Do riparian forest fragments provide ecosystem services or disservices in surrounding oil palm plantations?

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Do riparian forest fragments provide ecosystem services or disservices in surrounding oil palm plantations?

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Abstract

Agricultural expansion across tropical regions is causing declines in biodiversity and altering ecological processes. However, in some tropical agricultural systems, conserving natural habitat can simultaneously protect threatened species and support important ecosystem services. Oil palm cultivation is one of the fastest-growing industries in tropical areas, but the extent to which non-crop habitat supports biodiversity and ecosystem services in these landscapes is poorly documented. We investigated whether riparian forest fragments (riparian reserves) provide a pest control service or increase pest activity (disservice) within oil palm dominated landscapes in Sabah, Malaysian Borneo. We assessed the activity of potential predators of pest herbivores using plasticine caterpillar mimics and quantified herbivory rates on oil palm fronds in areas with and without riparian reserves. We also manipulated the shape and colour of the mimics to assess the extent to which artificial pest mimics reflect a predatory response. The presence of riparian reserves increased the attack rate on mimics by arthropods, but not by birds. Our methodological study suggested attacks on artificial pest mimics provide a better indication of predatory activity for birds than for arthropod predators. Herbivory rates were also not significantly affected by the presence of a riparian reserve, but we found some evidence that herbivory rates may decrease as the size of riparian reserves increases. Overall, we conclude that riparian forest fragments of 30 – 50m width on each side of the river are unlikely to provide a pest control service. Nevertheless, our results provide evidence that these riparian buffer strips do not increase the density of defoliating pests, which should reassure managers concerned about possible negative consequences of preserving riparian buffers.

Zusammenfassung

Die Ausweitung der Landwirtschaft in tropischen Regionen verursacht Abnahmen der Biodiversität und verändert ökologische Prozesse. Indessen kann in einigen tropischen

Agrarsystemen der Schutz von natürlichem Lebensraum gleichzeitig bedrohte Arten schützen und wichtige Ökosystemdienstleistungen unterstützen. Der Ölpalmenanbau ist die am schnellsten wachsende Industrie in tropischen Gebieten, aber das Ausmaß, in dem nicht bewirtschaftete Habitate Biodiversität und Ökosystemdienstleistungen in diesen Landschaften unterstützen, ist wenig dokumentiert. Wir untersuchten, ob fragmentierte Uferwälder (Uferreservate) in von Ölpalmen dominierten Landschaften von Sabah (Borneo, Malaysia) eine Schädlingskontrolldienstleistung erbringen oder die Schädlingsaktivität steigern. Wir bestimmten die Aktivität von potentiellen Räubern von Schädlingen, indem wir Raupenimitate aus Knetmasse benutzten, und quantifizierten den Schädlingsbefall an Ölpalmwedeln in Gebieten mit und ohne Uferreservate. Wir variierten auch die Gestalt und Farbe der Imitate, um das Ausmaß abzuschätzen, mit dem künstliche Raupenimitate Reaktionen seitens der Räuber wiedergeben. Das Vorhandensein eines Uferreservats steigerte die Angriffsraten von Arthropoden, aber nicht die von Vögeln. Die Breite des Uferreservates hatte keinen signifikanten Einfluss auf die Angriffsraten der beiden Räubergruppen. Unsere Untersuchung zur Methodik legt nahe, dass die Angriffe auf künstliche Schädlingsimitate die Aktivität von Vögeln besser wiedergeben als die von Arthropoden. Der Befall durch Pflanzenfresser wurde ebenfalls nicht signifikant vom Vorhandensein eines Uferreservates beeinflusst. Insgesamt schließen wir, dass Uferreservate vermutlich keine Dienstleistung für die Schädlingskontrolle erbringen. Nichtsdestotrotz belegen unsere Ergebnisse, dass Pufferstreifen an Flussufern nicht zu einer Steigerung der Dichte von blattfressenden Schädlingen führen. Dieser Befund sollte Manager, die um mögliche negative Folgen des Schutzes von Uferwäldern besorgt sind, beruhigen.

Keywords: Tropical, Forest, Conservation, Riparian strip, Riparian buffer, Herbivory, Pest control

Introduction

Agricultural production relies on many ecosystem services; pollination, pest control and decomposition are among the most important. However, recent agricultural expansion and intensification has caused declines in biodiversity, undermining many ecological processes. In some agricultural systems this has caused an increase in production costs and a drop in yields (Power, 2010). It is therefore increasingly important that we understand the biological systems underpinning key ecosystem services.

