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Biological control in Indonesian oil palm potentially enhanced by landscape context

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ABSTRACT

Oil palm plantation expansion is occurring at a rapid pace. However, substantial yield losses from pest attacks are becoming major threats to the oil palm industry, while the potential role of conservation biological control, a sustainable and environmentally friendly solution for pest control, is still largely unknown. The type of vegetation surrounding oil palm plantations is likely to influence pest predation, and we tested this in Indonesia (Sumatra), the world's largest palm oil producer. We studied six different vegetation types adjacent to oil palm plantations: another oil palm plantation (control), weedy oil palm, weedy rubber, scrub, jungle rubber, and secondary forest. Each border type was replicated eight times. We quantified predation rates and predator occurrences using dummy caterpillars and mealworms 20 m inside of the adjacent vegetation (OUT 20) as well as 20 m (IN 20) and 50 (IN 50) m inside the oil palm plantation. Ants and bush crickets were the most prominent predators in the plantations, whereas birds, bats, monkeys, beetles, and molluscs played a minor role. Mean percentage of ant and cricket predation rate in control border OUT 20 were 16.39% and 7.16% respectively, IN 20 were 16.03% and 6.1%, and IN 50 were 14.47% and 7.48%, while for other borders other than control, mean percentages OUT 20 m were 28.90% and 12.26% respectively, IN 20 m were 26.61% and 12.40%, and IN 50 m were 22.93% and 10.58%. Predation rates were ~70% higher in non-oil palm habitat, indicating the need for improved vegetation diversification inside plantations. Overall predation rates in oil palm decreased slightly but significantly with distance to the border. Our results suggest that maintaining non-oil palm vegetation in the areas adjacent to plantations and promoting weedy strips within the plantations are potentially effective management tools for conserving and developing biological control in oil palm in the future.

1. Introduction

Oil palm plantation expansion is occurring at a rapid pace (Foster et al., 2011), particularly due to it being the highest yielding vegetable oil crop per unit area (Murphy, 2009). However, substantial yield losses from pest attacks are becoming major threats to the oil palm industry (Constantin et al., 2013; Kamarudin and Wahid, 2010; Woruba et al., 2014). Pests can be potentially controlled through two main methods, chemical inputs (pesticides) or biocontrol (Wood, 2002). Compared to pesticide applications, biocontrol is known as a sustainable and ecofriendly solution to reduce pest numbers below economic level by using natural enemies (Hajek, 2004; Norris et al., 2003). However, research on factors influencing biocontrol agents in oil palm plantations, such as landscape context or local management, is lacking but urgently needed to understand the potential for biocontrol methods to stop yield losses from pest attacks.

Oil palms are attacked by a large number of insect pests (e.g. trunk borers and defoliators) and diseases (e.g. *Ganoderma*, *Fusarium*, and *Phytomonas*) (Corley and Tinker, 2008). Both of which occur often in oil palm plantations and have a high impact on oil palm production (Corley and Tinker, 2008; Foster et al., 2011; Wood, 2002). However, defoliating pests, in particular bagworms

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(Psychidae) and nettle caterpillars (Limacodidae), play one of the most important roles in reducing crop yield due to their high reproduction and mobility (Wood, 2002). For example, bagworms can cause up to 50% yield loss at high infestation levels (Basri et al., 1995; Kamarudin and Wahid, 2010), while nettle caterpillars can cause 29% and 31% yield reduction after the first and second year of infestation respectively (Potineni and Saravanan, 2013). Significant pest attacks can be related to an imbalance between pests and their natural enemies (Igbinosa, 1992; Wood, 2002). In the past, pest resurgence after insecticide application was assumed to be a major cause of the imbalance (Wood, 1971). However, despite the decline in use of broad spectrum-long residual contact-insecticides (bslrcs), pest numbers have still continued to reach detrimental numbers in many locations (Kamarudin and Wahid, 2010; Wood, 2002). Investigation of methods for promoting biocontrol agents in plantations is therefore crucial for decreasing pest outbreaks and maintaining or increasing production levels (Corley and Tinker, 2008; Foster et al., 2011).

