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Impact of forest fragments on bee visits and fruit set in rain-fed and irrigated coffee agro-forests

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ABSTRACT

Forest fragments in agricultural landscapes are recognised to provide a variety of ecosystem services, several of which benefit neighbouring agricultural land uses. Pollination of crops is one such service that has attracted much research and public attention, yet the dependency of crops on pollinators, and the role of forest fragments in providing this service, remains contentious. Indeed, the trend towards increasing crop production through intensification is at odds with the expected concurrent decline in pollination. We investigated the combined effect of distance from forest and forest size on pollinator abundance at coffee agro-forests in Kodagu District, India, under two contrasting flowering scenarios: irrigation triggered flowering in a single agro-forest, and rain triggered flowering at all the remaining agro-forests that received rain but were not previously irrigated. Three social bee species, *Apis dorsata*, *Apis cerana* and *Tetragonula iridipennis* were the main flower visitors. In rain-fed agro-forests, the total visitor abundance at coffee flowers decreased with increasing distance to the nearest forest. When the three main pollinators were analysed separately, the abundances of *A. dorsata* and *T. iridipennis* decreased with increasing distance from a neighbouring forest patch but this distance effect was reduced with an increase in size of the nearby forest. An increase in pollinator abundance at coffee flowers increased coffee fruit set in rain-fed agro-forests. Irrigated agro-forests had far higher pollinator abundance and fruit set than rain-fed agro-forests. We attribute this to the small-scale staggered flowering of irrigated agro-forests resulting in the concentration of pollinators at these sites regardless of its proximity to forests or the size of nearby forest. Agro-forest shade tree species richness also negatively affected pollinator abundance in rain-fed agro-forests. Although our results show that distance to forest and size of neighbouring forest fragments do affect the abundance of pollinators at coffee, at least in rain-fed agro-forests, justifying the conservation of large forest remnants is problematic on this account as there was no direct effect of forest on coffee fruit set. This is likely to be because there remains a high density of forest remnants within Kodagu, and a threshold of forest cover at which crop fruit set begins to be affected by pollinator scarcity has yet to be reached. By controlling the timing of flowering through irrigation or managing domesticated bee hives, farmers effectively reduce the dependency on nearby forest cover for pollinator services irrespective of the distance between forests and agro-forests, but these management practices incur costs that not every farmer can cover.

1. Introduction

Conversion of forested lands for agriculture has increasingly fragmented natural habitats leading to loss of suitable pollinator habitat (Kearns et al., 1998). Although fragmentation could lead to spatial isolation of habitats, the presence of a matrix (such as coffee grown under native shade) that is conducive for biodiversity around forest fragments may lessen the overall effect of fragmentation and could facilitate movement of forest-dependent species between forest fragments (Simberloff et al., 1992; Ricketts, 2001). Under such circumstances, forest fragments interspersed in an agricultural landscape may support a number of ecosystem services, including pollination (Ricketts, 2004; Julier and Roulston, 2009). In the tropics, coffee agro-forests retain varying degrees of shade and shade tree diversity, which in turn support high diversities of vertebrates, invertebrates and plants (Perfecto et al., 2007). This is expected to have a positive effect

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on ecosystem services such as pollinator services (see study on coffee by Jha and Vandermeer, 2009). In the event that pollinator abundance promotes higher crop fruit set, then pollination services can be used as an economic justification for conserving remnant forests and traditional shade trees within coffee agro-forests.