In some tropical systems, the protection of natural habitat can increase densities of important service providers and enhance ecosystem services. Pollination and fruit set in coffee plantations increase with proximity to natural habitat (Klein, Steffan–Dewenter, & Tscharntke, 2003; Ricketts, 2004). Positive relationships between pollination rate and proximity to forest have also been found for other tropical crops such as longan (Blanche, Ludwig, & Cunningham, 2006) and eggplant (Gemmill-Herren & Ochieng, 2008). Similarly, proximity to forest increases the densities of bird and bat species that feed on common pest species in coffee (Karp et al., 2013) and cacao plantations (Maas, Clough, & Tscharntke, 2013).

One of the crops expanding rapidly across the tropics is oil palm (*Elaeis guineensis*), but the extent to which non-crop habitats support ecosystem services in oil palm landscapes remains poorly documented. Mayfield (2005) found no relationship between proximity to forest and pollination rates of oil palm in Costa Rica, and recent evidence from Borneo also suggests that there is no relationship between distance from native forest and oil palm yield (Edwards, Edwards, Sloan, & Hamer, 2014). However, the relative provisioning of services and disservices by non-crop habitat in oil palm plantations is still unclear.

Of the processes potentially affected by non-crop habitat, the dynamics of pest populations and their predators is of particular interest. Many plantations in Malaysia and Indonesia (which currently produce > 80% of the global supply of palm oil (FAO, 2014)) practice Integrated Pest Management approaches; they do not routinely apply pesticides and are therefore affected by naturally occurring densities of pests and pest predators (Corley & Tinker, 2003; Koh, 2008).

Forest is commonly retained along waterways in oil palm plantations to maintain water quality, reduce flood risk and prevent soil erosion (e.g. Sabah Water Resources Enactment 1998). However, these riparian reserves can also conserve forest-dependent species not otherwise found in areas of oil palm (Gray, Slade, Mann, & Lewis, 2014). As spillover from forest fragments increases species richness in adjacent areas of oil palm (Lucey & Hill, 2012; Lucey et al., 2014) it is possible that the abundance or diversity of pests and/or pest predators increase with proximity to riparian reserves. However, non-crop habitat can also harbour crop-damaging insects (Naiman & Decamps, 1997) and birds (Deschênes, Bélanger, & Giroux, 2003). Overall, the extent to which riparian reserves support ecosystem services or disservices within agricultural landscapes remains understudied.

Here, we assess whether riparian reserves affect the activity of defoliating pests and their potential predators within an oil palm dominated landscape in Sabah, Malaysia. We hypothesised that proximity to a riparian reserve could either a) increase predation on pests and decrease herbivory rates, or b) increase pest activity and herbivory rates. In addition, as positive relationships have been found between the size and species richness of forest fragments and the richness of species spilling over into surrounding oil palm (Lucey et al., 2014), we hypothesised that any increase or decrease in pest activity would be enhanced with greater riparian reserve widths.

Materials and methods

Data collection

All study sites were located around the Stability of Altered Forest Ecosystems (SAFE) project site in Sabah, Malaysian Borneo (117.50 N, 4.60 E). Details of the landscape are given in Ewers et al. (2011).

We collected data from a total of 14 riverside sites (see Appendix A: Fig. 1) between April and November 2012. Eight sites had a riparian reserve flanking the river (mean forest width measured on one side of the river = 54 m, sd = 38, minimum width = 12 m, maximum width = 101 m. Appendix A: Table 1 gives widths and data on vegetation structure for all sites). All riparian reserves had been previously logged before conversion to oil palm and were structurally similar to nearby logged forest. Riparian reserve widths varied around the legal requirements for the state of Sabah (20 m either side of rivers wider than 3 m, Sabah Water Resources Enactment 1998) and fall within or above the guidelines specified by the Malaysian National Interpretation of RSPO principles and criteria (RSPO, 2010). Six sites were lacking riparian forest. All sites were at least 1.5 km apart, and oil palms at all sites were planted between 2006 and 2011.

