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Promoting landscape heterogeneity to improve the biodiversity benefits of certified palm oil production: Evidence from Peninsular Malaysia

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ABSTRACT

The Roundtable on Sustainable Palm Oil (RSPO) is responsible for the certification of palm oil producers that comply with sustainability standards. However, it is not known whether RSPO-certified plantations are effective in maintaining biodiversity. Focusing on Peninsular Malaysia, we show that both RSPO-certified plantations and uncertified large-scale plantations are characterized by very low levels of landscape heterogeneity. By contrast, heterogeneity measures were many times higher in palm oil producing smallholdings, despite their lack of RSPO certification. The low heterogeneity of large-scale oil palm plantations, including those certified by the RSPO, is likely to severely limit their value for biodiversity conservation. Uncertified smallholdings, in contrast, are much more heterogeneous and therefore hold substantially greater promise for the integration of palm oil production and biodiversity conservation than large-scale plantations. With oil palm agriculture further expanding, certification schemes should mandate producers to improve biodiversity conservation through landscape management that promotes greater landscape heterogeneity.

1. Introduction

Oil palm agriculture has been controversial because of the global conversion of vast areas of natural tropical rainforests to oil palm monocultures (Donald, 2004; Fitzherbert et al., 2008; Danielsen et al., 2009; Wilcove and Koh, 2010; Sayer et al., 2012). Industrial oil palm expansion has caused tremendous loss of biodiversity and habitat destruction in the tropics (Immerzeel et al., 2014). Existing oil palm plantations are known to maintain few species compared to native forests (Koh, 2008; Edwards et al., 2010; Fayle et al., 2010; Azhar et al., 2011). Large-scale oil palm agriculture is growing rapidly in biodiversity-rich, but poverty-stricken rural regions of the Amazon, Equatorial Africa, and Southeast Asia. Many areas of natural rainforests are now surrounded by oil palm monocultures. Most large-scale oil palm plantations consist of a single commodity crop, and the oil palm matrix can exert multiple pressures (e.g. poaching, encroachment and forest fire) on the remaining natural forest patches (Harvey et al., 2008).

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The palm oil industry has been heavily criticized by environmental NGOs for causing massive deforestation and unprecedented biodiversity loss in the tropics (Tan et al., 2009). In response, in 2004, oil palm stakeholders established the Roundtable on Sustainable Palm Oil (RSPO). The RSPO aims to improve environmental performance of producers and users of palm oil (Laurance et al., 2010). In spite of heavy criticism from environmental NGOs, the RSPO is widely accepted to be one of very few effective multi-stakeholder initiatives aiming to reconcile oil palm production and environmental conservation (Wilcove and Koh, 2010; Schouten and Glasbergen, 2011). With a growing membership already exceeding 800 certified manufacturers, retailers and growers, GreenPalm, the sustainable palm oil certificate-trading programme, has traded eleven million certificates, and RSPO-certified palm growers have collectively earned premiums of over US$73 million over the past six years (Roundtable on Sustainable Palm Oil, 2014).

At present, the RSPO has implemented 39 sustainability criteria, organized under eight general principles, which are designed to limit environmental and social impacts of growing and processing palm oil (Laurance et al., 2010; Roundtable on Sustainable Palm Oil, 2013). Surprisingly, the RSPO has sidelined landscape heterogeneity in its criteria. One principle emphasizes 'environmental responsibility and conservation of natural resources and biodiversity'. The criteria associated with this principle focus on issues such as reducing pesticide impacts, air pollution, and biodiversity loss, as well as on social and legal concerns. With respect to biodiversity conservation, the RSPO has rightly stressed the importance of areas that contain High Conservation Value (HCV) biodiversity features. Biodiversity features are assumed to be present if there are natural forest patches in or around the plantation, or if the plantation contains or shares borders with other natural habitats. However, relatively few plantations abut or contain natural forest patches, and where they do, plantation stakeholders may lack both the legal mandate and the necessary technical expertise to effectively manage such patches. Moreover, the potential function of the oil palm matrix in biodiversity conservation has been largely overlooked by stakeholders. Evidence from farmland around the world strongly suggests that the heterogeneity of farmland is a highly influential driver of biodiversity (Benton et al., 2003; Bennett et al., 2006; Karp et al., 2012). Oil palm plantations that are structurally complex at local-scale, particularly in the understory, may increase biodiversity (Aratrakorn et al., 2006; Azhar et al., 2011; Nájera and Simonetti, 2010). By contrast, large, homogeneous (e.g. equal stand age) areas of oil palm monocultures are particularly likely to be detrimental to *in-situ* biodiversity conservation and to species movements.

