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Tropical forest fragments contribute to species richness in adjacent oil palm plantations

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ABSTRACT

In Southeast Asia, large-scale conversion of rainforest to oil palm plantations is one of the major causes of biodiversity declines. Recommendations for reducing species losses and increasing the sustainability of palm oil production advocate the retention of natural forest patches within plantations, but there is little evidence for the effectiveness of this strategy. Here, we examine to what extent rainforest remnants with different characteristics contribute to biodiversity within surrounding plantations. We sampled ground-dwelling ants in Sabah (Malaysian Borneo) using unbaited pit-fall traps along 1 km transects spanning forest-plantation ecotones of 10 forest fragments (area 5 ha–500 ha) and two continuous forest sites which bordered plantations. Ant species richness in plantations varied according to richness in adjacent forest fragments, which increased with fragment size. A trend of declining species richness in plantations with distance from the forest ecotone was consistent with spillover of forest species into plantations adjacent to forest remnants. Ant assemblages in plantations also contained more carnivorous species adjacent to large forest fragments, suggesting large fragments may have benefits for pest control in plantations, as well as benefits for local biodiversity. Our results indicate that large forest fragments support distinctive ant assemblages and increase diversity within the planted area, but small fragments (<~200 ha) contribute little to plantation diversity. Thus retaining large fragments of forest may help mitigate the loss of species within oil palm plantations.

1. Introduction

Globally, the loss of natural habitats due to the continuing expansion of agriculture is a major threat to biodiversity (Millenium Ecosystem Assessment, 2005). In most regions, the relatively small area of land that is protected is not sufficient to prevent biodiversity losses (Franklin and Lindenmayer, 2009; Perfecto and Vandermeer, 2010) and research has shifted to investigating the potential for agricultural landscapes to help support diversity (Dauber et al., 2003; Tscharntke et al., 2005; Vandermeer and Perfecto, 2007). In Southeast Asia, forest clearance to make way for oil palm (*Elaeis guineensis* Jacq.) plantations is a major driver of biodiversity losses (Corley, 2009; Sodhi et al., 2010; Wilcove and Koh, 2010; Wilcove et al., 2013). Retaining natural habitat fragments within agricultural landscapes could improve species richness, as well as provide source populations of beneficial species (e.g. for pest control) and other ecosystem services for agriculture (e.g. Duelli and Obrist, 2003; Ricketts, 2004; Ricketts et al., 2004). Accordingly, this method has been proposed as a way of improving the sustainable production of palm oil (RSPO, 2013). However, there is little information on the efficacy of forest fragments for maintaining or improving species richness within plantations (Edwards et al., 2010; Koh, 2008; Mayfield, 2005). It is important to identify the properties of forest patches necessary to support species richness within plantations, because retaining forest fragments that are too small, too isolated or with poor quality habitat may result in substantial economic losses from unplanted land in return for negligible conservation benefits.

Species richness in agricultural areas has been shown to increase with proximity to natural habitats (e.g. Dolia et al., 2008; Livingston et al., 2013; Perfecto and Vandermeer, 2002) due to "spillover" of individuals from source to sink habitats (Lucey and Hill, 2012), as well as the presence of edge species (De Vries

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et al., 1997). Species-area relationships (SARs) in which species richness increases with habitat patch size (MacArthur and Wilson, 1967) are well documented in tropical forest fragments (e.g. Benedick et al., 2006; Bruhl et al., 2003; Hill et al., 2011), and the habitat quality of forest fragments is also likely to influence their species richness (Thomas et al., 2001). Intuitively, higher species richness in larger, higher quality forest fragments might be expected to generate greater spillover effects of forest species into surrounding agricultural habitat. Forest fragments may also vary in their faunal composition, with potential consequences for spillover if species with particular ecological traits are more or less likely to cross ecotones. Previous studies have considered spillover of insects from single fragments (Dolia et al., 2008; Perfecto and Vandermeer, 2002; Ricketts et al., 2001), and how the quality of the agricultural matrix affects spillover (Perfecto and Vandermeer, 2002), but the effect of the characteristics of the forest fragment itself on the species richness in the surrounding matrix, has not been considered.

Ants were chosen as our study taxon because of their diverse functional roles and their potential benefits as predators of agricultural pests (Holldobler and Wilson, 1990; Philpott et al., 2008). Ants are sensitive to land-use changes (Woodcock et al., 2011), and their species richness is reduced in oil palm plantations compared with forest (Bruhl and Eltz, 2010; Fayle et al., 2010; Lucey and Hill, 2012). They also occupy diverse trophic positions (Bluthgen et al., 2003) which may be an important determinant of extinction vulnerability in disturbed habitats (Bascompte and Sole, 1998).

