Mammalian Biology 94 (2019) 48–53

Contents lists available at ScienceDirect

Mammalian Biology

journal homepage: www.elsevier.com/locate/mambio

Original investigation

The effect of oil palm agricultural expansion on group size of long-tailed macaques (*Macaca fascicularis*) in Peninsular Malaysia

Sze Ling Tee[a], Ahmad Solihhin[a], Shahidin A. Juffiry[a], Tengku Rinalfi Putra[b], Alex M. Lechner[c], Badrul Azhar[a,d,*]

[a] *Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[b] *Faculty of Veterinary, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[c] *School of Environmental and Geographical Sciences, University of Nottingham Malaysia Campus, 43500 Semenyih, Selangor, Malaysia*
[d] *Biodiversity Unit, Institute of Bioscience, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

ARTICLE INFO

Article history:
Received 22 March 2017
Accepted 17 December 2018
Available online 18 December 2018

Handled by Jan Okrouhlik

Keywords:
Oil palm
Large-scale plantation
Logged forest
Long-tailed macaque
Smallholdings
Unlogged forest

ABSTRACT

Large-scale expansion of oil palm (*Elaeis guineensis*) monocultures across Southeast Asia are creating ecosystems with homogenous habitats with low species diversity. However, heterogeneity varies between oil palm smallholdings and large-scale plantations, with greater habitat heterogeneity found on smallholdings. To date, there has been a paucity of field research on primate species, particularly macaques in oil palm plantations. In this study, we investigate the group size of long-tailed macaques (*Macaca fascicularis*) in four habitat types: unlogged forest, logged forest, large-scale oil palm plantations, and smallholdings. Field censuses were conducted in 2015 and 2016 to determine the group size of *M. fascicularis* in large-scale oil palm plantations and oil palm smallholdings. These data from oil palm plantations were compared to surveys conducted on a logged lowland forest reserve and a previous study in an unlogged lowland forest. We found that group size of *M. fascicularis* in large-scale plantations was lower compared to smallholdings, logged forest and unlogged forest. The chi-square test showed that the age class (juvenile or adult) of *M. fascicularis* was associated with farming systems. The paper concludes that the expansion of large-scale oil palm monocultures should be limited because of its adverse impacts on biodiversity including common species such as *M. fascicularis*.

Introduction

Tropical rainforest landscapes are home to a diverse range of flora and fauna, however, habitat loss and fragmentation are leading to massive biodiversity losses, largely from agricultural expansion (Laurance et al., 2002; Anderson et al., 2007; Koh and Wilcove, 2008; Bernard et al., 2009; Wilcove and Koh, 2010; Adila et al., 2017; Tee et al., 2018). In tropical South-east Asia, oil palm agriculture is one of the main drivers of deforestation (Fitzherbert et al., 2008; Yaap et al., 2010; Linder, 2013; Linder and Palkovitz, 2016), degrading its biodiversity-rich landscapes (Fitzherbert et al., 2008; Koh and Wilcove, 2008; Azhar et al., 2011; Linder, 2013; Gallmetzer and Schulze, 2015). The remaining wildlife is found in fragmented and low-quality habitats, leaving species at risk of extinction (Bernstein et al., 1976; Anderson et al., 2007; Gallmetzer and Schulze, 2015) and forcing some species to modify their natural behaviours to survive (Yaap et al., 2010; Gumert et al., 2011; Sha and Hanya, 2013a; Ancrenaz et al., 2015).

Biodiversity loss in South-east Asian oil palm production landscapes is a major concern (Koh and Wilcove, 2008; Azhar et al., 2011, 2017; Linder et al., 2013) with monoculture oil palm plantations characterised by low-quality and species-poor habitats, which sustain a small number of ẅinneršpecies (Smart et al., 2006). A ẅinneršpecies is a geographically widespread species that is an ecological generalist, characterized by omnivory, high population growth rates and the ability to thrive in human-modified landscapes (Smart et al., 2006; Hoffmann and Sago, 2011; Tabarelli et al., 2012).

Research on the impacts of oil-palm plantations have been carried out on birds, amphibians, reptiles, and rodents, yet little attention has been given to primate species, especially monkeys which are often found utilitising plantations (Azhar et al., 2011; Gillespie et al., 2012; Azhar et al., 2014; Gallmetzer and Schulze, 2015). In particular, no research has been conducted on the impact of oil-palm plantations on the long-tailed or crab-eating

---

* Corresponding author at: Faculty of Forestry, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
E-mail address: b_azhar@upm.edu.my (B. Azhar).

https://doi.org/10.1016/j.mambio.2018.12.006
1616-5047/

Table 1
The summary of the study sites.