In Southeast Asia, exotic oil palm crops are commercially planted either in large-scale plantations or in smallholdings (area < 50 ha) (Lee et al., 2013; Azhar et al., 2014). Palm oil produced in smallholdings has been shown to be generally more environmentally friendly than palm oil grown in large-scale plantations (Azhar et al., 2011; Lee et al., 2013; Azhar et al., 2014)—with very few exceptions, e.g. potentially higher poaching rates (Azhar et al., 2013). However, it is unknown whether RSPO-certified plantations are actually more biodiversity-friendly than non-certified planted areas (including large-scale plantations as well as smallholdings) (Savilaakso et al., 2014). If oil palm landscapes are to be included as part of comprehensive conservation strategies, it is essential to understand what landscape characteristics are associated with different types of oil palm management, and how landscapes can be designed for better conservation outcomes (Harvey et al., 2008).

In this study, we predicted that smallholdings would be characterized by higher landscape heterogeneity, improving their likely benefits for biodiversity, than large-scale plantations, irrespective of their certification status. We distinguished between compositional heterogeneity, defined as the number of different elements present and their relative proportions (Bennett et al., 2006), and configurational heterogeneity, defined as the spatial pattern of patches (Fahrig et al., 2011). We proposed three hypotheses: (1) that compositional landscape heterogeneity represented by the number of different types of patches in oil palm smallholdings is higher than that in large-scale RSPO-certified and uncertified plantations; (2) that configurational landscape heterogeneity in oil palm smallholdings is higher than that in RSPO-certified and uncertified large-scale plantations, corresponding to a smaller mean patch size in smallholdings; and (3) that edge density for the uncertified smallholdings is greater than in RSPO-certified and uncertified large-scale plantations.

2. Materials and methods

2.1. Site selection

To identify potential study landscapes, we used Google Earth (GE) Pro to select 210 landscapes in the states of Negeri Sembilan, Selangor, and Perak on the west coast of Peninsular Malaysia (between 4° 7′ 17.28″N, 100° 44′ 22.29″E and 2° 36′ 33.73″N, 101° 48′ 48.16″E) (Fig. 1). Landscapes were randomly identified on GE images, and the latitude and longitude coordinates of the centre of the sampled landscape were specified. Each landscape was a circular plot with a 1 km diameter (Fahrig et al., 2011). Seventy spatial replicates were sampled for each of RSPO-plantations, uncertified large-scale plantations, and uncertified smallholdings. We used the RSPO online database http://www.rspo.org/en/rspo_members to determine the membership status of private businesses that were managing the plantations. The replicates did not include riparian habitats and forest patches. Such exclusions were taken in order to consider plantations established before the onset of RSPO certification scheme. These plantations are unlikely to retain natural areas and therefore have low heterogeneity, even if these plantations have subsequently become RSPO-certified. In addition, we are aware of the spill over effect from these natural areas on farmland biodiversity (Gilroy et al., 2014; Lucey and Hill, 2012). Consistent with widely used standards in the social sciences, the identity of plantation and smallholding operators is kept anonymous in this study.

