivore	Yes	Least concern	Non-passerine
	White-throated kingfisher	*Halcyon smyrnensis*	Piscivore	No	Least concern	Non-passerine
Ardeidae	Little egret	*Egretta garzetta*	Piscivore, carnivore	No	Least concern	Non-passerine
	Purple heron	*Ardea purpurea*	Piscivorous, carnivore	No	Least concern	Non-passerine
Cisticolidae	Ashy tailorbird	*Orthotomus ruficeps*	Insectivore	Yes	Least concern	Passerine
	Rufescent prinia	*Prinia rufescens*	Insectivore	Yes	Least concern	Passerine
	Yellow-bellied prinia	*Prinia flaviventris*	Insectivore	No	Least concern	Passerine
Columbidae	Little cuckoo-dove	*Macropygia ruficeps*	Frugivore	Yes	Least concern	Non-passerine
	Zebra dove	*Geopelia striata*	Frugivore	No	Least concern	Non-passerine
	Pink-necked green-pigeon	*Treron vernans*	Frugivore, granivore	Yes	Least concern	Non-passerine
	Spotted dove	*Streptopelia chinensis*	Frugivore	No	Least concern	Non-passerine
Coraciidae	Oriental dollarbird	*Eurystomus orientalis*	Insectivore, carnivore	Yes	Least concern	Non-passerine
Corvidae	House crow	*Corvus splendens*	Carnivore, frugivore	No	Least concern	Passerine
Cuculidae	Greater coucal	*Centropus sinensis*	Carnivore, frugivore	Yes	Least concern	Non-passerine
Estrildidae	White-headed munia	*Lonchura maja*	Granivore	No	Least concern	Passerine
Laniidae	Tiger shrike	*Lanius tigrinus*	Insectivore, carnivore	Yes	Least concern	Passerine
	Brown shrike	*Lanius cristatus*	Insectivore, carnivore	Yes	Least concern	Passerine
Muscicapidea	Oriental magpie-robin	*Copsychus saularis*	Insectivore	No	Least concern	Passerine
Nectariniidae	Olive-backed sunbird	*Cinnyris jugularis*	Nectarivore, insectivore	Yes	Least concern	Passerine
Oriolidae	Black-naped oriole	*Oriolus chinensis*	Insectivore, frugivore	No	Least concern	Passerine
Passeridae	Eurasian tree sparrow	*Passer montanus*	Granivore	No	Least concern	Passerine
Phasianidae	Red junglefowl	*Gallus gallus*	Carnivore, granivorous, frugivore	Yes	Least concern	Non-passerine
Picidae	Common flameback	*Dinopium javanense*	Insectivore, frugivore	No	Least concern	Non-passerine
Pycnonotidae	Olive-winged bulbul	*Pycnonotus plumosus*	Frugivore, insectivore, nectarivore	Yes	Least concern	Passerine
	Yellow-vented bulbul	*Pycnonotus goiavier*	Frugivore, insectivore, nectarivore	No	Least concern	Passerine
Rallidae	White-breasted waterhen	*Amaurornis phoenicurus*	Insectivore, carnivore, piscivore	No	Least concern	Non-passerine
Rhipiduridae	Pied fantail	*Rhipidura javanica*	Insectivore	No	Least concern	Passerine
Sturnidae	Asian glossy starling	*Aplonis panayensis*	Insectivore, frugivore, nectarivore	No	Least concern	Passerine
	Common myna	*Acridotheres tristis*	Insectivore, frugivore, nectarivore	No	Least concern	Passerine
	Javan myna	*Acridotheres javanicus*	Insectivore, frugivore, nectarivore	No	Least concern	Passerine
Sylviidae	Common tailorbird	*Orthotomus sutorius*	Insectivore	No	Least concern	Passerine
	Rufous-tailed tailorbird	*Orthotomus sericeus*	Insectivore	No	Least concern	Passerine
Tytonidae	Barn owl	*Tyto alba*	Carnivore	No	Least concern	Non-passerine

prone (Fig. 3). The outcomes are compatible with the Integrated Pest Management (IPM) and RSPO's standards followed by the oil palm industry in the major producing countries of Malaysia and Indonesia. The use of herbicides in the control plantations removed nearly half of the grass cover and exposed more bare soil surface than the plantations grazed with cattle, either systematically or non-systematically grazed. In addition to the immediate effect of chemical herbicides, these habitat conditions would be less favorable to the bird community, particularly insectivorous birds in oil palm plantations as less vegetative cover and food are available to them for several weeks after the spraying of herbicides (Azhar et al. 2011, 2013). Herbicides can directly lessen the availability of non-target plant species and, indirectly, arthropods that serve as avian food resources (Taylor et al. 2006).