Location	Area (ha)	Status	Vegetation Type	Study Period	Reference
Krau Wildlife Reserve (3°42’53.33Ň, 102°15’50.76Ë)	60,394	Primary forest	Lowland evergreen dipterocarp. Poor in dipterocarps but rich in Leguminosae	July 1974 to January 1976	Aldrich-Blake (1980)
Ayer Hitam Forest Reserve (3° 1’9.76Ň, 101°38’38.25Ë)	1,176	Logged forest patch.	Lowland dipterocarp	July to December 2012	Current study
Tanjung Karang, Selangor (3°22’37.82Ň, 101°12’45.46Ë)	7,810	Oil palm smallholding operated by smallholders.	Either monoculture oil palm trees or polyculture (oil palm, *Musa sp.*, *Cocos nucifera*, *Manihot esculenta*, and fruits trees	July to August 2015	Current study
Bukit Pasir, Muar, Johor (2° 9’51.77Ň, 102°43’18.93Ë)	1,690	Large-scale oil palm plantation operated by RSPO-certified plantation company.	Monoculture oil palm trees	January to February 2016	Current study

macaque (*Macaca fascicularis*), a common, widespread primate found throughout Southeast Asia. Studies on *M. fascicularis* have been conducted on populations in Southeast Asia, India, Mauritius, and Micronesia (Poirier and Smith, 1974; Fittinghoff, 1978; Wheatley, 1978; Sussman and Tattersall, 1986; Malaivijitnond and Hamada, 2008; Sha et al., 2009; Narasimmarajan and Raghunathan, 2012; Riley et al., 2015) but none in oil palm plantations. Potentially the impact on primates may be less than on other species as forest-agriculture ecotone habitats found in oil plantation may provide alternative food sources (Riley, 2007). However, these habitats might be limited where vegetation is homogeneous as in large-scale oil palm plantations.

M. fascicularis inhabits a wide range of habitat types from undisturbed virgin forests to highly human-disturbed areas such as urban and agricultural landscapes (Wheatley, 1978). It is a generalist species that benefit from habitat disturbances (Richard et al., 1989; Malaivijitnond and Hamada, 2008; Gumert, 2011) and a well-known pest that raids crops and harasses the public in recreation areas (Richard et al., 1989; Riley, 2007; Eudey, 2008; Malaivijitnond and Hamada, 2008). Research on *M. fascicularis* is especially limited in Malaysia, however, there are some studies in forested and urban areas (Southwick and Cadigan, 1972; Aldrich-Blake, 1980; Karimullah and Anuar, 2012). In Peninsular Malaysia, there is only one study that has been conducted; in an unlogged forest at Kuala Lompat in the Krau Wildlife Reserve (Aldrich-Blake, 1980). *M. fascicularis* is listed as species of least concern in the IUCN Red List, while in Malaysia it is listed as protected, yet it is still illegally hunted.

This study examines the effects of large-scale oil palm plantation (OPP) on *M. fascicularis* populations. We contrasted differences in group size between large-scale OPP and oil palm smallholdings (OPS), logged forest, and unlogged forest. Previous studies have shown that large-scale OPP supports lower levels of biodiversity than OPS and native forests (Azhar et al., 2011, 2014). We predicted that large-scale OPP might support smaller *M. fascicularis* group sizes than OPS, logged and unlogged forests. We also investigated whether the various oil palm farming systems (large-scale OPP and OPS) affect the social organisation of *M. fascicularis*. Our study is important, as understanding *M. fascicularis* group sizes in oil palm production landscapes is pivotal in determining the ecological impacts brought on by large-scale OPPs on faunal biodiversity.

Material and methods

Study areas

Population surveys of *M. fascicularis* were conducted in three habitat types (Table 1) from 2012 to 2016 at: 1) large-scale OPP (Bukit Pasir, Muar, Johor), 2) OPS (Tanjung Karang, Selangor) and 3) logged forests (Ayer Hitam Forest Reserve, Selangor) on the west coast of Malaysia (Fig. 1). Data from these sites was compared to a baseline population survey of unlogged forests from a previous study at the Krau Wildlife Reserve (Kuala Lompat, Pahang) (Aldrich-Blake, 1980).

The study site at Bukit Pasir is a large-scale OPP operated by a major Roundtable on Sustainable Palm Oil (RSPO)-certified plantation with an area of 1690 ha (Table 1). The vegetation at the site was dominated by mature stands of oil palm trees (>5 years). The second site located at Tanjung Karang comprised OPS operated by local farmers with a total area of 7810 ha. Most of the farmers had farms of less than 50 ha and lived nearby their smallholdings. These farms were either oil palm trees monocultures or polyculture with oil palm trees integrated with cash crops (*Musa* sp., *Cocos nucifera*, *Manihot esculenta*, and other fruit trees). The area was formerly peat swamp forest and mangrove forest which was cleared in the 1950s. The third site, Ayer Hitam Forest Reserve (AHFR) is a logged lowland/hill dipterocarp forest patch which was selectively logged in the 1960s (Table 1). The final site in Kuala Lompat was located in the Krau Wildlife Reserve. The reserve is an unlogged lowland/hill dipterocarp forest that has not been subjected to commercial-scale logging (Table 1).

Sampling protocols

All population surveys were conducted using the total count method (Plumptre et al., 2013). This method was used because the surveyed areas were relatively small, the population size was small, and each group could be identified and separated from others. Alternative methods such as the line transect method were not used as only small sample counts would be obtained, making it difficult to extrapolate the population size to larger areas, especially as long-tailed macaques are always moving making detection and identification of individuals uncertain (Riley et al., 2015).