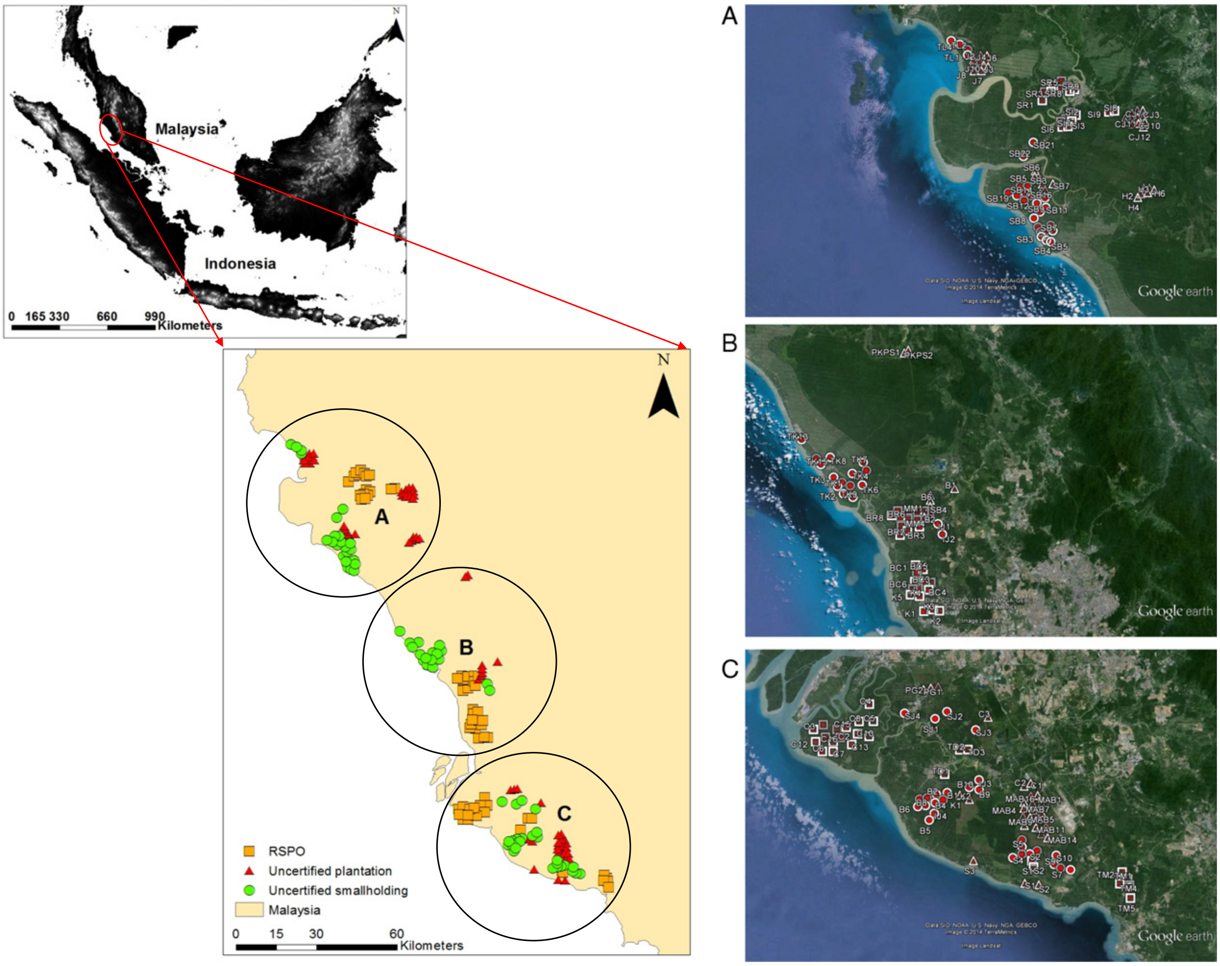

Fig. 1. Map of study sites. A total of 210 sites were sampled for landscape metrics on the west coast of Peninsular Malaysia. Symmetrical design was used to study oil palm landscapes ($n = 70$ for each treatment level). These landscapes were subjected to three management systems, namely RSPO-certified plantation (square), uncertified large-scale plantation (triangle), and uncertified smallholding (circle).

2.2. Plantation and smallholding management characteristics

Large-scale plantations were defined as oil palm landscapes that covered more than 50 ha of oil palm monoculture each and were operated by companies (Azhar et al., 2011). Plantations are predominantly planted with oil palms. Intercropping practice is very rare in the plantations. The use of agrochemicals (e.g. fertilizers and pesticides) is common in plantations to sustain crop productivity. Oil palm plants are systematically planted on large planting blocks. The planting density is usually standardized (140 plants per ha). Plantation management (e.g. harvesting) is supported by both manual work and modern machinery. The perimeters of plantations are typically fenced and trenched, and guarded by security staff to deter theft of oil palm fruit.

