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Research paper

Plant-pollinator interactions and bee functional diversity are driven by agroforests in rice-dominated landscapes

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ABSTRACT

Wild and domestic bees are essential for the pollination of crops in home gardens, agroforests and vegetable fields of rice smallholders. However, it remains unclear how rice fields and agroforests affect pollinator communities. We investigated the effects of habitat loss and isolation on four different components of bee diversity: abundance, species richness, functional diversity, and plant-pollinator interactions.

Flower-visiting bees were recorded in a lowland rice-based production region on the Philippines. We sampled two different land use systems (agroforests and rice fields) and along a gradient of habitat isolation (isolated rice fields and rice fields connected to agroforests).

All components of bee diversity were higher in agroforests than in rice fields. Especially above-ground nesting and long-tongued species were adversely affected by rice field habitats and body sizes decreased with isolation from agroforests. For plant-pollinator interactions we found that plants received less diverse pollinator visits in isolated rice fields.

In conclusion, agroforests provide important food and nesting resources for bees that translate into taxonomically and functionally diverse pollinator communities as well as stable pollinator visitation networks. These cultivation systems should therefore be maintained or expanded to ensure pollination services and biodiversity conservation. On the contrary, rice fields provide habitat for only few generalist bee species and flower visitation is reduced in isolated rice fields, possibly also leading to impaired pollination of wild plants and crops. Connectivity between bee habitats located in rice production areas is probably disrupted even after a few hundred meters and should therefore be promoted by measures like flower strips in rice fields.

1. Introduction

Pollination is one of the key ecosystem services in agricultural landscapes with a steadily increasing monetary value for food production over the last decade (200–350 billion $ per year in 2005; Lautenbach et al., 2012). Moreover, insect-pollinated crops are often rich in micronutrients and vitamins and thus play an important role in human diets (Chaplin-Kramer et al., 2014). This is particularly important for poor smallholders, like rice farmers in South-East-Asia, who suffer from malnutrition due to uniform rice-based diets (Zamora et al., 2013) and are therefore encouraged to produce nutrient-rich and insect-pollinated crops in agroforests, home gardens and rice fields during the off-season (Huong et al., 2013; Zamora et al., 2013). Tomatoes, cucumbers and pumpkins are commonly planted and it is well-known that the yield and quality of those crops can be substantially enhanced through insect pollination (Klein et al., 2007). Despite the importance of pollinators, studies focusing on their management in rice production landscapes are largely lacking.

Global land use changes including the application of fertilizer, pesticides and mechanization (Foley et al., 2011) can also be observed in South-East-Asia, often resulting in intensively managed rice production monocultures (FAO, 2014). Therefore, ongoing pollinator declines might cause pollination limitation, reduced yields and severe economic losses for farmers (Garibaldi et al., 2016; Potts et al., 2010).

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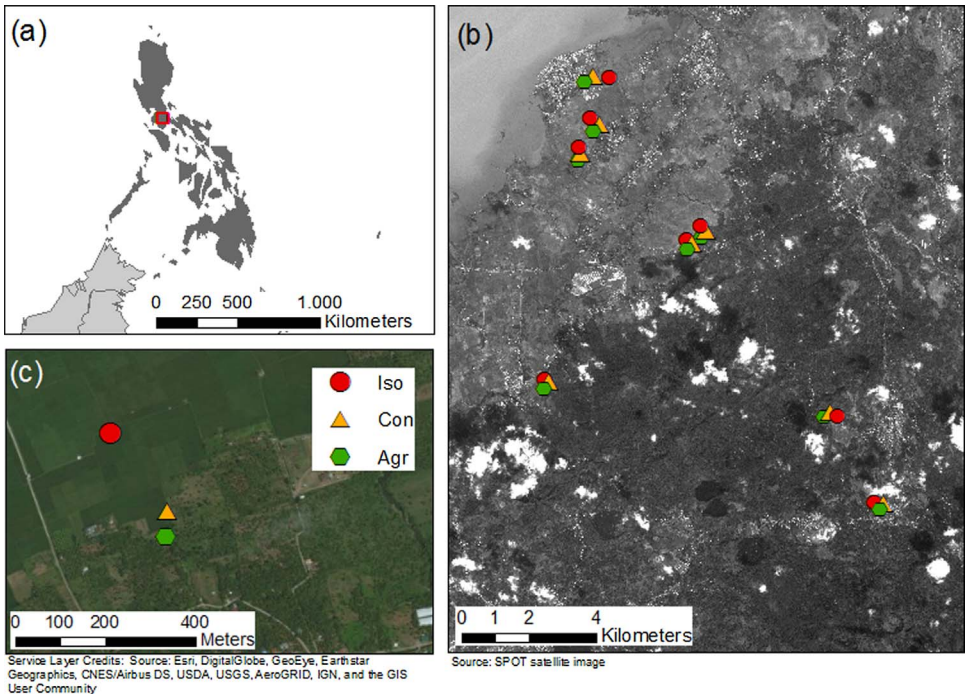

