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Oil-palm yields in diversified plantations: Initial results from a biodiversity enrichment experiment in Sumatra, Indonesia

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ABSTRACT

The expansion of oil-palm plantations threatens tropical biodiversity and ecosystem functioning. While the expansion of oil palm has been associated with positive welfare effects, the strong dependence of local livelihoods on a single crop species also entails social and economic risks. Alternative management strategies could be important in mitigating negative ecological and socio-economic consequences. Yet, there is little empirical knowledge on the biological effectiveness and economic viability of such approaches. To bridge this gap, we experimentally established tree islands in varying sizes (25, 100, 400, and 1600 m^2) within a conventional oil-palm plantation and reduced the oil-palm density on these islands by thinning. After two years, we found enhanced yields per oil palm inside and also directly adjacent to the experimental plots. Estimating the net yield changes including opportunity costs and spillover effects for different sizes of tree islands, we found evidence that – in particular for larger tree islands – yield gains at least compensated for the reduced number of oil palms. Though these effect on yields may change as trees grow taller, the results obtained during the early phase of tree island establishment are promising in terms of identifying sustainable management options for oil palm that reconcile ecological and economic functions.

1. Introduction

The expansion of oil-palm (*Elaeis guineensis*) plantations is currently among the most serious threats to tropical ecosystems and biodiversity, and ongoing land conversion for oil-palm plantations is expected for the near future (Fitzherbert et al., 2008). Apart from the species loss directly associated with the conversion of forests into oil-palm plantations (Drescher et al., 2016; Fitzherbert et al., 2008; Foster et al., 2011), more indirect effects jeopardize the maintenance of local ecosystem functioning, e.g. through a decline of specific groups such as predators in the food web (Barnes et al., 2014) and a loss of regulating ecosystem services (Dislich et al., 2016). At larger scales, greenhouse gas emissions, mainly caused by preceding land conversion (Abood et al., 2015; Germer and Sauerborn, 2008), contribute to global climate change.

Oil-palm plantations expand at particularly large scale in Indonesia. In response to a steadily rising global demand for palm oil in the last decades (Sayer et al., 2012), the oil-palm area has increased more than eight-fold in Indonesia between 1990 and 2010 (FAO, 2016). At the same time, the country is currently experiencing the world's highest deforestation rates (Margono et al., 2014), with land transformations related to oil-palm expansion considered to be among the strongest direct and indirect drivers (Abood et al., 2015; Sodhi et al., 2010). The forest loss dramatically reduces the area of adequate habitat for Indonesia's unique flora and fauna, which is among the most species-rich on the globe (Sodhi et al., 2004).

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Oil-palm adoption is associated with both opportunities and risks for local famers. Oil palm is the most productive oil crop on an area-basis (Basiron, 2007) and requires comparatively low labor input (Drescher et al., 2016). Consequently, oil-palm cultivation improves incomes and livelihoods of many Indonesian farmers (Euler et al., 2015; Feintrenie et al., 2010). Currently, more than 40% of the oil-palm plantations are smallholder-owned, and this proportion is further increasing (Euler et al., 2016; Gatto et al., 2015). Despite the economic benefits, the agricultural homogenization in the landscape is associated with a strong dependence on a single crop, minimizing the resilience to agronomic and economic shocks, such as pest outbreaks, climate variability (Lin, 2011) and fluctuating world market prices (Index Mundi, 2016). A range of ecosystem services are currently deteriorating (Dislich et al., 2016), notably those which are crucial for safeguarding agricultural productivity (De Groot et al., 2002). Moreover, local people face serious health threats that are, among other drivers, directly related to the recent oil-palm intensification, including air pollution during recurring "haze"-episodes in Southeast-Asia from land clearing (Behera et al., 2015; Gaveau et al., 2014) and declines in water quality and availability (Merten et al., 2016).