We defined smallholdings as semi-traditional cultivation areas covering less than 50 ha that are owned by individual farmers. Because of that, each smallholding is subjected to different management characteristics (e.g. weeding, fertilizer application, replanting and harvesting). Unlike large-scale plantations, smallholdings are less dependent on modern infrastructure, and fruit is manually harvested rather than by machinery. Smallholdings typically support multiple-age stands of oil palms that are intercropped with other commercial plants (e.g. bananas, cassavas, coffee, pineapples, or indigenous fruit trees) (Amoah et al., 1995). Old oil palm plants in smallholdings are not always clear-cut at the end of productive cycle (25–30 years), unlike in large-scale plantations. Similar to large-scale oil palm plantations, harvesting of oil palm fruit usually takes place every two weeks in smallholdings.

2.3. Measurement of landscape metrics

We measured the patch area and edge length of each patch. Patches of habitat were classified by their vegetation characteristics, defined floristically or structurally (Bennett et al., 2006). These habitat patches were characterized by

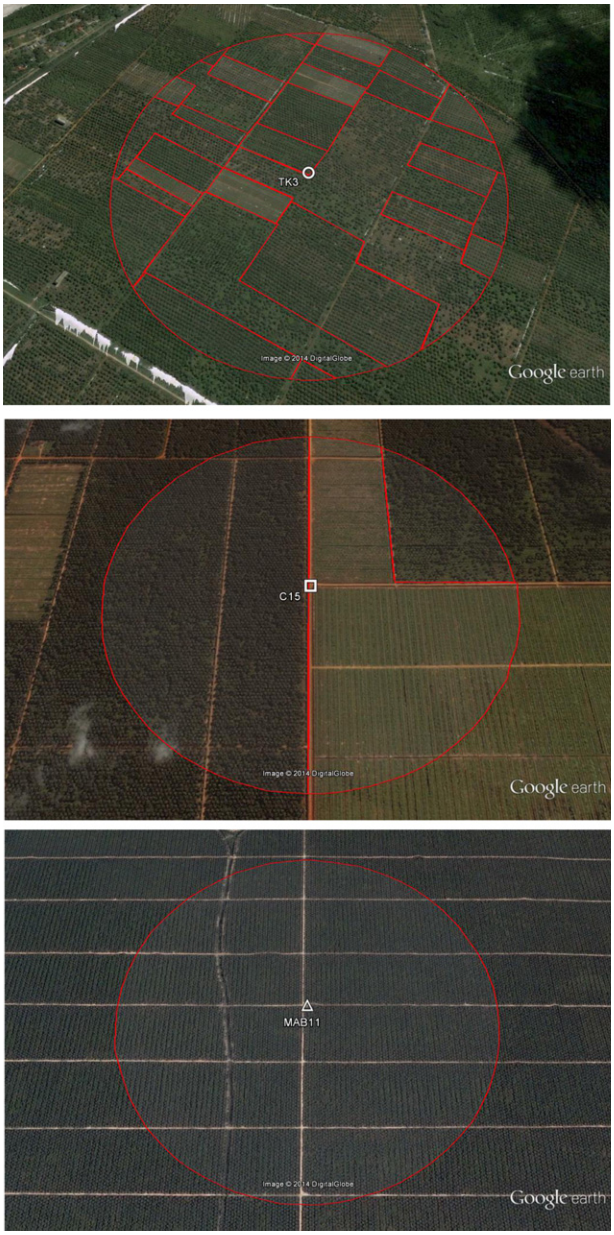

Fig. 2. Different oil palm management systems characterized by unique landscape metrics. Landscape metrics were quantified on GE images gathered from 210 landscapes (the circle illustrated is 1 km in diameter) randomly sampled in oil palm landscapes. Uncertified smallholdings were characterized by high numbers of patches and small patch areas (Top). RSPO-certified plantations (Middle) had a similarly low number of large patches and low edge density as uncertified large-scale plantations (Bottom).

different oil palm age categories, namely young (<5 years), mature (5–15 years), and old (>15 years) (Härdter et al., 1997). The larger landscape context around each sampled site was examined by navigating (e.g. zoom, rotate, tilt) within Google Earth (GE) Pro (Clark and Aide, 2011). To differentiate compositional cover types, such as various oil palm stand ages and other crop plants or non-crop plants, we interpreted the images visually based on geometrical shape, size, colour, context, and pattern (Horning et al., 2010). We detected oil palm crown based on its unique "star fish" shape (6–7 fronds) and green colour. To delineate different cover types, we used the polygon function in GE Pro. We also measured potential confounding factors, namely distance to coast and elevation at each site. Unfortunately, we could not collect time of forest conversion because it was impossible to obtain accurate historical records from stakeholders.