Cattle grazing, systematically or non-systematically, produced favorable conditions for bird habitat by maintaining a greater understory layer compared to herbicides. Systematic grazing

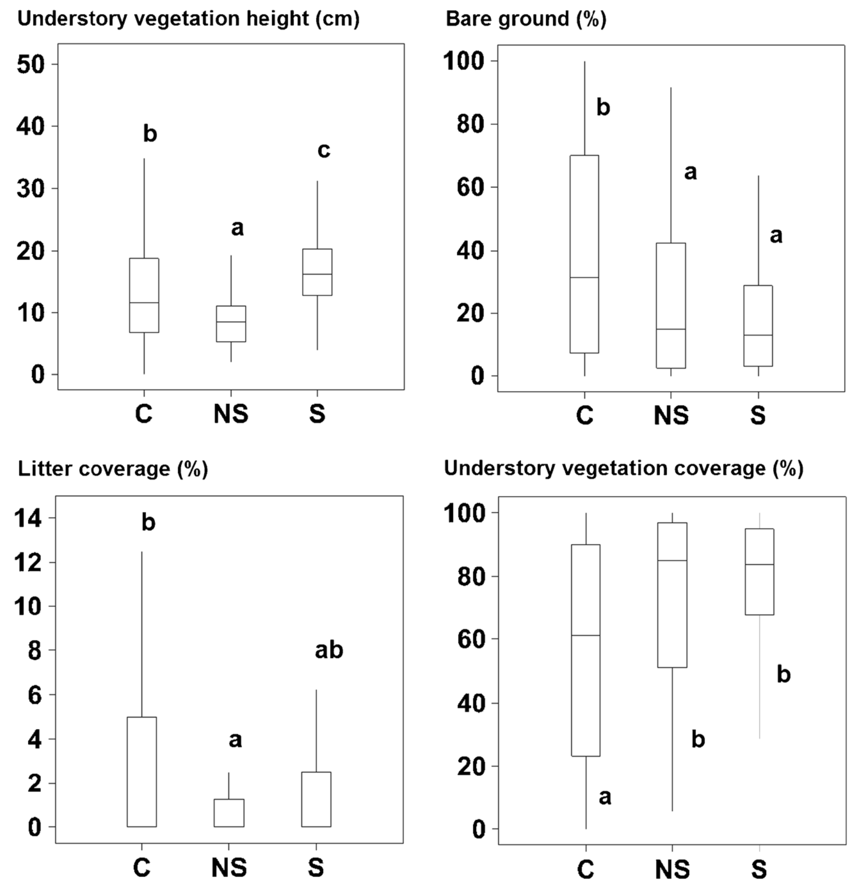

Fig. 3 Boxplots showing stand-level habitat quality attributes under targeted grazing-weed control treatments (systematically grazed is denoted by S, non-systematically grazed is denoted by NS, and control [herbicide-applied] is denoted by C) in 45 oil palm plantations across Peninsular Malaysia. Here, letters represent the results of Tukey's post hoc comparisons of group means

resulted in the tallest grass height, significantly greater than control and non-systematic grazing. However, the height of understory vegetation in systematically grazed plantations is considered acceptable according to plantation management (Rosli 2000). Bare ground and understory vegetation coverage were not significantly different in systematic and non-systematic grazed plantations.

Selecting the right type of livestock for a specific targeted grazing task in oil palm plantations is a crucial step in achieving management objectives (e.g., weed control and biodiversity conservation). Cattle provide a good tool to help with controlling understory vegetation and decreasing the amount of standing, dead biomass (Bruegger et al. 2016). With their massive body size, they would cause plant damage by trampling the understory vegetation. Hence, cattle grazing would affect the vegetation community composition, vegetation structure, and soil chemical parameters (Hayes and Holl 2003). Grazing by large ungulates promotes habitat heterogeneity that maintains biodiversity and agricultural productivity that can be a useful tool in conservation (Kohyani et al. 2008; Eaton et al. 2011; Roche et al. 2012).

