Agriculture, Ecosystems and Environment 235 (2016) 1–12

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Landscape structure influences bee community and coffee pollination at different spatial scales

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ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form 2 October 2016
Accepted 5 October 2016
Available online xxx

Keywords:
Ecosystem services
Landscape ecology
Multi scale analysis
Crop pollination
Bees
Spatial scale
Coffee
Land-use change

ABSTRACT

Although several studies have shown that the presence of bees results in increased crop yields, the mechanisms that determine pollination service across different spatial scales are still largely unknown. Here, we evaluated the influence of landscape structure over bee community composition and coffee (*Coffea arabica*) pollination. Our study was undertaken in one of the most important coffee-producing regions of Brazil, and comprised nine landscapes of sun coffee plantations surrounded by different amounts of Atlantic Forest remnants. Using floral exclusion experiments we evaluated fruit set in 15 coffee shrubs per landscape. We also sampled the bees visiting coffee flowers. Our analyses were made at two landscape scales, with 1 and 2 km radii, and one shrub scale, with 300 m radius around each coffee shrub. We collected 241 bee individuals and identified a total of 22 species. The honeybee *Apis mellifera* (Apini) was the most abundant flower visitor followed by *Trigona spinipes* (Meliponini). Native bee abundance, richness and diversity were positively affected by forest cover at the shrub scale. Honeybee abundance, on the other hand, was negatively affected by forest cover at the shrub scale. The presence of bees resulted in an increase in coffee fruit set of 28%. *A. mellifera* abundance positively affected fruit set across spatial scales, while the composition of the native bee community affected fruit set differently at the landscape scales than at the shrub scale. Our work shows that bee pollination services are affected by landscape structure at different spatial scales. These findings can be used in conservation and agricultural planning to maximize crop production while safeguarding biodiversity and the provision of pollination services.

1. Introduction

Crop pollination is a regulation ecosystem service (MEA, 2005), which can control the size and quality of harvests (Aizen et al., 2009; Heard, 1999; Klein et al., 2007; Roubik 1995). Several crops distributed worldwide show a positive relationship between fruit production and pollinator density and richness (Garibaldi et al., 2016, 2013). Actually, more than 70% of the world crops are depending upon animal pollination and the majority of these crops are most effectively pollinated by bees (Aizen et al., 2009; Klein et al., 2007). The contribution of bees to agricultural production is therefore remarkable, as 35% of global food production comes from crops that depend on pollination (Klein et al., 2007).

This impressive numbers are mostly a consequence of a landscape complementation between natural habitats and agricultural fields that can provide different kind of resources to pollinators. Temporal pulses in resource availability in crop fields can intensify a cross-habitat spillover of bees from adjacent natural habitats to crop fields (Tscharntke et al., 2012), thereby providing or enhancing crop pollination service. This spillover effect generally occurs with more generalist species, presenting high dispersal ranges and more prone to use matrix resources (Tscharntke et al., 2012).

Bee pollination services are increasingly threatened by the human-mediated modification of natural habitats (Biesmeijer et al., 2006; Kremen et al., 2007; Potts et al., 2010; Vanbergen and Initiative, 2013). In particular, habitat loss and fragmentation have been identified among the major drivers of global bee declines (Brown and Paxton 2009; Gonzalez-Varo et al., 2013; Potts et al., 2010). Because natural habitats supply food and nesting resources for pollinators (Roubik, 1992), the loss and fragmentation of these habitats can affect the density and behavior of pollinators (Hadley and Betts, 2012). As the rates of pollinator loss seem to be faster in the tropics (Ricketts et al., 2008), probably due to the fast

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http://dx.doi.org/10.1016/j.agee.2016.10.008
0167-8809/

conversion of natural habitats to agricultural landscapes (Hansen et al., 2013), there is a pressing need to understand how land use changes impact the provision of pollination services in the tropics (Viana et al., 2012).

Few studies have quantified the effect of landscape structure on bee community and fruit set. These include works in watermelon (Kremen et al., 2004), sweet cherry (Holzschuh et al., 2012), maize (Danner et al., 2014), blueberry (Benjamin et al., 2014), eggplant (Gemmill-Herren and Ochieng, 2008), cucumber (Motzke et al., 2016) and coffee (Jha and Vandermeer, 2010). In these studies, the analysis of landscape structure mainly consisted in measuring the distance to forest patches (Carvalheiro et al., 2010; Krishnan et al., 2012; Ricketts, 2004; Ricketts et al., 2004; Saunders and Luck, 2014) or the total amount of native habitat (Brosi et al., 2008; Holzschuh et al., 2010; Le Féon et al., 2010). Indeed, pollination services and crop production has been shown to decrease with increasing distance to natural habitats (see Garibaldi et al., 2011). Other pollination studies have also assessed the effect of type/intensity of farm management (Boreux et al., 2013a,b; Bravo-Monroy et al., 2015; Carvalheiro et al., 2011; De Marco and Coelho, 2004; Klein et al., 2003b, 2002; Shuler et al., 2005; Vergara and Badano, 2009). However, the influence of matrix composition and habitat configuration (besides habitat isolation) over the structure and dynamics of pollinator assemblies and their resulting pollination services are still insufficiently understood, despite theoretical models showing that landscape fragmentation can modulate the provision of different services (Mitchell et al., 2015).