The GE technology has some advantages for mapping specific land use/cover types with good spatial characteristics (Yu and Gong, 2012; Hu et al., 2013). The GE images, acquired between 1 June and 4 September 2014, have a spatial resolution of 15 m per pixel and as high as 0.6 m per pixel at some locations (Landsat; http://landsat.usgs.gov) (Potere, 2008). A total of

142 sites were visited for verification (60 sites were smallholdings, 49 sites were uncertified plantations, and 33 sites were RSPO-certified plantations) between January and September 2014. These sites were georeferenced in order to visualize them on GE images.

We used the historical imagery function to identify patches of different oil palm stand ages. To avoid images with high level of cloud cover, we also used the historical imagery feature in visual interpretation. This feature allowed us to browse imagery from different years for selected locations. All locations were provided with a minimum of three images of different dates, and image spatial resolution generally improved over time (Visser et al., 2014). Dates of the imagery provided by GE were between 2006 and 2012. The size area of each replicate or the sampled landscape unit was 79.41 ha with a perimeter of 3.12 km (Fig. 2). We then determined the total number of patches and computed the mean size of patches for each replicate (Leitao et al., 2006). To determine the edge density for each replicate, total edge was divided by total area. To deter sampling bias in visual interpretation, all sites were interpreted by an image analyst (B.A.) who is familiar with oil palm cultivation in the study area.

2.4. Data analysis

First, we counted the number of different patches within selected landscapes in the three management systems. Second, we calculated the mean patch size for each replicate. Third, we computed the edge density (i.e. total edge length was divided by total area) for each replicate. To test our hypotheses, we then used single factor analysis of covariance (ANCOVA) to compare the means of the landscape metrics (patch number, mean patch area and edge density) between RSPO-certified plantations and other management systems (Zar, 1999; Quinn and Keough, 2002). Oil palm management system was used as treatment effect. Covariates including distance to coast and elevation, which were not part of the main experimental design but may influence the dependent variables. This inclusion of covariates was undertaken to remove any potential bias of confounding variables and to reduce within-group error variance (Quinn and Keough, 2002). Variables were tested for normality (Shapiro–Wilk test) and homogeneity (Bartlett's test) to meet assumptions of statistical tests. We transformed patch number (square root), mean patch size ($\log_{10}(x + 1)$) edge density ($\log_{10}(x + 1)$), distance to coast ($\log_{10}(x + 1)$), and elevation ($\log_{10}(x + 1)$). Because there were three types of factors (i.e. management systems), specific comparison of means was implemented. Tukey's HSD test was used to determine the difference in group means between pairs of management system. We used Eta squared ($\eta^2 = SS_{effect}/SS_{total}$) to calculate effect size in the analyses. All statistical analyses were conducted in GenStat version 15 (VSN International, Hemel Hempstead, UK). We examined the spatial autocorrelation in residuals by calculating Global Moran's Index in the ArcGIS™ version 10.1 (ESRI). The P value was used to reject or accept the null hypothesis which states that the analysed attribute is randomly distributed among the features in the study area (Mitchell, 2005). We used inverse distance (nearby neighbouring features have a larger influence on the computations for a target feature than features that are far away) to compute Global Moran's Index. The distance method used was Euclidean distance (the straight-line distance between two points).

