Towards more sustainable palm oil: macaques can contribute to greener practices when used as biological pest control

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Conversion of tropical forests into oil palm plantations reduces the habitats of many species, including primates, and frequently leads to human-wildlife conflicts. Contrary to the widespread belief that macaques foraging in the forest-oil palm matrix are detrimental crop pests, we show that the impact of macaques on oil palm yield is minor. More importantly, our data suggest that wild macaques have the potential to act as biological pest control by feeding on plantation rats, the major pest for oil palm crops, with each macaque group estimated to reduce rat populations by about 3,000 individuals per year. If used for rodent control in place of the conventional method of poison, macaques could provide an important ecosystem service and enhance palm oil sustainability.

The area of primary rainforest converted into oil palm plantations has dramatically increased over the past decades. Today, oil palm plantations cover 18.7 million hectares of land worldwide [1]. Malaysia is ranked among the world's leading palm oil producers, reaching an annual production of approximately 19.5 million tons [2] (30% of world production). This expansion has had negative ecological impacts, as isolated forest fragments suffer from reduced species and genetic diversity, impaired climate regulation, and lower resilience [3]. At the same time, plantations offer habitat to a range of species, some of which negatively affect the plantations by eating or damaging oil palm fruits. Rats (*Rattus* spp.), for example, can cause losses of up to 10% of the yield [4], which in Malaysia alone is equal to crops grown over up to 580,000 hectares [2] (approximately US$ 930 million per year). The use of rodenticides in pest control is not only expensive and largely inefficient [5] but has also proven to be harmful to non-target wildlife and the environment [6]. This highlights the global importance of improving sustainable palm oil production, including the use of efficient and environmentally friendly pest control. Southern pig-tailed macaques (*Macaca nemestrina*) are directly affected by the dramatic decline of forest habitat in Malaysia [7]. In fragmented forests they increasingly divert their foraging activities into oil palm plantations, where they

are widely regarded as crop pests [8]. However, we observed pig-tailed macaques actively foraging for plantation rats, suggesting that macaques may in fact decrease crop damage by rats. Hence, we investigated both the role of macaques as crop pest and as biological pest control. Here, we present 1) the first data on macaques' net damage on oil palm crops and 2) their effect on plantation rats.

One-year ranging and behavioral data of two habituated groups of pig-tailed macaques inhabiting the Segari Melintang Forest Reserve in Peninsular Malaysia and the surrounding oil palm plantation showed that approximately one third of the macaques' home range includes the plantation (Figure S1). Macaques spent an average of 2.9 hours per day at the plantation, with their feeding time at the plantation representing 44% of the overall feeding time. Although 74% of the macaques' plantation diet consisted of oil palm fruits, our results question the common perception of macaques as detrimental crop pests. Based on individual consumption rates of fresh fruitlets, we estimated the annual oil palm fruit consumption by an average group of macaques (N = 44 individuals) to be approximately 12.4 tons, which is equal to 0.56% of the overall oil palm production in the macaques' home range (see supplement). Hence, the damage by macaques is up to 17-fold lower than the crop damage reported for rats (10%) [4].