The population surveys were conducted using census walks in the mornings from 0700 to1200. The surveys were conducted for six consecutive days every week in July to August 2015 (Tanjung Karang), January to February 2016 (Bukit Pasir) and July to December 2012 (Ayer Hitam Forest Reserve). Active searching (for a detailed description, see Plumptre et al., 2013) was used to locate and count *M. fascicularis* through direct sighting, movements, and vocalisations (Sha et al., 2009; Plumptre et al., 2013; Riley et al., 2015). To habituate *M. fascicularis*, only one or two observers, preferably the same people followed the macaque groups.

We observed *M. fascicularis* groups at a distance of 10–30 m to prevent scaring them. The Alpha male has the role of being a ẇatchdog̈(Aldrich-Blake, 1980) and is normally first sighted by the observer (Fig. 2). Once an individual was spotted, we recorded: 1) observed group size; 2) age class (juvenile or adult) and sex of each individuals based on physical appearance; and 3) GPS coordinates. Different groups of *M. fascicularis* were identified by their physical characteristics (e.g. general facial configuration, body size, hair colouring, and hair patterns) and the area where they were present

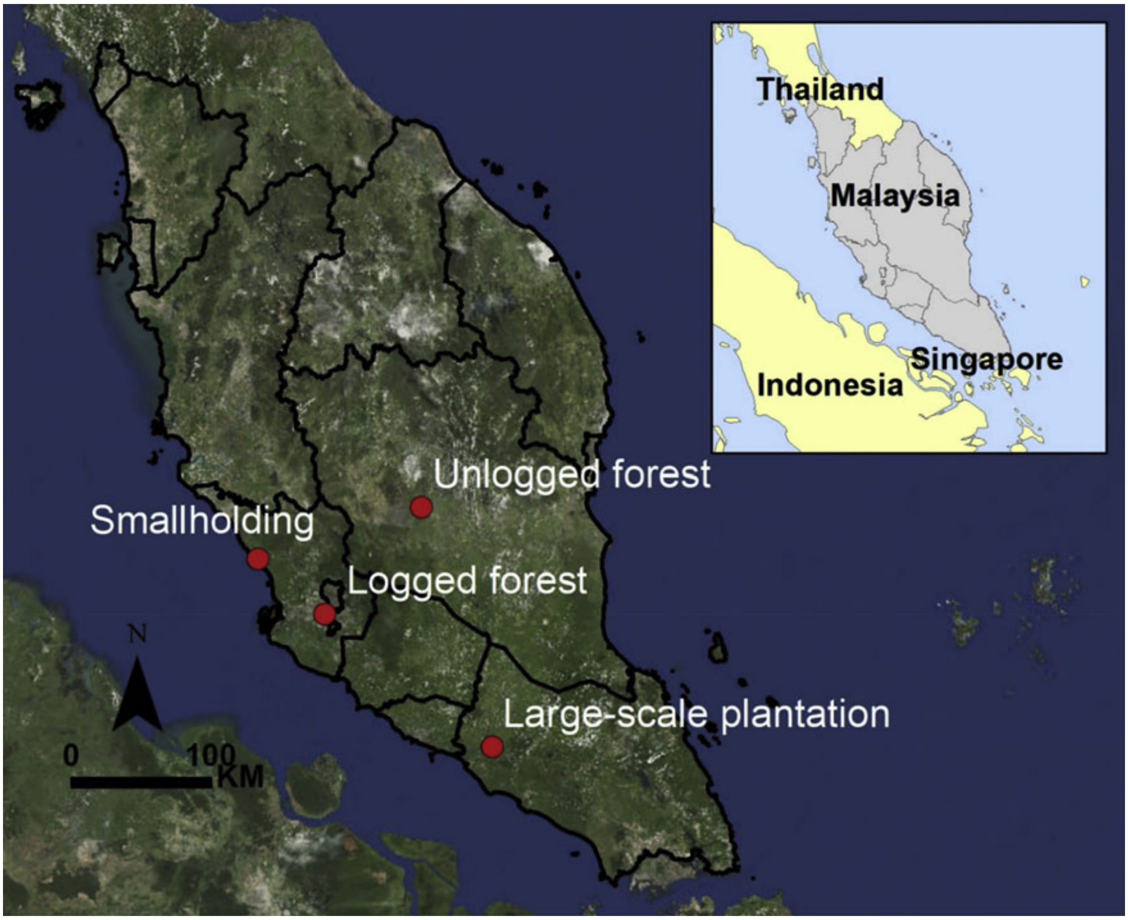

Fig. 1. Long-tailed macaques were studied in four types of habitat in Peninsular Malaysia. We surveyed large-scale oil palm plantation, smallholdings, and logged forest. Study in unlogged forest was conducted by Aldrich-Blake (1980).

Fig. 2. Long-tailed macaques were observed on mature oil palm plants that provide vantage point to monitor surrounding areas, but they would spend their time on the ground foraging for food.

(Swartz, 1983; Hamada et al., 2006). Although we managed to record the number of individuals for each group, the animal sex for populations at OPS and logged forests were not recorded due to the difficulty in identifying the genitals of *M. fascicularis* in those habitats.