One of the most studied tropical model systems is coffee, because it is one of the most widely cultivated and economically valuable crops in the tropics (Donald, 2004; Jha et al., 2014), involving 25 million farmers and 125 million people indirectly (Ngo et al., 2011). Since the arrival of coffee to Brazil in the 18th century (Conab, 2015), the country has become the world's largest coffee producer (FAOSTATS, 2012). It is also one of Brazil's main export commodities, representing 30% of the world production (ABIC, 2012). In Brazil, coffee is mostly produced in monoculture systems under full sun (89% of all coffee grown in the country in 2012, Jha et al., 2014). Although coffee (*C. arabica*) flowers are self-compatible and present high rates of self-pollination (Carvalho and Krug, 1949), the crop exhibits increased per-bush fruit set and increased field-level crop yields when exposed to insect pollination (De Marco and Coelho, 2004; Klein et al. 2008,2003b; Ricketts et al. 2004). Several studies have demonstrated that the presence of bees in coffee plantations results in an increase in grain production (De Marco and Coelho, 2004; Klein et al., 2003a; Ngo et al., 2011; Ricketts et al., 2004; Vergara and Badano, 2009).

Although coffee pollination can be affected by isolation to forest and farm management (De Marco and Coelho, 2004; Klein et al., 2003b; Krishnan et al., 2012; Ricketts et al., 2004), the broader effects of landscape structure on coffee pollination at different spatial scales is still poorly known. As species perceive and use space differently (Ritchie and Olff, 1999), bee species can respond differently to local and landscape factors (Benjamin et al., 2014; Brosi et al., 2008). The response of bees to landscape structure should be directly influenced by their foraging ranges, which can also be affected by environmental conditions and life-history characteristics, such as sociality or trophic specialization (Greenleaf et al., 2007). The optimal spatial scale to detect the landscape effects on coffee pollination, i.e. the scale of effect, is thus expected to vary with bee body size, which is a good predictor of foraging range (Greenleaf et al., 2007), and other pollinators life-history characteristics. It is therefore important to consider different spatial scales when assessing the influence of landscape on pollination services (Veddeler et al., 2006; Tscharntke et al., 2012; Benjamin et al., 2014). Our study aimed to fill this knowledge gap, by assessing the multi-scale relationship between landscape structure, bee community and pollination service in coffee plantations.

By analyzing nine landscapes from one of the main coffee-producing regions of Brazil, composed by mosaics of sun coffee

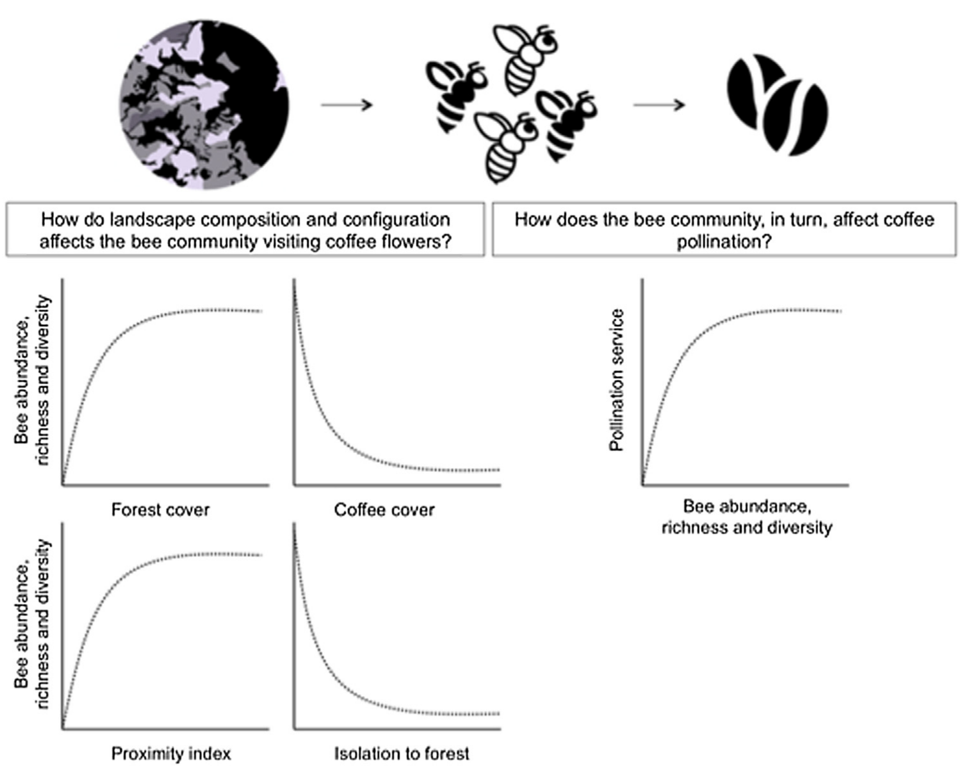

Fig. 1. Predicted relationships between landscape structure metrics, bee community variables and pollination service.