3.6 Benefits of targeted grazing to bird biodiversity

Our results show that bird species richness increased with size of grazing area, understory vegetation height, number of times selective herbicide spraying was applied, and litter cover. In contrast, bird species richness decreased with the greater number of circular herbicide sprayings, and increasing percentage of canopy cover, number of cattle, and area of mature oil palm stand. Grazing can change the spatial heterogeneity of vegetation, affecting ecosystem processes and biodiversity (Adler et al. 2001). Habitats with a complex vegetation structure, influenced by livestock grazing, can sustain a higher diversity of bird species (Martin and Possingham 2005).

Bird abundance was greater in plantations with systematic grazing system and thus increased understory vegetation height, but was lower in plantations of larger mature oil palm stand area and greater cattle stocking density. Herbivore grazing creates greater heterogeneity in vegetation structure, which modifies prey availability, resulting in a greater abundance of birds (Evans et al. 2006). The foraging behavior of various bird species is partly determined by vegetation height, which alters prey availability, and hence grazed areas are often selected by invertebrate-feeders (Vickery et al. 2001). Overgrazing or low grazing, might lead to reduced food availability and thus be unfavorable to birds (Evans et al. 2005). Land areas managed for livestock production are often homogeneous landscapes with heavy grazing (Sandercock et al. 2015). This can also occur in oil palm plantations without systematic