Data analysis

The data collected was summarised and comparison tests performed in the IBM SPSS Statistics 20th Edition software. First, we used the Shapiro-Wilk test to determine whether the data were normally distributed. Prior to the test we used a square-root transformation of the count data (i.e. animal abundance) to improve the linearity of data. We then compared *M. fascicularis* mean group sizes between large-scale OPP, OPS, unlogged forest, and logged forest using a one-way ANOVA. In addition, we performed post-hoc Dunnett's T3 with a large-scale OPP as a control group to test for significant differences between habitat types. This post-hoc test did not assume equal variances.

A chi-square independence test was used to determine whether there was a significant association between oil palm farming systems (large-scale OPP and OPS) and age class (juvenile or adult) of *M. fascicularis*. Our research did not involve direct contact with *M. fascicularis* in the field. Fieldwork was conducted with permission from the Selangor forestry department, smallholders, and an anonymous plantation manager.

Results

Group size in large-scale OPP, OPS, logged forest and unlogged forest

A total of 13 groups of *M. fascicularis* comprising 98 individuals were recorded at the large-scale OPP (Table 2). There was also a higher juvenile abundance (59 individuals) compared to adults

Table 2
The number of observations and groups of *M. fascicularis* in large-scale OPP, OPS, logged forest and unlogged forest.

Habitat	Number of observations	Number of groups	Mean group size ± SD
Large-scale OPP	98	13	7.54 ± 3.80
OPS	298	18	16.56 ± 7.26
Logged Forest	69	4	17.25 ± 17.25
Unlogged Forest	61	4	15.25 ± 9.39

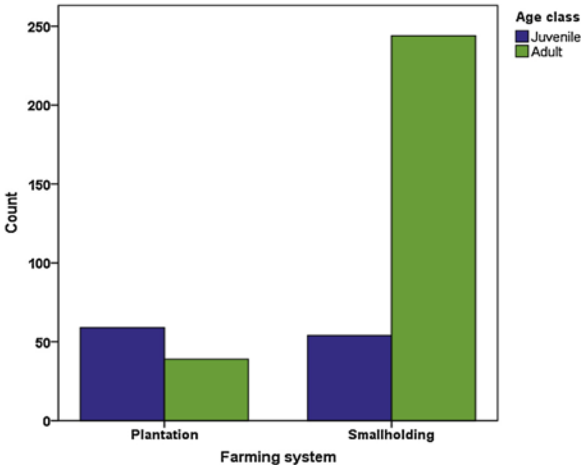

Fig. 3. The number of *M. fascicularis* observations according to age class in large-scale plantation and smallholding.

Table 3
Summary of mean comparison for *M. fascicularis* group size between large-scale OPP, logged forest and unlogged forest based on post-hoc Dunnet's T3.

Habitat type (I)	Habitat type (J)	Mean difference (I-J)	*p*
Large-scale OPP	Unlogged forest	−7.71	0.585
Large-scale OPP	Logged forest	−9.71	0.818
Large-scale OPP	OPS	−9.02	0.001

(39 individuals) (Fig. 3). The minimum group size was two individuals, while the maximum was 13 individuals. Eighteen and four groups of *M. fascicularis* were recorded at the OPS and logged forests respectively. A total of 298 individuals were recorded in OPS, while 69 individuals were recorded in the logged forest (Table 2).

The statistical analysis detected significant differences in *M. fascicularis* mean group sizes between different habitat types (F (3,35) = 3.659; $p =$ 0.021). A key result from our analysis was that *M. fascicularis* groups sizes at the large-scale OPP (median = 8; 1 st quartile - 3rd quartile: 4.5–10.5) were significantly lower (post-hoc Dunnett's T3, p = 0.001) than at the OPS (median = 15; 1 st quartile - 3rd quartile: 12–18) (Table 3). The comparison between the existing data describing unlogged forest and our surveyed data on logged forests found median group sizes of *M. fascicularis* were 17 (1 st quartile - 3rd quartile: 7.5–23) and 12 (1 st quartile - 3rd quartile: 4.5–30) individuals per group, respectively (Table 2).

Relationship between age class of M. fascicularis *and farming practice*

A chi-square test was performed and the age class (juvenile or adult) of *M. fascicularis* was found to be associated with the farming system (large-scale OPP and OPS), X^2 (df = 1, N = 396) = 64.046, $p <$ 0.001. The number of observations of juvenile *M. fascicularis* in large-scale OPP was greater compared to the OPS (Table 4; Fig. 3).

Table 4
Two-way contingency table summarizing the relationship between age class of *M. fascicularis* and different types of oil palm farming system.

Farming system	Age class		
	Juvenile	Adult	Total
Large-scale OPP	59 (52.2%)	39 (13.8%)	98 (24.7%)
OPS	54 (47.8%)	244 (86.2%)	298 (75.3%)
Total	113 (100%)	283 (100%)	396 (100%)

Finally, the number of observations of adult *M. fascicularis* in large-scale OPP was lower than the OPS (Table 4; Fig. 3).