At each site we attached pest mimics to 29 existing, healthy oil palms. We used artificial pest mimics to avoid the problems associated with rearing large numbers of prey items and difficulties in establishing the identity of predators. Mimics were created from plasticine to resemble bagworms (Lepidoptera: Psychidae). Bagworms are one of the most important pests of oil palm; outbreaks resulting in defoliation of only 10 – 13% can reduce yields by up to 43% (Basri, Norman, & Hamdan, 1995; Kamarudin & Wahid, 2010). Plasticine pest mimics have been used to indicate predation rates in both tropical (Howe, Lövei, & Nachman, 2009; Koh &

Menge, 2006; Richards & Coley, 2007; Tvardikova & Novotny, 2012) and temperate ecosystems (Lluch, González-Gómez, Vega, & Simonetti, 2009; Skoczylas, Muth, & Niesenbaum, 2007). At sites with riparian reserves, the 29 palms were located in the first terrace adjacent to the riparian reserve boundary (i.e. along a transect running parallel to and approximately 15m from the riparian reserve edge, see Appendix A: Fig. 2). Palms were 5 - 10m apart (mean = 7.8m). Due to variation in reserve width we could not standardise the distance between these palms and the river across all sites. To ensure that any effects of riparian reserve presence were not confounded with distance to a river, at non-riparian reserve sites we selected palms to match the overall mean and distribution of the palm to river distances in riparian reserve sites. The distance of focal oil palms from the river did not differ significantly between sites with and without riparian reserves ($F_{1,424} = 1.9$, $p = 0.17$).

Each bagworm mimic was a cylinder (diameter 3.5mm, length 25mm) of non-toxic brown plasticine (Scholaquip Colorclay). Mimics this size were light enough to attach with a small amount of Loctite gel superglue and matched the dimensions of early instar bagworms (Mohd Basri & Kevan, 1995). Twenty-five palms at each site were baited with brown caterpillar mimics; two mimics were attached to each frond, 50 cm apart and on leaflets either side of the midrib. Two fronds on each palm were baited in this way (i.e. four mimics per palm) and mimics were recovered after 48 hours. Deployment and recovery of caterpillars always occurred between 8:30 am and 4pm, avoiding disruption to peak hours of pest predator foraging.

To clarify the extent to which attack rates on the mimics reflect expected predatory behaviour, we also recorded attack rates on mimics of different shapes and colours. Two additional palms at each site were baited with red caterpillar mimics and two with brown cubes. We expected that if the visual cues of the mimics elicited a predatory response, changing the shape of the mimic (to a cube, a neutral shape that does not resemble any natural prey item) or providing aposematic colouring (using red plasticine) would reduce attack rates.

Attack marks on the mimics were identified under a x20 field microscope using images from previous publications (Howe et al., 2009; Koh & Menge, 2006; Slade, 2007; Tvardikova & Novotny, 2012) and specimens from preliminary exclusion experiments. For each mimic, we recorded the presence or absence of attacks from mammals, arthropods and birds (Fig S3 gives examples of attack marks).

At each site we planted three palms to record herbivory rates. All were 14 months old and obtained from the same nursery. Excess fronds were removed so that all palms were approximately 1.3 m tall and only the five youngest fronds remained. The palms were planted 50 m apart at each site, along the same transects as the pest mimics (see Appendix A: Fig. 2) but 1 – 10 days after mimics were collected (to retain temporal continuity but avoid interference between the two stages of data collection). We photographed all the new growth on the palms (ensuring that herbivory recorded had occurred after planting) after approximately 5 months (mean = 138 days, sd = 7 days). This period of time was considered sufficient to detect any effects of riparian reserves on herbivore activity as a similar study detected significant differences in herbivory rates on palms of a similar age after only 21 days (Koh, 2008).

Analysis

All analyses were carried out in R (R Core Team, 2013), using the package lme4 (Bates, Maechler, & Bolker, 2014)

As potential predators could easily move between fronds on the same palm, caterpillars on the same palm are unlikely to be independent. Therefore, we calculated the total number of caterpillars attacked (successes) or not (failures) on each palm (n = 349 palms across 14 sites), for all potential predators combined, and then for each predator group separately. In each case we used the combined successes and failures as a two-column response variable in a binomial GLMM, specifying riparian reserve presence/absence as a fixed factor and oil palm age and site as random factors.

To test for differences in herbivory rates, we calculated the proportion of surface area lost for each frond using Image J software (Rasband, 2012) (number of fronds = 193, number of surviving palms = 36, across 14 sites). We tested for differences in the proportion of palm frond surface area lost to herbivores using a GLMM with presence/absence of riparian reserve and duration of exposure as fixed factors (the variation in exposure times was very limited in oil palm sites so we could not test for the two-way interaction). We specified palm ID nested within site as a random factor to take account of lack of independence within palm but retain statistical power. The proportion data were logit-transformed to meet model assumptions.