The main objective of the study was to examine species richness and faunal composition of ants in forest sites and adjacent oil palm plantations. First, we examined factors affecting ant species richness within forest fragments in relation to forest fragment area, isolation, and habitat quality. We then examined relationships between species richness in fragments and adjacent plantations. In order to test whether these relationships could be due to spillover of forest ant species into adjacent oil palm, we tested whether species richness patterns in plantations varied in relation to distance from forest edges. Finally, we investigated changes in the faunal composition of ants between forest fragments and adjacent plantation sites, and used stable nitrogen isotope analysis to assess the trophic organisation of ant assemblages in each habitat.

2. Methods

2.1. Study sites

We sampled ground-dwelling ants along 1-km transects at 12 sites in Sabah, Malaysian Borneo (5°N,117°5′E); 10 forest fragment sites and adjacent oil palm plantations, and two sites where plantations bordered continuous forest (Fig. 1). The study region experiences climate typical of the moist aseasonal tropics, with an average annual temperature of 27 °C and average annual rainfall of 2849 mm per year (Walsh et al., 2011).

The 10 forest fragment sites were located in, or adjacent to, five estate plantations belonging to three companies, one of which is a member of the Roundtable for Sustainable Palm Oil (RSPO, 2013, Fig. 1 and Table A1). Forest fragments ranged from 5 ha to 500 ha in size (Table A1). The two largest fragments (250 ha, 500 ha) were 'Virgin Jungle Reserves' (VJRs) and managed and protected by the Sabah Forestry Department. The eight smaller fragments (5–120 ha) were classified as 'High Conservation Value' (HCV) forest (www.hcvnetwork.org) and under the management of the plantation. The two sites where plantations bordered continuous forest were both in the Ulu Segama forest reserve within the Yayasan Sabah forestry concession (~1 million hectares of production forest, Reynolds et al., 2011, Fig. 1). This continuous forest had been selectively logged in 1993 (~15 years before the study) when timber trees ⩾0.6 m DBH were removed (Reynolds et al., 2011). There are no oil palm plantations bordering primary forest in the region.

All oil palm plantations that were sampled comprised mature fruiting palms between 10 and 19 years old, and palm trees were of similar height (10–15 m) and spread (~10 m diameter of palm tree crown from frond tip to frond tip), creating an even, closed canopy. Management practices were similar across plantations, with palms planted 10 m apart and vegetation kept clear around the palm bases. Ground cover was dominated by ferns and grasses, and herbicides were used to keep palm bases clear. Insecticide use is rare and was not applied at study sites during the study period.

2.2. Ant sampling and identification

We used unbaited pitfall traps to sample ants along transects. The traps consisted of 45 ml clear plastic tubes containing 15 ml of water with a small amount of detergent to reduce surface tension. The rims were lined with Fluon to prevent escape (Carney et al., 2003). Sampling took place in the drier season (March–September) between July 2008 and September 2010, when the sampling methods were not compromised by heavy rainfall. At each site, a 1-km transect was set-up perpendicular to the forest-plantation boundary, to sample 500 m into each habitat either side of the ecotone. The ecotones between forest and oil palm plantations at the sampling sites were sharp transition zones of ~1–3 m width, containing grasses and pioneer species. Stations were established at 100 m intervals along each transect (i.e. $N = 11$ stations per transect, five stations in forest, five in oil palm and one at the ecotone), except at the smallest remnant (Site 12, 5 ha), where stations were placed 50 m apart to avoid proximity to other edges of the fragment. Transects ran in straight lines except within forest in some small fragments, when the transect detoured, but minimum distances as previously described were always maintained between stations. At each station, five pitfall traps were placed in a square formation with the central traps placed directly on the transect and four other traps placed 10 m N, S, E and W of the central trap. Traps were buried flush with the ground, and sheltered beneath a suspended plastic cup to prevent rainfall displacing captured individuals. Traps were left in place for three days then collected and replaced with five new traps which were placed 5 m away from the original traps in the direction away from the ecotone in order to obtain greater spatial coverage, and left for a further three days. This sampling design resulted in a total sampling effort of 3960 trap-days (12 sites × 11 stations × 10 traps × 3 days).

Ants were preserved in 95% alcohol and identified to genus following Hashimoto (2003). Some ants could be identified to species using reference collections at the Natural History Museum (London), and on-line resources (www.antweb.org; www.antbase.net). Reproductive individuals were excluded from identification and subsequent analyses because they do not necessarily indicate the presence of an established colony. Unnamed species that occur in www.antweb.org were given the same number as the on-line collection, and morphospecies not featured were subsequently submitted to the collection. Voucher specimens are deposited at the Forest Research Centre, Sandakan, Sabah.

2.3. Estimating ant species richness

We present analyses using raw species richness, but we also ran analyses with seven commonly-used species richness estimators in order to avoid biases associated with using any one estimator ('Estimate S' software, Colwell, 2006; Species Richness and Diversity v.2, Henderson and Seaby, 1998, see Table A2 for results). Ants live colonially in nests so individuals cannot be considered independent sampling units and abundance of individuals can be