Discussions

The group size of *M. fascicularis* in the large-scale OPP was notably lower than in habitats with greater heterogeneity. Although *M. fascicularis* has always been known as ẅeed speciesör ẅinnerẗhat can thrive in highly disturbed habitats, the current study does not support previous research (Richard et al., 1989; Gumert, 2011). A possible explanation for the lower number of observations of *M. fascicularis* in large-scale OPP is its lower habitat quality with a smaller range of vegetation types and lower food availability (Takasaki, 1981; Marshall, 2010). *M. fascicularis* population were more abundant in diverse, heterogeneous and resource-rich habitats such as OPS, logged and unlogged forest. In unlogged forests, *M. fascicularis* are primarily frugivorous and leaves, flowers, insects and bark provide the remainder of their diet (Yeager, 1996). *M. fascicularis* consume at least 33 plant species as food sources, but more than 60% of the diet is supplied by only five species in unlogged forests (Yeager, 1996). In contrast, *M. fascicularis* in highly disturbed human dominated habitats have been reported as using less forest habitats if they have access to anthropogenic food sources and were likely to spend less time feeding on natural fruits and flowers (Sha and Hanya, 2013a,2013b).

A critical finding of this research that has implications for managing oil palm plantations for biodiversity is that the mean group size of *M. fascicularis* in large-scale OPP was lower than at the OPS site. This is most likely because the monoculture practice used in large-scale OPP results in highly homogenous vegetation, primarily composed of oil palm, *Elaeis guineensis*. The homogenised environment in large-scale OPP has limited resources creating low-quality of habitat (Takasaki, 1981; Thierry et al., 2004) consequently leading to a lower mean group size of *M. fascicularis*. Homogenous vegetation not only limits food resources but also has been shown to limit the choice of sleeping sites for *M. fascicularis* (Kamarul et al., 2014). During the survey, we found that the largest group of *M. fascicularis* were in a shrubby area next to the large-scale OPP not in the actual oil palms. The main tree within this area that *M. fascicularis* group utilised was *Pometia pinnata*. *P. pinnata* may provide *M. fascicularis* shelter and food resource such as insects from flowers and leaves (Thomson and Thaman, 2006; Hadi et al., 2007). Another reasonable explanation for the low group sizes is anthropogenic intervention. Even though there was a banana farm next to the large-scale OPPs, no observations were recorded of *M. fascicularis* raiding the farm during the site survey. This is likely to be because banana farmers have set up traps or used firecrackers to prevent crop raiding by *M. fascicularis* (Eudey, 2008; Azhar et al., 2013).

Larger group sizes in OPS may be explained by the existence of farm houses, scattered within the smallholdings. Brotcorne et al. (2014) suggested that *M. fascicularis* preferentially select sleeping trees located within or near human-modified zones, especially when human food was abundant and natural food was scarce. Edible crops such as tapioca, banana, and coconut in OPS may support a greater level of biodiversity by providing alternative food resources and better habitat quality for *M. fascicularis* groups (Azhar et al., 2014, 2015). In contrast the housing areas associated with OPP were centralized at designated location at long distances from oil palm plantations. The possibility of anthropogenic threats in the large-scale OPP may also account for the lower observations of adult *M. fascicularis* compared to in OPS. Conflicts between pest species such as *M. fascicularis* and farming communities result in their extermination as the farmers become less tolerant of their crop-raiding behaviour (Azhar et al., 2013). Significant reduction of natural habitats such as forests, coupled with a dense and growing human population can exacerbate human-macaque conflict (Sha et al., 2009). However, the damage on oil palm yield caused by *M. fascicularis* is considered insignificant economically and hence no control is required in major plantations (Chung et al., 2016).

Our study also found higher mean group sizes of *M. fascicularis* in unlogged and logged forests compared to large-scale OPP, but surprisingly mean group size in OPS surpassed unlogged forest (Table 2). Natural or relatively undisturbed forest vegetation in the home range is essential to the subsistence of inhabiting monkeys (Takasaki, 1981). The unlogged Krau Wildlife Reserve have multiple food trees such as *Knema* sp. (Myristicaceae), *Eugenia* sp. (Myrtaceae), *Dialium* sp. (Leguminosae) and *Mangifera* sp. (Anacardiaceae) (Aldrich-Blake, 1980). *M. fascicularis* has been reported traveling from the forest into palm oil plantations to feed on palm nuts, however, such behaviour and movement are not supported by our study.

Our results indicated that *M. fascicularis* were thriving in the Ayer Hitam Forest Reserve and that the logged forest can provide adequate food sources for *M. fascicularis* especially from the human food wastes found in surrounding local residential areas (Mohd et al., 1999). This result matches those observed in earlier studies where *M. fascicularis* was abundant in the logged forest and occupied some habitats with the presence of human disturbances (Richard et al., 1989; Fuentes and Gamerl, 2005; Sha et al., 2009). The total individuals found in unlogged forest habitats were 61 from 4 groups, with the average group size of 15.25 individuals per group (Aldrich-Blake, 1980) and 352 individuals from 13 groups with 27.08 individuals per group (Karimullah and Anuar, 2012). *M. fascicularis* will adapt to human-driven changes in tropical forest habitats, characterized by the disappearance or decline of other species that compete with *M. fascicularis* for fruit (Gibson, 2011).