Fig. 1. Map showing (a) the study region on Luzon, the main island of the Philippines, (b) the location of the 24 study sites in the study region close to the city Los Banos and (c) the experimental design in an example landscape with the three different habitats representing different land use types and a gradient of isolation from structurally complex agroforests. Within a minimum radius of 100 m around isolated rice fields (Iso) only rice fields were present. Connected rice fields (Con) were placed at a minimum distance of 300 m from the isolated rice field and adjacent to an agroforest (Agr).

In many regions of the Philippines practically no natural habitat is left (Mohri et al., 2013) making it especially important to study how remaining human-altered land use types affect pollinators. For instance, agriculturally managed habitats like agroforests can play an essential role for managing ecosystem services, agricultural production and also biodiversity conservation (Clough et al., 2011).

In fragmented landscapes local habitat quality and connectivity are two major drivers for pollinator communities (Hagen et al., 2012), as mobile organisms move between different habitat and land use types (spillover; Blitzer et al., 2012; Mandelik et al., 2012). Despite the great importance of rice cultivation in tropical agroecosystems, its habitat suitability for pollinators has to our knowledge never been studied although field bunds and fallow stages may provide valuable flower and nesting resources for bees. Stable and diverse pollinator communities in these habitats are especially important if the rice fields are used for additional fruit and vegetable production during the off-season. Additionally, the habitat suitability of rice fields is crucial as the matrix between habitats determines the strength of habitat fragmentation effects (Newmark et al., 2017; Watling et al., 2011). Therefore, it is important to know whether rice fields are a hostile matrix for bees or whether they may connect populations between habitat types where pollination services are needed for wild plants and crops.

Several studies focus on the effects of habitat loss and isolation on pollinator richness and abundance (Garibaldi et al., 2011) and more recently on functional diversity and the functional structure of pollinator communities (Forrest et al., 2015; Rader et al., 2014). Land use intensification causes shifts in the dominating traits within communities usually resulting in a loss of specialized species (Gámez-Virués et al., 2015) reflecting, for instance, differences in the availability of floral resources, nesting habitats and habitat isolation (Bommarco et al., 2010; Forrest et al., 2015).

Plant-pollinator networks represent a different aspect of biodiversity that focuses on the interaction of species (Dormann et al., 2009). They have been analyzed with respect to local land use management (Forup et al., 2008; Weiner et al., 2014), but studies that investigate habitat fragmentation effects on pollination networks are rare (but see Carvalheiro et al., 2011). Novel approaches aim at the linkage of functional diversity and network architecture (Schleuning et al., 2015) by integrating traits in plant-pollinator interaction networks.

These different components of biodiversity, i.e. the species, their functional traits and interactions, are vital for the effectivity and stability of ecosystem functions and services (Cardinale et al., 2012). To our knowledge there is no study comprehensively analyzing land use and connectivity effects on taxonomic and functional diversity as well as the diversity of plant-pollinator interactions (e.g. Shannon interaction diversity; Dormann et al., 2009).

This study focuses on the effects of spillover of bees from agroforestry systems into rice areas to assess the habitat suitability of both and to determine the matrix quality of rice fields and their potential to connect different agroforests, home gardens or crops planted within rice fields that require pollination services for smallholder fruit and vegetable production in the Philippines. Our aim is to develop concrete management recommendations for optimized pollination services and biodiversity conservation. We analyze the effects of different land use types (rice fields and agroforestry systems) and habitat isolation on four components of biodiversity, i.e. abundance, taxonomic and functional diversity of bee communities and the complexity of plant-pollinator interactions. Additionally, we investigate how these drivers cause shifts of certain traits (i.e. body size, tongue length and nesting requirements) within bee communities.

The following hypotheses were tested:

(1) Agricultural land use is an important factor shaping bee communities and biotic interactions. We expect higher bee abundance, taxonomic and functional diversity in structurally complex agroforests than in rice fields. Furthermore, we expect plant-pollinator interactions to be more complex in agroforests.
(2) Isolation from structurally complex habitat types such as agroforests should have negative impacts on bee communities. We hypothesize that increasing isolation from agroforests decreases bee abundance, taxonomic and functional diversity in rice fields. Additionally, we expect that the complexity of plant-pollinator interactions will be reduced.