Further, an extrapolation of foraging data estimated a consumption rate of 3,135 rats per year per macaque group. Pig-tailed macaques seem to be particularly effective pest control agents due to their way of foraging. They actively search for rats, mostly by removing persistent leaf bases (boots) from oil palm trunks. Uncovering rats which seek shelter under boots during the day was the most successful strategy (90% of rats were caught under boots, Figure S2A). This shows that macaques not only apply different hunting strategies (Figure S2B), but also occupy a different foraging niche than traditional rat predators (e.g. barn owls [6], small carnivores [9]), which hunt for rats on the ground during the night. A capture program on plantation rats, which related rat abundance to macaque presence, further corroborated the effect of macaques on pest rodents. We considered the actual number of rat captures as a proxy for rat abundance, which we found to be lower in plantation areas that had recently been visited more frequently by macaques. Controlling for other factors potentially impacting rat populations, i.e. rainfall, presence of undergrowth, distance to the forest edge, trapping session and spatial autocorrelation between trap sites, this relationship was statistically highly significant (GLMM estimate ± SE = -0.72 ± 0.18, $p < 0.001$, n = 575 traps, see supplement). For example, an increase from 0 to 25% of days with macaque visits (i.e. every fourth day) leads to a decrease in rat numbers by 79% (Figure 1). This suggests that, as compared to their absence, regular visits of pig-tailed macaques in Malaysia's oil palm plantations could reduce crop damage from 10% to less than 3% (2.1% by rats; 0.56% by macaques), corresponding to a yield increase equal to crops grown over approximately 406,000 hectares (approximately US$ 650 million per year).

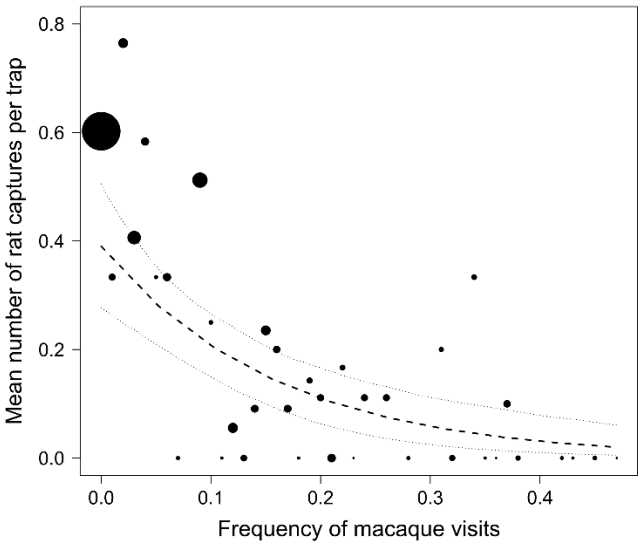

Figure 1. Mean number of rat captures per trap as a function of the frequency of macaque visits. The frequency of macaque visits refers to the number of days the macaques were present at a trap site during the last 90 days prior to sampling. The area of the circles represents the sample size (total N = 575 traps). The dashed line shows the fitted model and the dotted lines its 95% confidence interval, conditional on continuous control predictors being on their average, and based on undergrowth and session manually dummy coded and then centered.

Pig-tailed macaques were listed as Vulnerable in their latest survey (IUCN 2008, [7]), however, given the dramatic decline of their natural habitat, macaque population size is assumed to have further decreased during the past decade. As umbrella species, macaques represent a wide range of species living in rainforest. However, appropriate management may allow them to also survive in multifunctional landscapes that include plantation [10]. Our results have important implications for mitigating human-wildlife conflicts by encouraging farmers and palm oil companies to protect primates in their natural habitat via wildlife corridors between forest patches and viable interfaces between forests and plantations. This could maintain functional connectivity and gene flow between macaque populations while increasing environmental sustainability and productivity of existing oil palm plantations, promoting win-win solutions for palm oil producers and biodiversity.

Acknowledgements

We thank the Perak State Forestry Department and the Department of Wildlife and National Parks Peninsular Malaysia for research permits. We are very grateful to Amira Rahman, Hafizuddin Sa'adan, Javaan Stevardson, Juliette Bertin, Laura Morgan, Léo Guthmann and Matthias Reese for their assistance in the field. Special thanks to Roger Mundry for statistical advice. The study was funded by The Rufford Foundation UK (RSG 19842-2, awarded to NR) and USM Short-Term Grant (304/PBIOLOGI/6313256, to NR). Additional funding was provided through a PhD grant from the University of Leipzig as well as from DAAD and the Gesellschaft für Primatologie (to AH).

Declaration of interests

The authors declare no competing interests.

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