Competition between members within same group may also be one of the reasons for the lower observed adult abundance of *M. fascicularis* in large-scale OPP as food resources were limited in these homogenous habitats. The dominance hierarchy present in the *M. fascicularis* groups may result in competition between male *M. fascicularis* in seeking mates (Wheatley, 1978). The social hierarchy allows dominant ranking males to have higher reproductive success than the lower ranking males (Wheatley, 1978; Van Noordwijk and Van Schaik, 1985). Hence, the lower ranking males may leave their original group and migrate into adjacent groups including those located outside OPP (Wheatley, 1978; Van Noordwijk and Van Schaik, 1985).

One key limitation of our study is that each study site had different areas and a range of human pressures. Our estimations of group size may be conservative because we did not account the area of each study site. However, finding replicate sites of similar areas can be almost impossible due to the variability in sites and difficulty in obtain permission to conduct surveys.

Conclusions

Greater attention needs to be paid to *M. fascicularis* because the species is declining in some regions due to habitat modification and the animal trade (Eudey, 2008). Even though *M. fascicularis* is perceived to be common in human-modified landscapes, its group size was the lowest in large-scale OPP. The detrimental impacts brought by large-scale OPP are more severe than OPS. Hence, large-scale oil palm monocultures should be minimised as it causes adverse impacts on biodiversity including common species such as *M. fascicularis*. Agro-forestry practices can be applied in the large-scale OPP to minimise the human-wildlife conflicts (Bhagwat and Willis, 2008) by providing areas planted with fruit trees for *M. fascicularis*. The planting and propagation of mutually important tree species for the macaques and local people at forest-agricultural ecotones would curb crop raiding (Riley and Fuentes, 2011). Long-term studies should be encouraged to gather accurate data on *M. fascicularis* populations and other species. Such data is pivotal for developing a management plans for biodiversity in oil palm agricultural landscapes.

Acknowledgements

We thank Sim Poh Kang, Lim Chiew Teng, Chia Shu Ting, Chan Chien Chien, Lim Liyen, and Tee Zhun How for assisting in data collection in the field. We thank Adham Ashton-Butt for his insightful comments on the manuscript, as these comments led to significant improvements. We are grateful to the Faculty of Forestry, an anonymous plantation manager, and smallholders who gave us permission to conduct this research in the Ayer Hitam Forest Reserve and oil palm agricultural areas.

References

Adila, N., Sasidhran, S., Kamarudin, N., Puan, C.L., Azhar, B., Lindenmayer, D.B., 2017. Effects of peat swamp logging and agricultural expansion on species richness of native mammals in Peninsular Malaysia. Basic Appl. Ecol. 22, 1–10.

Aldrich-Blake, F.P.G., 1980. Long-tailed macaques. In: Chivers, D.J. (Ed.), Malayan Forest Primates: Ten Years' Study in Tropical Rain Forest. Plenum Press, New York, pp. 147–165.

Ancrenaz, M., Oram, F., Ambu, L., Lackman, I., Ahmad, E., Elahan, H., Kler, H., Abram, N.K., Meijaard, E., 2015. Of *Pongo*: palms and perceptions: a multidisciplinary assessment of Bornean orang-utans *Pongo pygmaeus* in oil palm context. Oryx 49, 465–472.

Anderson, J., Rowcliffe, J.M., Cowlishaw, G., 2007. Does the matrix matter? A forest primate in a complex agricultural landscape. Biol. Conserv. 135, 212–222.

Azhar, B., Lindenmayer, D.B., Wood, J., Fischer, J., Manning, A., McElhinny, C., Zakaria, M., 2011. The conservation value of oil palm plantation estates, smallholdings and logged peat swamp forest for birds. For. Ecol. Manage. 262, 2306–2315.

Azhar, B., Lindenmayer, D., Wood, J., Fischer, J., Manning, A., McElhinny, C., Zakaria, M., 2013. Contribution of illegal hunting, culling of pest species, road accidents and feral dogs to biodiversity loss in established oil-palm landscapes. Wildl. Res. 40, 1–9.

Azhar, B., Puan, C.L., Zakaria, M., Hassan, N., Arif, M., 2014. Effects of monoculture and polyculture practices in oil palm smallholdings on tropical farmland birds. Basic Appl. Ecol. 15, 336–346.

Azhar, B., Saadun, N., Puan, C.L., Kamarudin, N., Aziz, N., Nurhidayu, S., Fischer, J., 2015. Promoting landscape heterogeneity to improve the biodiversity benefits of certified palm oil production: evidence from Peninsular Malaysia. Glob. Ecol. Conserv. 3, 553–561.

Azhar, B., Saadun, N., Prideaux, M., Lindenmayer, D.B., 2017. The global palm oil sector must change to save biodiversity and improve food security in the tropics. J. Environ. Manage. 203, 457–466.

Bernard, H., Fjeldså, J., Mohamed, M., 2009. A case study on the effects of disturbance and conversion of tropical lowland rain forest on the non-valant small mammals in North Borneo: management implications. Mammal Study 34, 85–96.

