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Effects of monoculture and polyculture farming in oil palm smallholdings on terrestrial arthropod diversity

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ABSTRACT

Oil palm agriculture has become one of the economic mainstays for biodiversity-rich countries in the tropics. The conversion of native forests to oil palm monoculture plantation has caused unprecedented biodiversity loss in Southeast Asia. Little is known about the effects of oil palm polyculture farming on arthropod diversity. In this study, arthropods were sampled using pitfall traps at 120 sites in Peninsular Malaysia. We examined how arthropod biodiversity responded to different oil palm farming practices and local-scale vegetation structure characteristics. We found that the number of arthropod orders was significantly greater in polyculture than monoculture smallholdings. However, we did not detect a significant difference in arthropod order composition nor abundance between monoculture and polyculture practices. In situ habitat characteristics explained 16% of the variation in arthropod order richness, with key predictor variables including farming practice, height of oil palm stands, and number of immature palm. The findings of this study suggest that polyculture farming together with management for in situ habitat complexity may be a useful strategy in supporting biodiversity within in oil palm plantations.

Introduction

Arthropods including insects, are the most numerous phylum on Earth and represent more than 80% of global species richness (Wilson, 1992). They are also responsible for a wide range of important ecosystem functions, including biological control of pests (Letourneau et al., 2009) and pollination, both in natural habitats and in agricultural landscapes (Thiele, 2005; Klein et al., 2007; Ramirez et al., 2010). In agroecosystems, these arthropods also aid in the decomposition of organic matter in soil (Ahmad and Ahmad, 2009) and at the same time are food sources for their natural predators (Greenberg et al., 2000). However, intensively managed agriculture (e.g. monoculture oil palm plantations) could significantly reduce arthropod biodiversity in comparison to the native forests (Bruhl and Eltz, 2010; Luke et al., 2014).

Conversion of natural forests into agricultural lands is currently one of the major threats to global biodiversity (Ewers et al., 2009) and represents a major conservation challenge. Over the past few decades, oil palm (*Elaeis guineensis* Jacq.) has become one of the most rapidly expanding tropical crops in the world (Clay, 2004; Koh and Wilcove, 2007). Vast areas of natural forests have been converted to commercial plantations, and the crop makes a substantial contribution to the economy of producing countries (Koh and Wilcove, 2007). This is particularly true in Malaysia, with the country currently producing 39% of the world's palm oil production and 44% of world's export (MPOC, 2014). Within Malysia, the State of Sabah contains the biggest oil palm plantation area, accounting for around 29% of total oil palm plantation area in Malaysia (MPOB, 2015).

The large scale expansion of oil palm monoculture plantations has raised concerns about the impacts of oil palm expansion on biodiversity. Thus, it has reduced species richness and abundance in terms of biodiversity (Fitzherbert et al., 2008; Danielsen et al., 2009; Foster et al., 2011). For example, compared to forest, oil palm plantations have been found to contain a lower species richness of butterfly and birds (Koh and Wilcove, 2008) and ground-dwelling ants (Fayle et al., 2010). Protecting forest biodiversity from the ecological impact of oil palm expansion is a primary concern. However, maintaining farmland biodiversity in existing oil palm production landscapes is also important

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(Koh and Wilcove, 2007; Fayle et al., 2010). Previous studies have shown that oil palm can still host common or open-area species (Koh, 2008; Azhar et al., 2011). Oil palm production landscapes can also be habitats for a small number of forest species, given that oil palm farms are planted with other crops that provide shelter and foraging grounds for other wildlife (Kim et al., 2006; Nair, 2007; Foster et al., 2011). Polyculture farming is a common practice and considered to be ecologically more complex than monoculture farming (Rice and Greenberg, 2000; Altieri and Nicholls, 2004; Harvey et al., 2006). This has led to a focus on multi-cropping systems as a possible means of conserving farmland biodiversity (Dietsch et al., 2007; Steffan-Dewenter et al., 2007; Tylianakis et al., 2007). The planting of multiple crop species in commercial plantations has been found to have positive effects on insect diversity (Chung et al., 2000; Jones et al., 2003). For instance, studies have found that polyculture farming systems that integrate two or more crop species contain higher animal biodiversity compared to monoculture systems (Perfecto et al., 1996; Siebert, 2002).

Faunal diversity is often associated with plant diversity (Weibull et al., 2003). In agroecosystems, increasing plant diversity has been linked to an increase in insect diversity. Increased diversity can also result in lower insect herbivory damage, perhaps due to an increase in interspecific competition among pest and non-pest species, and a higher number of natural enemies (Cardinale et al., 2006). Oil palm plantations adjacent to forest can serve as a complementary habitat for arthropods originating from nearby disturbed forest (Lucey and Hill, 2012). Although many biodiversity studies have been carried out in oil palm landscapes, these have been mostly limited to large-scale monoculture plantations, where management practices are different from oil palm smallholdings. In addition, smallholdings are characterized by greater landscape heterogeneity than large-scale plantations (Azhar et al., 2015).