To test for an effect of riparian reserve width and vegetation complexity on frond herbivory rates, we used data just from riparian reserves (115 fronds across eight sites). The width of the riparian reserve at the point next to each experimental oil palm was calculated in a GIS (ArcMap version 10.1) to give an average width for each site. Vegetation complexity was calculated from a set of measurements taken at 12 points, each 30 m apart, in the centre of the focal section of each riparian reserve. At each point, we measured tree height, humus depth, canopy cover, mid-storey and understorey density, and calculated one numerical index capturing the greatest variation in these data (see methods in Gray et al., 2014). We then ran generalised linear models on data summarised to site level, using proportion leaf area lost (logit transformed) as a response variable, and width and vegetation complexity as fixed factors.

To retain a balanced design whilst testing for effects of mimic shape and colour we used data from the two palms with cubes and red caterpillars and the nearest two palms with brown caterpillar mimics. We calculated the total number of mimics with and without attack marks on each palm as above and ran separate binomial GLMMs with either colour (n = 56 across 14 sites) or shape (n = 56 across 14 sites) specified as a fixed factor, and oil palm age, riparian reserve presence and site specified as random factors.

Results

We retrieved 1547 plasticine mimics and 36 oil palms from which we measured the attack rate of potential predators of pests and corresponding herbivory rates. 474 caterpillars were attacked by arthropods, 322 by birds, and only 10 by mammals.

Pest control service

53% of mimics were attacked in sites with a riparian reserve, compared to 37% in areas of oil palm without a riparian reserve; this difference was marginally non-significant (Fig. 1A; Table 1). The proportion of mimics attacked by arthropods was significantly higher in areas with a riparian reserve (Fig. 1B; Table 1). There was no difference in the proportion of mimics attacked by birds between sites with and without a riparian reserve (Fig. 1C; Table 1). There were too few mammal attacks to carry out a meaningful analysis on these data.

There was no significant effect of the presence of a riparian reserve on the proportion of oil palm leaf area consumed by herbivores but there was a significant positive relationship between herbivory and duration of exposure (Table 1; Fig. 2).

We found a weakly significant negative relationship between herbivory rate and riparian reserve width, but herbivory did not vary with vegetation complexity (Table 2; Appendix A: Fig. 4).

Colour and Shape

We found no significant effect of shape on the overall foraging activity of all predators combined, or on the subset of arthropod attacks. However, bird predation on caterpillar mimics was higher than on cubes (Table 3; Fig. 3). There was no significant effect of colour on overall foraging activity, bird attacks or arthropod attacks. There were no mammal attacks on the mimics in these data.

Discussion

Oil palm is one of the most rapidly expanding crops in tropical regions, but very little research has examined the extent to which non-crop habitat provides ecosystem services in these landscapes. We found some evidence that riparian reserves increase arthropod foraging activity in oil palm plantations, but in general this did not correspond to a change in herbivory on palm fronds. However, our data suggest that herbivory rates may be lower on oil palm adjacent to larger riparian reserves.

Pest control service

Our results suggest that retaining riparian reserves increases the foraging activity of arthropods that bite or chew prey (e.g. ants, centipedes, beetles) on oil palms. This is likely to be the result of spillover from populations in the riparian reserves (Lucey & Hill, 2012; Lucey et al., 2014). However, our methodological study (see below) calls into question the extent to which the higher proportion of attack marks from arthropods reflects a higher level of predation on real pests. It may be that the increase in arthropod attacks results from an overall increase in arthropod foraging activity, but not of pest predators in particular.

We found that the proportion of artificial pest mimics attacked by birds was not elevated in the vicinity of riparian reserves. This may be because forest fragments do not increase bird abundance or diversity in surrounding areas of oil palm (Edwards et al., 2010), and/or because populations of birds existing exclusively within oil palm plantations provide adequate pest control services. The results of our methodological study (see below) indicate that attack rates on mimics by birds are more likely to reflect real predation on living pests than data on mimic attack rates by arthropods. We can therefore be more confident that the data on bird attack rates reflects the role of riparian reserves in provisioning of ecosystem services.