Bernstein, I.S., Balcaen, P., Dresdale, L., Gouzoules, H., Kavanagh, M., Patterson, T., Neymann-Warner, P., 1976. Differential effects of forest fragmentation on primate populations. Primates 17, 401–411.

Bhagwat, S.A., Willis, K.J., 2008. Agroforestry as a solution to the oil-palm debate. Conserv. Biol. 22, 1368–1369.

Brotcorne, F., Maslarov, C., Wandia, I.N., Fuentes, A., Beudels-Jamar, R.C., Huynen, M.C., 2014. The role of anthropic, ecological, and social factors in sleeping site choice by long-tailed Macaques (*Macaca fascicularis*). Am. J. Primatol. 76, 1140–1150.

Chung, G.F., Lee, C.T., Chee, K.H., 2016. Pictorial Guide to Oil Palm Cultivation and Mammalian Pests. Agricultural Crop Trust, Malaysia.

Eudey, A.A., 2008. The crab-eating macaque (*Macaca fascicularis*): widespread and rapidly declining. Primate Conserv. 23, 129–132.

Fittinghoff, N.A., 1978. *Macaca fascicularis* of Eastern Borneo: Ecology, Demography, Social Behavior, and Social Organization in Relation to a Refuging Habitus. University Microfilms International, London.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielson, F., Brühl, C.A., Donald, P.F., Phalan, B., 2008. How will oil palm expansion affect biodiversity? Trends Ecol. Evol. 23, 538–545.

Fuentes, A., Gamerl, S., 2005. Disproportionate participation by age/sex classes in aggressive interactions between long-tailed macaques (*Macaca fascicularis*) and human tourists at Padangtegal monkey forest, Bali, Indonesia. Am. J. Primatol. 66, 197–204.

Gallmetzer, N., Schulze, C.H., 2015. Impact of oil palm agriculture on understory amphibians and reptiles: a Mesoamerican perspective. Glob. Ecol. Conserv. 4, 95–109.

Gibson, L., 2011. Possible shift in macaque trophic level following a century of biodiversity loss in Singapore. Primates 52, 217–220.

Gillespie, G.R., Ahmad, E., Elahan, B., Evans, A., Ancrenaz, M., Goossens, B., Scroggie, M.P., 2012. Conservation of amphibians in Borneo: relative value of secondary tropical forest and non-forest habitats. Biol. Conserv. 152, 136–144.

Gumert, M.D., 2011. The Common Monkey of Southeast Asia: Longtailed Macaque Populations, Ethnophoresy, and Their Occurrence in Human Environments. Monkeys on the Edge: Ecology and Management of Long-tailed Macaques and Their Interface With Humans. Cambridge University Press, New York, pp. 3–44.

Hadi, I., Suryobroto, B., Perwitasari-Farajallah, D., 2007. Food preference of semi provisioned macaques based on feeding duration and foraging party size. Hayati J. Biosci. 14, 13–17.

Hamada, Y., Urasopon, N., Hadi, I., Malaivijitnond, S., 2006. Body size and proportions and pelage color of free-ranging Macaca mulatta from a zone of hybridization in northeastern Thailand. Int. J. Primatol. 27, 497–513.

Hoffmann, A.A., Sgrò, C.M., 2011. Climate change and evolutionary adaptation. Nature 470, 479–485.

Kamarul, H., Ahmad, I., Badrul-Munir, M.Z., Syaizwan, Z., Aainaa, A., 2014. Ranging behavior of long-tailed macaques (*Macaca fascicularis*) at the entrance of Kuala Selangor Nature Park. Malays. Appl. Biol. 43, 129–142.

Karimullah, A.S., 2012. The dominant species of monkeys (*Macaca fascicularis*) in northern region of Peninsular Malaysia. Pak. J. Zool. 44, 1567–1574.

Koh, L.P., Wilcove, D.S., 2008. Is oil palm agriculture really destroying tropical biodiversity? Conserv. Lett. 1, 60–64.

Laurance, W.F., Lovejoy, T.E., Vasconcelos, H.L., Bruna, E.M., Didham, R.K., Stouffer, P.C., Gascon, C., Bierregaard, R.O., Laurance, S.G., Sampaio, E., 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. Conserv. Biol. 16, 605–618.

Linder, J.M., 2013. African primate diversity threatened by Ňew Waveöf industrial oil palm expansion. Afr. Primates 8, 25–38.

Linder, J.M., Palkovitz, R.E., 2016. The threat of industrial oil palm expansion to primates and their habitats. Ethnoprimatology, 21–45.

Malaivijitnond, S., Hamada, Y., 2008. Current situation and status of long-tailed macaques (*Macaca fascicularis*) in Thailand. Nat. Hist. 8, 185–204.

Marshall, A.J., 2010. Effect of habitat quality on primate populations in Kalimantan: gibbons and leaf monkeys as case studies. In: Indonesian Primates. Springer, New York, NY, pp. 157–177.

Mohd, A., Yaman, A.R., Jamaludin, M.A., 1999. Recreational opportunities for public use in Ayer Hitam forest: setting the stage and park management approach. Pertanika J. Trop. Agric. Sci. 22, 161–166.