Fostering native biocontrol in oil palm plantations through local or landscape management may be an important approach to decreasing pest populations. Conversion to oil palm plantations results in highly simplified landscapes leading to huge biodiversity losses for a wide range of organisms, including biocontrol agents (Barnes et al., 2014; Dislich et al., in press; Fitzherbert et al., 2008). Of particular concern is a decline in predatory species (Denmead unpublished data; Senior et al., 2013), which are the main cause of defoliator pest mortality in the field (Wood, 2002). For example, Aratrakorn et al. (2006), and Koh (2008a,b) found that insectivorous birds have difficulty adapting to oil palm plantations and therefore, have a reduced capacity for top-down control of crop pests (Aratrakorn et al., 2006; Koh, 2008a,b). Ant community composition is also largely changed, with many forest species lost and decline in predatory species (Rubiana et al., 2015; Denmead et al. in prep). Dejean et al. (1997) reported that when two predatory ants, *Crematogaster gabonensis* and *Tetramorium aculeatum*, occupied oil palm plantations in Cameroon, there were lower attack rates by a leaf-mining beetle (Coleoptera: Chrysomelidae). However, studies on the biocontrol of oil palm pests in the past have mostly focused on the introduction of exotic biocontrol agents to the field or assessments of potential agents (Bakeri et al., 2009; Kamarudin and Wahid, 2010; Zeddam et al., 2003), rather than evaluating factors influencing the native enemy population. There has been no comprehensive study that links pests to native biocontrol agents (Foster et al., 2011; Savilaakso et al., 2014). A potential method for increasing biodiversity, and in particular native biocontrol agents, in the plantations are the increase of landscape heterogeneity through such approaches as protecting riparian buffers (Gray and Lewis, 2014), leaving patches of natural forest and agroforestry within the landscape, and enhancing the understorey vegetation (Koh, 2008a; Koh et al., 2009). Thus, increasing landscape complexity and connectivity among habitats may provide a way to manipulate biological control in agroecosystems (Tscharntke et al., 2012, 2007).

Developing ecologically sound integrated pest management strategies in such a rapidly expanding agricultural system will be extremely important for the sustainability of the crop and the wider ecosystems in the long term. However, these concerns have only received little attention in the past. Here, we investigated if the surrounding landscape and the distance from border influence predator predation rates in oil palm plantations in Sumatra, Indonesia. We measured predation rates and predator occurrences using dummy caterpillars and mealworms in oil palm plantations bordered by important vegetation types such as another oil palm plantation (control), weedy oil palm, weedy rubber, scrub, jungle rubber, and secondary forest to determine if the border type can influence the potential for biocontrol in the plantations. We also surveyed a key predator group (ants) in different vegetation types to link predation rates with probable predators. Understanding how the landscape context and management can influence biocontrol agents in oil palm plantations is a crucial factor to allow farmers to promote biocontrol of crop pests.

2. Methods

2.1. Study area

The study was conducted within two regions in the Batanghari and Sarolangun Regencies in Jambi Province, Sumatra, Indonesia. Both study regions were located in the lowland area of the province with potential vegetation of tropical lowland rainforest. However, there has been considerable land-use change in the province over the past 50 years as result of the expansion of agricultural land. In particular, more recently, the area cultivated as oil palm plantations increased from 150,000 ha to 550,000 ha in the period from 1996 to 2011 (Gatto et al., 2015), making oil palm one of the most dominant crops in the province.

Four important vegetation types in the study area include degraded lowland rainforest, jungle rubber (agroforestry system consisting of degraded forest with rubber trees between native vegetation), rubber plantations, and oil palm plantations. A major arthropod predator group across all these vegetation types is ants, which maintains dominance across all systems, with even slightly higher abundances and richness in oil palm plantations compared to other systems (Table 1, Appendix A in Supplementary materials) and predatory ants lowest in the oil palm plantations (Table 1) (Denmead, unpublished data). Pest attacks, especially nettle caterpillars, were reported only in a few study sites. Farmers immediately spray pesticide when pests are observed within their plantations to manage them before reaching outbreak level. The most common herbivores in the area were Geometridae caterpillars which were found in all study sites, but they were not categorised as pest by farmers.

2.2. Experimental design

Sample and data collection were completed from October 2012 to June 2014 at the border of oil palm plantations that were surrounded by six different vegetation types: another oil palm plantation (control), weedy oil palm, weedy rubber, scrub, jungle rubber, and secondary forest (Fig. 1). In each of the two study

Table 1
Ant community composition measures (mean ± SE, n = 8) for each land-use system. Ant community responses to vegetation type were also tested using Linear Mixed-Effects models (LMEs) with region specified as a random effect (Table A1). Means (within rows) with different letters are significantly different (Tukey's HSD, $p \leq 0.05$) (Table A2). Community Weighted Mean (CWM) preference ratio = community weighted mean (abundance-weighted mean trait values for a community) for the protein/carbohydrate preference ratio, a higher ratio indicates increased predator abundance (Appendix A in Supplementary materials).

	Forest	Jungle rubber	Rubber	Oil palm
Ant species richness	9.25 ± 0.62 ab	8.75 ± 0.92 a	12.50 ± 0.68 bc	14.50 ± 1.35 c
Ant abundance	15.72 ± 3.93 a	14.57 ± 4.15 a	17.15 ± 2.85 a	26.13 ± 5.19 b
CWM preference ratio	0.77 ± 0.02 a	0.72 ± 0.03 ab	0.75 ± 0.02 a	0.65 ± 0.01 b