Correspondence

Macaques can contribute to greener practices in oil palm plantations when used as biological pest control

Anna Holzner[1,2,3], Nadine Ruppert[2,6,*], Filip Swat[2], Marco Schmidt[1], Brigitte M. Weiß[1,3], Giovanni Villa[2], Asyraf Mansor[2], Shahrul Anuar Mohd Sah[2], Antje Engelhardt[4], Hjalmar Kühl[3,5], and Anja Widdig[1,3,5]

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 (mitigating annual losses of 112 USD per hectare). 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] (monetary loss of approximately 930 million USD 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 pests and their potential utility as biological pest control. Here, we present the first data on macaques' net damage to oil palm crops and their effect on plantation rats.

Ranging and behavioral data (collected from January 2016 to September 2018) 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

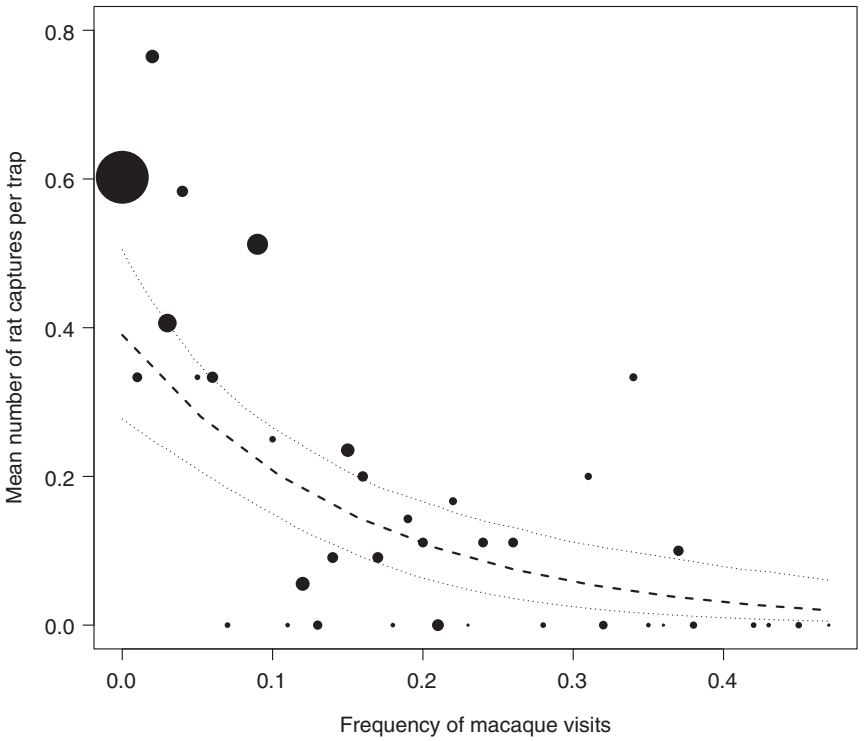

Figure 1. Mean number of rat captures per trap as a function of the frequency of macaque visits.
The frequency of macaque visits refers to the number of days the macaques were present at a trap site during the last 90 days prior to sampling. The area of the circles represents the sample size (total N = 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.

of oil palm fruits, our results question the common perception of macaques as 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 (2,197.6 tons; see Supplemental Information). 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 foraging behavior. They engage in multiple methods of actively foraging for rats. Removing persistent leaf bases (boots) from oil palm trunks to uncover rats that seek shelter in cavities under these boots during the day was the most successful strategy observed (90% of caught rats were found under boots, Figure S2A).This shows that macaques not only apply different hunting strategies (Figure S2B), but also occupy a different foraging niche than other rodent predators (such as barn owls [6] and leopard cats [9]) that hunt for rats on the plantation grounds 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 (specifically, rainfall, undergrowth, distance to the forest edge, trapping session and spatial autocorrelation between trap sites), this relationship was statistically highly significant (Generalized Linear Mixed Model estimate ± SE = –0.72 ± 0.18, $p < 0.001$, n = 575 traps, see Supplemental Information). For example, an increase from 0 to 25% of days with macaque visits (that is, 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 plus 0.56% by macaques), corresponding to a yield increase equal to crops grown over approximately 406,000 hectares (monetary gain of approximately 650 million USD per year).