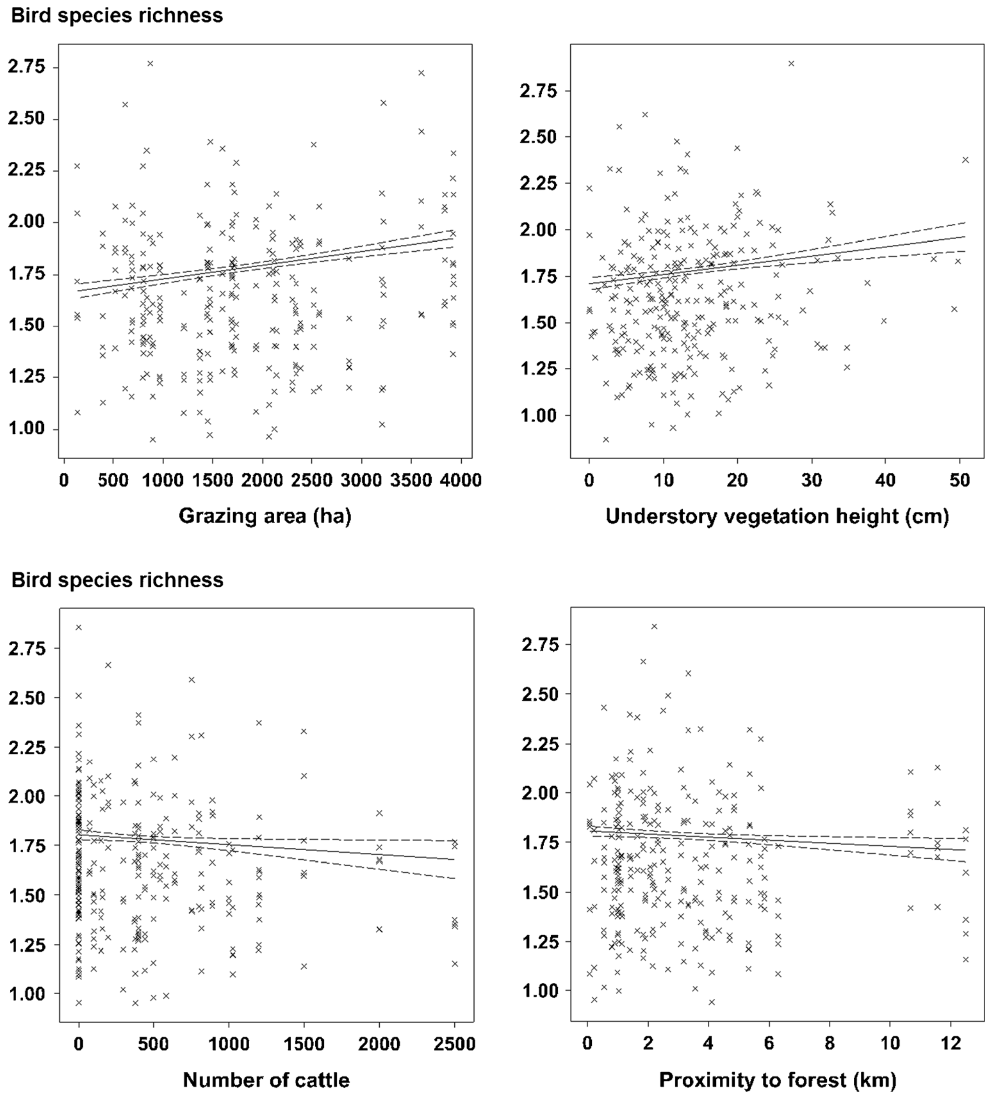

Fig. 4 Scatter plots showing relationships between bird species richness and abundance, and key management and landscape-level attributes of 45 oil palm plantations across Peninsular Malaysia. The attributes had significant effects on bird species richness and abundance. Scatter plots have 95% confidence intervals (dashed) on the regression (solid) line

grazing system. Rotational grazing which is similar to targeted grazing could be used to restore habitat heterogeneity (Sandercock et al. 2015).

Our study highlighted the detrimental effects of overgrazing, indicated by the larger number of cattle used in unsystematic grazed plantations and low understory vegetation height. Both bird species richness and abundance decreased with increasing cattle stocking density. Overgrazing by cattle has been found to modify vegetation structure through reducing foliage density, sward cover, vegetation diversity, and wild animal abundance (Negro et al. 2011; Dittmar et al. 2014). This implies that less free-range and more tightly-managed grazing such as systematic grazing is imperative to control understory vegetation in oil palm plantations without negative impacts on the environment, such as soil compaction (Launchbaugh et al. 2006).

3.7 Socioeconomic benefits

Integrating livestock grazing into understory vegetation (weed) control management in oil palm plantations has been found to benefit palm oil farmers in reducing labor costs by up to 50% per hectare per year, reducing herbicide spraying costs by 30–50%, increasing oil palm fresh bunch yields by 6–30%, lowering usage of chemical fertilizers, and improvement of soil structure through the addition of organic matter to the soil (Lam et al. 2009). Crowder and Jabbour (2013) suggested adopting crop and livestock integration to overcome negative environmental impacts from modern agriculture, such as nitrogen leaching, poor soil quality, and manure management. Managing oil palm plantations as integrated livestock-crop systems justifies the environmental sustainability of palm oil production while promoting food security initiatives (Lam et al. 2009).