Narasimmarajan, K., Raghunathan, C., 2012. Status of long-tailed macaque (*Macaca fascicularis*) and conservation of the recovery population in Great Nicobar Island, India. Wildl. Biol. Pract. 8, 1–8.

Plumptre, A.J., Sterling, E.J., Buckland, S.T., 2013. Primate census and survey techniques. In: Sterling, E.J., Bynum, N., Blair, M.E. (Eds.), Primate Ecology and Conservation: A Handbook of Techniques. Oxford University Press, Oxford, pp. 10–26.

Poirier, F.E., Smith, E.O., 1974. The crab-eating macaques (*Macaca fascicularis*) of Angaur Island, Palau, Indonesia. Folia Primatol. 22, 258–306.

Richard, A.F., Goldstein, S.J., Dewar, R.E., 1989. Weed macaques: the evolutionary implications of macaque feeding ecology. Int. J. Primatol. 10, 569.

Riley, C.M., 2007. The human-macaque interface: conservation implications of current and future overlap and conflict in Lore Lindu National Park, Sulawesi, Indonesia. Am. Anthropol. 9, 473–484.

Riley, E.P., Fuentes, A., 2011. Conserving social–ecological systems in Indonesia: human–nonhuman primate interconnections in Bali and Sulawesi. Am. J. Primatol. 73, 62–74.

Riley, C.M., Jayasri, S.L., Gumert, M.D., 2015. Results of a nationwide census of the long-tailed macaque (*Macaca fascicularis*) population of Singapore. Raffles Bull. Zool. 63, 503–515.

Sha, J.C.M., Gumert, M.D., Lee, B.P.Y.-H., Fuentes, A., Rajathurai, S., Chan, S., Jones-Engel, L., 2009. Status of long-tailed macaque *Macaca fascicularis* in Singapore and implications for management. Biodivers. Conserv. 18, 2909–2926.

Sha, J.C.M., Hanya, G., 2013a. Temporal food resource correlates to the behavior and ecology of food-enhanced long-tailed macaque (*Macaca fascicularis*). Mammal Study 38, 163–175.

Sha, J.C.M., Hanya, G., 2013b. Diet, activity, habitat use, and ranging of two neighboring groups of food-enhanced long-tailed macaques (*Macaca fascicularis*). Am. J. Primatol. 75, 581–592.

Smart, S.M., Thompson, K., Marrs, R.H., Duc, M.G.L., Maskell, L.C., Firbank, L.G., 2006. Biotic homogenization and changes in species diversity across human-modified ecosystems. Proc. R. Soc. Lond., B, Biol. Sci. 273, 2659–2665.

Southwick, C.H., Cadigan, F.C., 1972. Population studies of Malaysian primates. Primates 13, 1–18.

Sussman, R.W., Tattersall, L., 1986. Distribution, abundance, and putative ecological strategy of *Macaca fascicularis* on the Island of Mauritius, Southwestern Indian Ocean. Folia Primatol. 46, 28–43.

Swartz, K.B., 1983. Species discrimination in infant pig-tailed macques with pictorial stimuli. Dev. Psychobiol. 16, 219–231.

Tabarelli, M., Peres, C.A., Melo, F.P.L., 2012. The' few winners and many losers' paradigm revisited: emerging prospects for tropical forest biodiversity. Biol. Conserv. 155, 136–140.

Takasaki, H., 1981. Troop size, habitat quality, and home range area in Japanese macaques. Behav. Ecol. Sociobiol. 9, 277–281.

Tee, S.L., Samantha, L.D., Kamarudin, N., Akbar, Z., Lechner, A.M., Ashton-Butt, A., Azhar, B., 2018. Urban forest fragmentation impoverishes native mammalian biodiversity in the tropics. Ecol. Evol., http://dx.doi.org/10.1002/ece3.4632, in press.

Thierry, B., Singh, M., Kaumanns, W., 2004. Macaque Societies: a Model for the Study of Social Organization. Cambridge University Press, Cambridge.

Thomson, L.A.J., Thaman, R.R., Retrieved from 2006. *Pometia pinnata* (tava), ver 2.1. Species profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i, on 12 May 2016 http://www.traditionaltree.org.

van Noordwijk, M.A., van Schaik, C.P., 1985v. Male migration and rank acquisition in wild long-tailed macaques (*Macaca fascicularis*). Anim. Behav. 33, 849–861.

Wheatley, B.P., 1978. The Behavior and Ecology of the Crab Eating Macaque (*Macaca fascicularis*) in the Kutai Nature Reserve. University Microfilms International., East Kalimantan, Indonesia. London.

Wilcove, D.S., Koh, L.P., 2010. Addressing the threats to biodiversity from oil palm agriculture. Biodivers. Conserv. 19, 999–1007.

Yaap, B., Struebig, M.J., Paoli, G., Koh, L.P., 2010. Mitigating the biodiversity impacts of oil palm development. CAB Int. 5, 1–11.

Yeager, C.P., 1996. Feeding ecology of the long-tailed macaque (*Macaca fascicularis*) in Kalimantan Tengah, Indonesia. Int. J. Primatol. 17, 51–62.