3. Results

We identified 157 patches in RSPO-certified plantations, 143 patches in uncertified large-scale plantations, and 3225 patches in uncertified smallholdings. To test our first hypothesis, we compared the number of patches between RSPO-certified plantations, uncertified large-scale plantations, and uncertified smallholdings. We found that the patch numbers varied significantly across management systems ($F_{2205} = 685.01$; $P < 0.001$). One of the covariates (distance to coast) significantly influenced the patch numbers ($F_{1205} = 26.85$; $P < 0.001$), with patch numbers being higher near the coast (coefficient ± S.E. $= -0.790 \pm 0.216$). Using Eta-squared, 62% of the total variance was accounted for by the main treatment effect. Post hoc comparisons using the Tukey's HSD test indicated that the number of patches for uncertified smallholdings (Mean = 41.62; 95% confidence interval = 38.44–44.93) was significantly higher than that in both RSPO-certified and uncertified plantations (Fig. 3). However, RSPO-certified plantations (Mean = 2.21; 95% confidence interval = 1.53–3.02) did not significantly differ from uncertified large-scale plantations (Mean = 2.38; 95% confidence interval = 1.67–3.23) in terms of the number of patches (Fig. 3). These results suggest that compositional heterogeneity was far greater in uncertified smallholdings than in RSPO-certified and uncertified large-scale plantations.

To test our second hypothesis, we compared mean patch size in RSPO-certified plantations, uncertified large-scale plantations, and uncertified smallholdings. Mean patch size differed significantly between management systems ($F_{2205} = 635.01$; $P < 0.001$). The mean patch size was related to distance to coast ($F_{1205} = 30.66$; $P < 0.001$). Mean patch size was greater farther away from the coast (coefficient ± S.E. $= 0.207 \pm 0.050$). The effect of management system accounted for 60% of the total variance. The mean patch size in uncertified smallholdings (Mean = 2.28 ha; 95% confidence interval = 1.88–2.75 ha) was significantly smaller than that in the RSPO-certified and uncertified large-scale plantations (Fig. 3), but again, RSPO-certified plantations (Mean = 38.81 ha; 95% confidence interval = 33.83–44.50 ha) did not differ significantly from uncertified large-scale plantations (Mean = 40.78 ha; 95% confidence interval = 35.56–46.75 ha) (Fig. 3).

Finally, in terms of edge density, the management systems also varied significantly ($F_{2205} = 766.17$; $P < 0.001$), with the effect of management system explaining 63% of the total variance. Distance to coast again had a significant effect on the edge density ($F_{1205} = 24.56$; $P < 0.001$). Near the coast, edge density was higher (coefficient ± S.E. $= -0.013 \pm 0.004$).