Pig-tailed macaques were listed as Vulnerable in their most recent assessment by the International Union for Conservation of Nature in 2008, with habitat loss and human hunting being reported as their major threats [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 plantations [10]. Our results suggest important opportunities for mitigating human–wildlife conflicts: farmers and palm oil companies are encouraged 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.

SUPPLEMENTAL INFORMATION

Supplemental Information including two supplemental figures, experimental procedures and supplemental references can be found with this article online at https://doi.org/10.1016/j.cub.2019.09.011.

ACKNOWLEDGEMENTS

We thank the Perak State Forestry Department and the Department of Wildlife and National Parks Peninsular Malaysia for research permits. We are 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 N.R.) and Universiti Sains Malaysia Short-Term Grant (304/PBIOLOGI/6313256, to N.R.). Additional funding was provided through a PhD grant from the University of Leipzig as well as from the German Academic Exchange Service (DAAD) and the Gesellschaft für Primatologie (to A.H.).

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Meijaard, E., Garcia-Ulloa, J., Sheil, D., Wich, S.A., Carlson, K.M., Juffe-Bignoli, D., and Brooks, T.M. (2018). Oil palm and biodiversity: a situation analysis by the IUCN Oil Palm Task Force (Switzerland: IUCN, Gland).
2. Malaysian Palm Oil Board. (2018). Malaysian Oil Palm Statistics 2018. 38th Edition. (Bangi: Malaysian Palm Oil Board).
3. Dislich, C., Keyel, A.C., Salecker, J., Kisel, Y., Meyer, K.M., Auliya, M., Barnes, A.D., Corre, M.D., Darras, K., Faust, H., *et al.* (2016). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. Biol. Rev. *92*, 1539–1569.
4. Chung, G.F. (2000). Vertebrate pests of oil palm. In Advances in Oil Palm Research, B. Yusof, B.S. Jalani, and K.W. Chan, eds. (Malaysia: Malaysian Palm Oil Board), pp. 542–595.
5. Baker, S.E., Singleton, G., and Smith, R.H. (2007). The nature of the beast: using biological processes in vertebrate pest management. In Key Topics in Conservation Biology, D. MacDonald and K. Service, eds. (Oxford: Blackwell Scientific Publications), pp. 173–185.
6. Salim, H., Mohd Noor, H., Hamid, N.H., Omar, D., Kasim, A., and Zainal Abidin, C.M.R. (2014). Secondary poisoning in captive barn owls *Tyto alba javanica* from feeding with rats poisoned with chlorophacinone and bromadiolone. J. Oil Palm Res. *26*, 62–72.
7. Richardson, M., Mittermeier, R.A., Rylands, A.B., and Konstant, B. (2008). *Macaca nemestrina*. The IUCN Red List of Threatened Species 2008: e.T12555A3356892.
8. Linkie M., Dinata Y., Nofrianto A., and Leader-Williams N. (2007). Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. Anim. Conserv. *10*, 127–135.
9. Silmi, M., Mislan, Anggara, S., and Dahlen, B. (2013). Using leopard cats (*Prionailurus bengalensis*) as biological pest control of rats in a palm oil plantation. J. Nat. Hist. *1*, 31–36.
10. Caldecott, J.O. (1986). An Ecological and Behavioural Study of the Pig-Tailed Macaque. Contributions to Primatology (Basel: Karger).

[1]Behavioural Ecology Research Group, Institute of Biology, University of Leipzig, 04103 Leipzig, Germany. [2]School of Biological Sciences, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia. [3]Department of Primatology, Max Planck Institute for Evolutionary Anthropology, 04103 Leipzig, Germany. [4]Faculty of Science, School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool L3 3AF, UK. [5]German Center for Integrative Biodiversity Research, 04103 Leipzig, Germany. [6]Lead Contact
*E-mail: n.ruppert@usm.my