One of the key questions in tropical agricultural research is whether farmlands can provide a refuge for tropical biodiversity, including arthropods. Turner and Foster (2009) reported that different arthropod groups experience differing levels of decline between forest and oil palm plantation, with some groups having higher abundance in oil palm plantations compared to primary forests and logged forests in Sabah. In addition, although many species decline in oil palm plantations, some disturbance-tollerant species may also increase in abundance. For instance, a study from Papua New Guinea found that ant abundance and species richness were lower in monoculture oil palm compared to forest (Room, 1975), but that nine species of ants that had never been recorded in natural forest were found in oil palm plantations. Generally there therefore seems to be a community shift of ants towards non-forest taxa in oil palm plantations (Bruhl and Eltz, 2010).

To reconcile palm oil production and biodiversity conservation, it is important to understand factors that determine biodiversity patterns in oil palm production landscapes. Therefore, this study aimed to answer three research questions with respect to the pattern of terrestrial arthropod biodiversity associated with agricultural practices in oil palm smallholdings: (1) How does terrestrial arthropod abundance and richness differ between polyculture and monoculture oil palm smallholdings? (2) To what extent do in situ or local-scale habitat characteristics influence the arthropod abundance and order richness in oil palm smallholdings? (3) How does arthropod composition differ between polyculture and monoculture oil palm smallholdings?

Methods

Study area

The study was conducted at Banting (02′47.804’N, 101′31.420’E; area = 5244.82 ha), Tanjung Karang (03′21.511’N, 101′13.163’E; area = 3993.88 ha) and Sabak Bernam (03′48’09.1′N, 100′53’21.2′E; area = 5479.49 ha), in the state of Selangor on the west coast of Peninsular Malaysia (Fig. 1). All locations were below 10 m above sea level. All sites were located on coastal areas that were characterized by peat soil and flat terrain. The size of smallholdings in the study areas were less than 5 ha each and managed by local farmers or independent smallholders. We assigned each smallholding to a category of polyculture or monoculture farming system, based on the crop species planted by the smallholders. Monoculture smallholdings were those exclusively planted with oil palm, while polyculture smallholdings were planted with oil palm, bananas and other crop plants (e.g. coconut and cassava).

Sampling design

We used systematic sampling with random starting points (Morrison et al., 2008). Sampling points were distanced at least 500 m apart. Data were collected from the three locations (i.e. Banting, Tanjung Karang and Sabak Bernam) where each had 40 sampling points. These points were allocated equally into monoculture (n = 20 sampling points) and polyculture smallholdings (n = 20 sampling points). Arthropod sampling was conducted from January to August 2014, using pitfall traps. Pitfall traps consisted of open plastic containers (473 ml, with diameter of 9 cm) sunk into the ground, with the rim of each container level with the ground surface and covered with a lid to prevent flooding and disturbance (Southwood, 1994). We poured a water and detergent mix into the traps to kill any insects that fell in (Lemieux and Lindgren, 1999), with added salt to act as preservative for collected specimens. The fluid was filled up to 2 cm from the base of the cup.

A total of 15 pitfall traps were used at each site, with a total of 1800 pitfall traps used throughout the study period. Each pitfall trap was placed randomly within a 5–10 m radius from the other traps and at least 5 m from the edge of the smallholdings. Pitfall traps were left for three days at each site, which should be sufficient time to provide a reasonably good estimate of total arthropod richness and abundance (Olson, 1991). The arthropods were stored in 75% alcohol and identified to order in the laboratory (Capinera, 2010; Walters, 2011).

In situ habitat structure measurements

Thirteen habitat characteristics were assessed in 100 m × 100 m vegetation plots at each arthropod sampling point (Table 1). The percentage of understory vegetation cover of grass (i) and non-grass (ii) was measured at subpoints to the North, South, East and West (each plot 20 m apart). Mean height of the understory vegetation along the harvesting path was measured at subpoints to the North, South, East and West. This included (iii) height of grass cover and (iv) height of non-grass cover. Percentage canopy cover along the harvesting path was estimated using a canopy densiometer at subpoints to the North, South, East and West (v). The number of crop species at each plot was also counted (vi). In addition, (vii) the number of oil palms and (viii) the number of banana palms at each plot were counted. The number of crop plants within the vegetation plots was also counted. This included (ix) the number of mature oil palms, (x) the number of immature oil palms of less than five years (Härdter et al., 1997), (xi) the number of fallen dead oil palms and (xii) the number of dead standing oil palm at each plot. Finally, (xiii) the percentage epiphyte cover on four random oil palm trunks within a rectangular quadrat of 50 cm × 100 cm was measured.

Data analysis

To compare the abundance and number of orders between monoculture and polyculture smallholdings, we performed one-way Analysis of Variance (ANOVA). Count data were square-root transformed to meet the assumptions of the test (Ellison and Gotelli, 2004). We included different sampling months as blocks in the analysis.

The relationship between arthropod order richness and in situ habitat characteristics was compared using Generalized Linear Models (GLMs) (Schall, 1991). We used log-link function assuming a Poisson