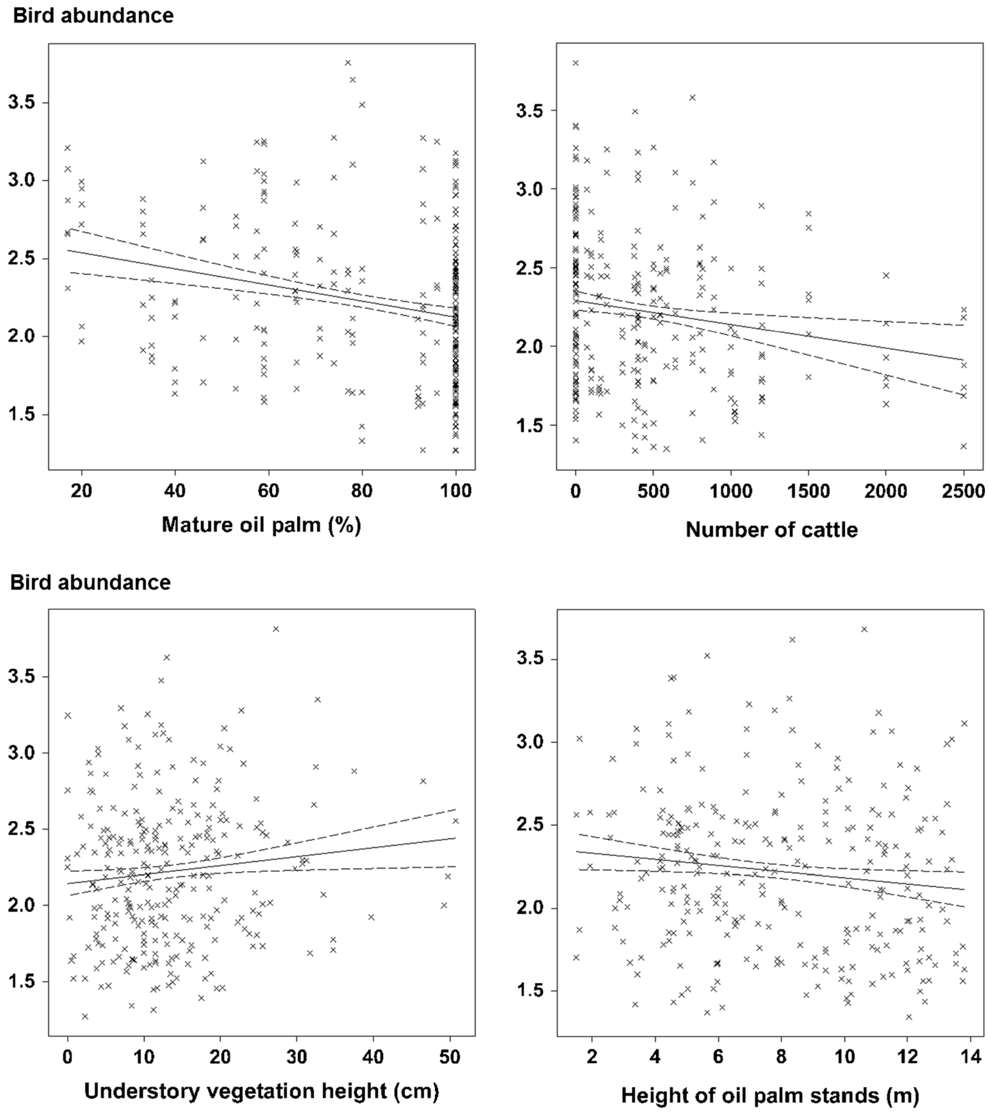

Fig. 4 (continued)

It is more costly to control weeds chemically in non-systematically grazed plantations compared to the control because some areas in non-systematically grazed plantations were overgrown with understory vegetation that require the use of large amount of herbicides. In non-systematically grazed plantations, the plantation management may spray herbicides on areas that are already grazed by cattle because of a lack of (or absence of) coordination between plantation management and cattle farming. These factors may inflate the cost of herbicides in non-systematically grazed plantations.

3.8 Future research directions for applying targeted grazing in oil palm agriculture

New studies on targeted grazing should be trialed in oil palm plantations. Aspects of targeted grazing including the use of different domestic species (e.g., goats, sheep, or mixed species grazing), foraging behavior (e.g., grazer, browser, or both), timing of grazing, and the interaction of these aspects of targeted grazing and the age of an oil palm stand, are the knowledge gaps that need to be filled in order to understand and refine this biological control method. "Before-After-Control-Impact" (BACI) design can be used to measure the efficacy of this biocontrol method. Furthermore, different animal indicators can be used to examine the ecological effect of targeted grazing on biodiversity in oil palm plantations, including various fauna and flora (Slade et al. 2014; Zamri-Saad and Azhar 2015).

4 Conclusions

Our findings suggest that targeted cattle grazing can be instrumental for improving biodiversity conservation in conventional oil palm agriculture. Targeted grazing can be used to accomplish vegetation management goals (e.g., lowered costs for management weed control) (Frost et al. 2012). To obtain the desired outcomes from livestock integration activity to bird diversity, livestock grazing integration within oil palm plantation must be conducted systematically. Payne (1985) has highlighted that the introduction of cattle into plantations appears to be an economic method of controlling the weeds that is compatible with biodiversity conservation (Jambari et al. 2012; Zamri-Saad and Azhar 2015). Targeted grazing is not suitable in immature oil palm stands less than 5 years old, as crops may become damaged by livestock. However, targeted grazing would reduce the use of herbicides from 75 sprayings in the typical plantation cycle down to 15 sprayings. At a global scale, targeted grazing is likely to be practical under field conditions in major palm oil producing countries (e.g., Indonesia, Malaysia, Brazil, Colombia, Ecuador, Thailand, and Papua New Guinea) which are located in the tropics with significant levels of biodiversity.

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