Many researchers highlight the need for more diversified oil-palm landscapes to mitigate the negative environmental consequences of this recent development (Fitzherbert et al., 2008; Foster et al., 2011; Koh, 2008; Koh et al., 2009). Oil-palm plantations enriched with trees could be a promising management option, as agroforestry-like systems increase the structural complexity and could thus make the landscapes more hospitable and permeable for native species (Bhagwat et al., 2008; Bhagwat and Willis, 2008; Koh et al., 2009). Yet, it is essential to take into account potential trade-offs between ecological and economic benefits. In this regard, specific tree species could potentially compensate for possible yield losses by adding social and economic value, e.g., they may provide food, timber and other resources, increase the resilience to environmental and economic change, and improve soil fertility (Tscharntke et al., 2011). For other crops such as cacao and coffee, well-managed agroforests have been shown to be both species-rich and economically viable (Clough et al., 2011; Perfecto et al., 2007). For oil palms, many scientists have questioned the economic viability of mixed-species stands of oil palm with other trees due to competition for resources (Corley and Tinker, 2003; Koh et al., 2009; Phalan et al., 2009). However, there is very little empirical evidence on the associated yield impacts of such alternative management approaches.

To shed light on the relationships between different plantation management strategies, oil-palm yields, and ecosystem functioning, we set up a long-term biodiversity enrichment experiment establishing tree islands in a conventional oil-palm plantation (Teuscher et al., 2016). Tree islands have been shown to be a cost-effective measure to enhance biodiversity and ecosystem functionality e.g. of abandoned pastures (Cole et al., 2010; Zahawi and Augspurger, 2006) and have also been suggested as components of agricultural landscapes (Rey Benayas et al., 2008). In the experiment, we planted tree islands in varying sizes and with varying diversity levels with up to six multipurpose, native tree species. In the tree islands, we thinned the oil-palm planting density.

In this study, we analyzed the initial effects of the experiment on oil-palm yields. First, we investigated the effects of agro-ecological and experimentally altered variables on yields per oil palm inside the experimental plots. Second, we analyzed spillover effects of the experimental treatments to the yields of adjacent oil palms. Finally, from the farmers' perspective, it is relevant to consider not only the changes in per-oil-palm yields, but also the overall net effect at the plot level. Therefore, we analyzed the net effects on yields at the aggregate plot scale. In this context, we considered yield changes inside the plots, spillover effects to yields of surrounding managed-as-usual oil palms, and opportunity costs for farmers resulting from oil-palm thinning. With our research, we aim to inform the development of more sustainable oil-palm-management strategies that can be implemented by large plantations and small-scale producers alike.

2. Materials and methods

2.1. Study site and experimental design

We established a biodiversity enrichment experiment (EFForTS-BEE), located at 01.95° S and 103.25° E in Jambi province, Sumatra, Indonesia with an altitude of the experimental plots of 47 ± 11 m a.s.l. (Teuscher et al., 2016). EFForTS-BEE serves as an experimental platform for the collaborative research project "Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems" (EFForTS) (Drescher et al., 2016). The experiment is located in a conventional, mid-sized oil-palm (OP) plantation with oil palms planted in a 9 × 9 m triangular grid, i.e. with 7.8 m between rows of alternating oil-palm arrangement, and an in-row distance of 9 m, resulting in approximately 143 oil palms per hectare. The mean yield in the plantation is 22.74 t/ha/year (Hasibuan, pers. comm.), equivalent to 159 kg/OP/year (hereafter referred to as plantation average). The management-as-usual is uniformly applied to the whole plantation surrounding the experimental plots and implies regular manual weeding of the understory vegetation, regular application of organic and inorganic fertilizer, and occasional application of herbicides and pesticides.

In December 2013, we established tree islands in the oil-palm plantation with up to six different multi-purpose tree species native to Sumatra under various management options. The species are native to Sumatra and thus beneficial to local ecosystems, and were also selected based on their economic value to the local population. Three of the planted tree species produce edible fruits (*Parkia speciosa*, Fabaceae; *Archidendron pauciflorum*, Fabaceae; *Durio zibethinus*, Malvaceae), two species provide timber

Table 1
Number of plots per tree island size class and information on thinning, experimental tree enrichment, and remaining and removed oil palms. OP = oil palms, y = yes, n = no, min = minimum, med = median, max = maximum

tree island size	no plots	thinning		tree enrichment		no. of OP remaining				no. of OP removed				yield data for analysis	
[m²]		y	n	y	n	min	med	max	total	min	med	max	total	inside plot	adjacent
25	13	0	13	12	1	0	0	0	0	0	0	0	0	N = 0	N = 13*3
100	13	13	0	12	1	0	0	1	5	1	1	1	13	N = 5	N = 13*3
400	13	13	0	12	1	1	2	5	31	1	3	4	32	N = 13	N = 13*3
1600	13	13	0	12	1	11	13	20	178	4	7	8	87	N = 13	N = 13*3
sum	52	39	13	48	4				214				132	31	156