The results from our assessment of herbivory rates provide the strongest evidence that riparian reserves characteristic of oil palm landscapes in our study area do not provide a pest control service; there was no significant difference in herbivore activity between sites with and without riparian reserves. However, we were not able to collect data during a pest outbreak. Outbreaks occur infrequently and are economically much more consequential than background herbivory rates (Basri et al., 1995; Kamarudin & Wahid, 2010). It is possible that service provision from riparian reserves is only apparent under such conditions, when the population of predators of pests supported by pure oil palm stands becomes saturated with prey. In addition, we were only measuring the impact of defoliating herbivores, and it is possible that the presence of natural habitat in oil palm reserves has a different effect on other pest guilds such as seed predators and stem or root pests.

Previous studies have found that increasing the width of riparian reserves in oil palm can increase the species richness or diversity of some species (Gray et al., 2014; Viegas, Stenert, Schulz, & Maltchik, 2014) and that spillover increases with forest fragment size (Lucey et al., 2014). We found some evidence that wider reserves may provide a better pest control service, but as our sample size was very small we hesitate to draw strong conclusions about the extent to which this is the case. In addition, the undergrowth in the oil palm plantations, proximity to larger blocks of forest and the complexity of forest fragment edges may affect the pest and pest predator abundances, and the impact of these factors also deserves further investigation.

Although we found little evidence that conserving riparian forest provides a pest control service, it is equally important that we found no pest “disservice” created by retaining the reserves. This evidence should reassure oil palm managers concerned about negative impacts of conserving non-crop habitat. The extent to which riparian reserves provide other ecosystem services aside from hydrological services also deserves further attention. For example, in our study area in Borneo, aboveground biomass is higher in riparian reserves compared to adjacent areas of oil palm (Singh, 2012). Combining all the possible costs and benefits of conserving riparian reserves will be necessary to inform management guidelines and policy.

Colour and shape

The results of studies using artificial mimics should be interpreted with caution, as the extent to which attack marks on mimics correlate with real predation rates remains unclear (Howe et al., 2009). We found that bird attacks dropped when the mimic no longer resembled a prey item, but that there was no change in arthropod attacks, suggesting that attack marks from birds are more likely to correspond to predatory behaviour. This is probably because birds rely more on visual cues, whereas arthropods rely much more on olfactory cues and are unlikely to be mistaking the mimics for potential prey (Tvardikova & Novotny, 2012). It is possible that the plasticine mimics elicit a response from foraging arthropods that would not attack pest species on oil palm. Therefore, we suggest that attack rates on plasticine pest mimics are indicative of density or activity of foraging arthropods rather than an actual predation rate.

We did not find lower attack rates from either birds or arthropods on aposematic (warning) mimics. The dependence of arthropods on olfactory cues may also explain this result, whereas the lack of an effect of colour on bird attacks may be because frugivorous species mistook the mimic for the red colour of the ripe oil palm fruits; several bird species within oil palm plantations are known to feed on palm fruit (Chenon & Susanto, 2006). It is not possible to determine from our data whether the attacks on brown and red mimics are similar because they both attract the attention of the same bird species, or those with different feeding behaviours.

We hope that this methodological assessment will provide a useful insight for future such studies. Comparative studies with live bait and temporally matched data on the densities of foraging arthropods will be very valuable to clarify what information is obtained from attack marks on plasticine mimics.

Conclusions

The riparian reserves typical of current oil palm plantations may increase the foraging activity of arthropods in adjacent areas of oil palm, but our results do not suggest that this corresponds to a reduction in herbivory on palm fronds under normal pest densities. However, the extent to which wider reserves may provide pest control services deserves further investigation. Our data suggest that the use of artificial pest mimics is likely to be more informative about the predatory behaviour of birds than arthropods, and this should be taken into account by future studies using this method. Importantly, our results show that riparian reserves do not increase defoliating pest activity, and this information should be highlighted in circumstances where doubt over pest problems may prevent the protection of this habitat.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at XXXXX.

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Legends

Fig. 1. The proportion of caterpillar mimics showing bite marks from a) all potential pest predators, b) arthropods and c) birds on oil palms near rivers with and without riparian reserves. While our analyses used the combined successes and failures as a two-column response variable, for clarity we present data here as proportions. Plots show mean ± 95% CI.

Fig. 2. The proportion of leaf area lost to herbivory in sites with and without a riparian reserve. Plot shows mean ± 95% CI.

Fig. 3. The proportion of mimics attacked by birds against mimic shape. While our analyses used the combined successes and failures as a two column response variable, for clarity we present data here as proportions. Plot shows mean ± 95% CI.