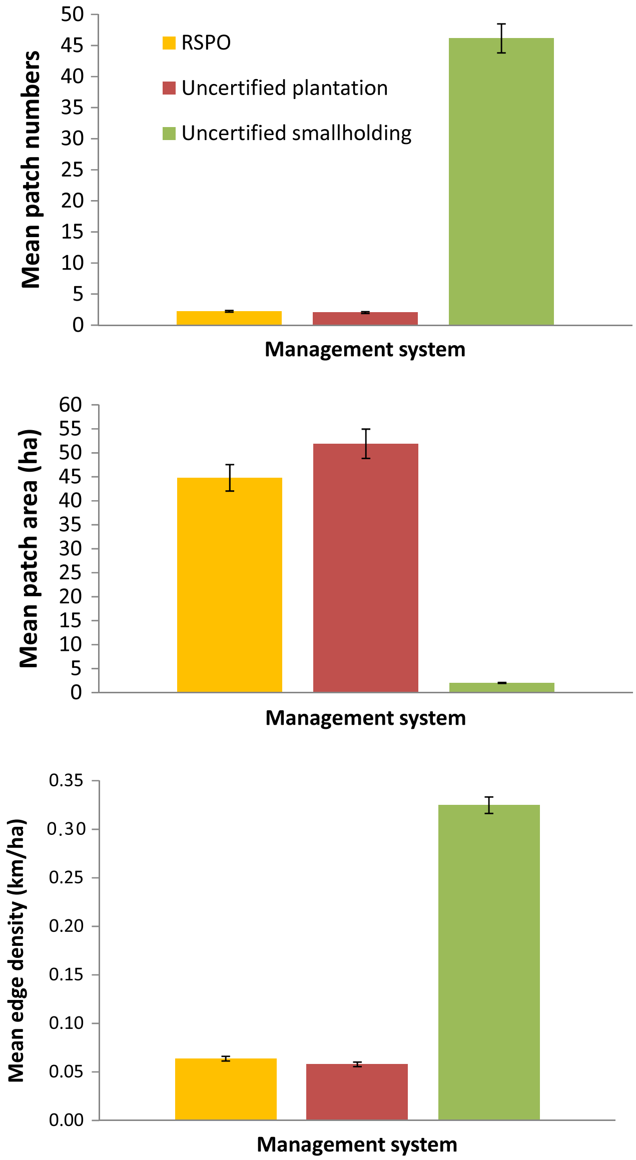

Fig. 3. Landscape heterogeneity in different oil palm management systems. All analyses were undertaken within circular landscapes with a 1 km diameter. The number of patches (representing compositional landscape heterogeneity) was greater in uncertified smallholdings than in RSPO-certified and uncertified large-scale plantations (Top). Configurational landscape heterogeneity was higher in smallholdings than in RSPO-certified and uncertified plantations. Mean patch areas in the RSPO-certified and uncertified large-scale plantations were higher than in uncertified smallholdings (Middle). Edge density for the uncertified smallholdings was higher in smallholdings than in RSPO-certified and uncertified large-scale plantations (Bottom). Error bars represent 95% confidence intervals.

Edge density for uncertified smallholdings (Mean = 0.31 km/ha; 95% confidence interval = 0.30–0.33 km/ha) was significantly greater than that in the two plantation management systems (Fig. 3), but there was no difference in edge density between the uncertified large-scale plantations (Mean = 0.06 km/ha; 95% confidence interval = 0.05–0.07 km/ha) and RSPO-certified plantations (Mean = 0.06 km/ha; 95% confidence interval = 0.05 to 0.07 km/ha) (Fig. 3).

For all three hypotheses, we investigated the spatial distribution of residuals. In all cases, the spatial distribution of residuals was the result of random spatial process (patch size Moran's Index = 0.107; z-score = 0.158; $P = 0.875$; mean patch area Moran's Index = 0.049; z-score = 0.074; $P = 0.941$; edge density Moran's Index = 0.017; z-score = 0.031; $P = 0.975$).

4. Discussion

Our findings cast serious doubt on the "biodiversity-friendliness" of certified large-scale oil palm plantations, especially when compared with uncertified smallholdings. For all three indices, smallholdings exhibited vastly higher levels of landscape heterogeneity (Fig. 3). Landscape heterogeneity underpins the conservation of farmland biodiversity (Fahrig et al., 2011; Karp et al., 2012; Steckel et al., 2014). Other things being equal, structurally and floristically complex landscapes maintain more species than simple landscapes (Tscharntke et al., 2012).

A great number of animal species require two or more landscape elements to fulfil their biological needs (Forman and Godron, 1986). Moreover, landscape composition and configuration strongly influence the extent and ease of movement of many species among distinct habitats (Goodwin and Fahrig, 2002; Holzschuh et al., 2010). In oil palm agro-ecosystems, compositional and structural heterogeneity is closely related to the different ages of oil palm stands. Mature oil palm stands can support greater biodiversity than newly planted stands because of their more complex habitat structure, opportunities for undergrowth to develop, and perhaps a more suitable climate (Luskin and Potts, 2011). Hence, landscapes which retain some mature stands could have some conservation benefits (Sheldon et al., 2010).

Large-scale oil palm plantations require substantial resources to maximize palm oil yield per hectare, secure the best arable land, and maintain irrigation and other infrastructure. However, they are extremely uniform and lack landscape heterogeneity which is expected to reduce biodiversity (Foster et al., 2011; Karp et al., 2012). Previous studies have indicated that landscape heterogeneity is necessary to improve biodiversity conservation in agricultural landscapes and hence, increasing the compositional heterogeneity of oil palm landscapes may result in greater biodiversity (Fahrig et al., 2011; Steckel et al., 2014)—for example because smaller field sizes with greater shape complexity will increase juxtaposition and resource accessibility (Fahrig et al., 2011). In the case of smallholdings with increasing landscape heterogeneity or patchiness, such settings may allow animals to exploit multiple resources (food and habitat) and to escape from hazardous agro-chemicals, predators, or fire.

Our findings imply that palm oil stakeholders, especially large-scale plantation operators, ought to enhance the heterogeneity of their estates at the landscape level. Landscape heterogeneity could be enhanced by diversifying patch types, including patches of different shapes and sizes, and by incorporating structurally and floristically complex vegetation. Although without doubt, HCV areas (e.g. natural forest patches) are of primary importance for biodiversity conservation, their value could be limited if they are embedded within an oil palm matrix that lacks heterogeneity. Heterogeneity is pivotal to facilitate animal movement between patches and to create diverse habitats suitable for various species. Landscape composition and configuration also determine trophic levels differently and may even be more important for biodiversity than local land-use intensity (Steckel et al., 2014).

Newly launched certification systems such as Indonesian Sustainable Palm Oil (ISPO) and Malaysian Sustainable Palm Oil (MSPO) should emphasize the importance of landscape heterogeneity in large-scale plantations. Consideration of landscape heterogeneity is lacking from existing certification schemes, but is likely to be key for successful biodiversity conservation in the context of a "land sharing" strategy (*sensu* Phalan et al., 2011 and Gilroy et al., 2014). Notably, we do not argue that improving landscape heterogeneity ought to be done at the expense of "land sparing" of natural forests (*sensu* Phalan et al., 2011). Rather, improving landscape heterogeneity could usefully complement conventional approaches such as the creation of natural forest patches within oil palm landscapes, and the protection of larger areas of forest from oil palm conversion.

In Peninsular Malaysia, our recommendation is cost-effective because the net incomes per hectare gained by large-scale plantations (MYR1276 per hectare) and smallholdings (MYR1211 per hectare) were similar (Ismail et al., 2003). However, it is important to bear in mind possible negative economic implications of our recommendation to increase stand age heterogeneity in the landscape. In other oil palm regions, smallholder management systems may result in much lower yields than large-scale plantations. Management recommendations which greatly reduce profits per hectare may, in turn, require more land in which to meet the same economic outputs—which would put further pressure on forests which are most important for conserving biodiversity.

In contrast to large-scale plantations, from a heterogeneity perspective, it is highly likely that smallholdings will be much better at maintaining biodiversity. Notably, landscape heterogeneity in uncertified smallholdings is providing benefits for farmland biodiversity although smallholdings are managed independently, without any certification standards, monitoring or external financial incentives. The extreme landscape homogeneity prevalent in both RSPO-certified plantations and uncertified plantations is likely to be disadvantageous to biodiversity. By contrast, the potential conservation value of smallholdings deserves serious attention from palm oil consumers and other stakeholders. Smallholdings could provide a high quality and heterogeneous matrix. Given their likely greater contribution to biodiversity conservation, small-scale oil palm farmers arguably deserve premium prices more so than the operators of certified large-scale plantations. A similar argument is now widely accepted for certified coffee and cacao production (Perfecto et al., 2005; Bisseleua et al., 2009), but to date has received very little attention by researchers in the oil palm sector.

5. Conclusions and recommendations

We acknowledge that palm oil production in smallholdings is not a panacea. For example, to safeguard fauna in smallholdings, it may be necessary to more actively control illegal hunting (Azhar et al., 2013). Moreover, our study indirectly suggests that most smallholders in Peninsular Malaysia are not currently certified by the RSPO scheme. Possible explanations could be that the certification cost might be prohibitively high for independent smallholders (FoodNavigator, 2014), or that the process of certification is too complicated. Smallholders account for as much as 33% of the output in Indonesia and Malaysia, two of the world's largest oil palm producers (Roundtable on Sustainable Palm Oil, 2014). In Malaysia alone, there were 87,717 independent smallholders managing 320,836 ha of oil palm production area in 2001 (Ismail et al., 2003). Given the prominence of smallholders, greater efforts to involve them in existing and new certification schemes including options for financial incentives seem justified.

Finally, an important caveat of our study is that we did not quantify species diversity within the landscapes whose heterogeneity we measured. As such, we cannot prove unambiguously that heterogeneity actually benefits biodiversity in our study landscapes. However, our interpretation of landscape homogenization having likely negative consequences for biodiversity is firmly grounded in a wide range of previous studies on farmland biodiversity (Fahrig et al., 2011; Karp et al., 2012; Steckel et al., 2014). We recommend that future research in palm oil landscapes include biodiversity assessments at the landscape scale. In the meantime, we suggest it is reasonable to err on the side of existing evidence from elsewhere—which suggests that considering landscape heterogeneity ought to be given higher priority in palm oil certification schemes.

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