In addition to loss of pollinator habitats, an increasing demand for pollination services due to ever expanding agricultural fruit set could cause a deficit in pollination services for many crops (Ghazoul, 2005). Several studies on a variety of crop species demonstrated the importance of entomophilous pollination service for initial fruit set (Blanche et al., 2006; Klein et al., 2007) or crop fruit set (De Marco and Coelho, 2004), even in some self-fertile species (De Marco and Coelho, 2004; Degrandi-Hoffman and Chambers, 2006). Other studies showed that proximity to forests increases pollinator abundance and diversity within agricultural crops, even in biodiversity rich areas (Perfecto and Vandermeer, 2002; Klein et al., 2003a,b; Ricketts, 2004; Blanche and Cunningham, 2005; Blanche et al., 2006; Chacoff and Aizen, 2006; Carvalheiro et al., 2010). Most of the studies on coffee, however, have investigated the effects of only a few forest remnants on fruit set (e.g. Klein et al., 2003a,b: one fragment of undetermined size, but exceeding 100,000 ha; Ricketts, 2004: three fragments of 34, 46 and 111 ha) and have not explored the effects of forest fragments of varying size and distances to agro-forests on pollinator abundance and final crop fruit set. Furthermore, the role of very small forest fragments (i.e. less than 5 ha) as sources of pollinators is often ignored. Larger landscape scale studies on pollination services and their contribution to crop fruit set are needed, not least to bridge the gap between the many local scale studies that indicate the dependency of crop fruit set on pollinators which are supported by natural habitats (see studies on various crops including coffee by Klein et al., 2003b; Ricketts, 2004; Blanche and Cunningham, 2005; Chacoff and Aizen, 2006; Carvalheiro et al., 2010), and global studies that show that fruit set of pollinator-dependent crops has kept up with other crops despite habitat degradation (Aizen et al., 2008; Ghazoul and Koh, 2010).

In recent years farmers have been increasingly relying on irrigation to induce flowering due to irregular rainfall patterns. Irrigation triggers flowering in individual agro-forests (i.e. only the agro-forest that has been irrigated) leading to staggered flowering at a small-scale while rainfall leads to synchronous flowering across the landscape at all the remaining agro-forests (i.e. the ones that were not irrigated previously) that receives rain. Since irrigation and rain create different scenarios in terms of distribution of flowering resources, it could influence pollinator abundance especially since coffee flowers remain fresh for only 1 day. Other characteristics of coffee agro-forests, such as shade tree species richness and density, shade cover (which is not necessarily correlated with shade tree density), as well as relative humidity which reportedly influences visitor abundance (Jha and Vandermeer, 2009; Vergara and Badano, 2009), were also included in the study. Since the foraging ranges and nesting preferences vary among the three main coffee pollinators in southern India, namely *Apis dorsata* F., *Apis cerana* Fabr. and *Tetragonula iridipennis* (Wille, 1983; Dyer and Seeley, 1991), we expected to find species specific responses to landscape attributes.

This study investigates the following objectives under irrigated and rain-fed agro-forests: (1) the effects of distance and size of the nearest forest fragment on pollinator abundance at coffee flowers and final fruit set (2) the influence of agro-forest characteristics (relative air humidity, shade, density of non-native shade trees, shade tree species richness) on pollinator abundance at coffee flowers and fruit set (3) the role of pollinator abundance on coffee fruit set.

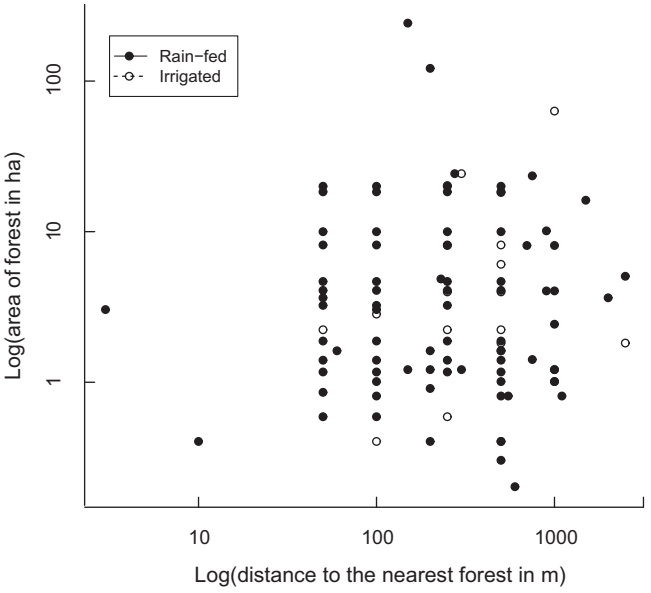

Fig. 1. Distribution of distance and size of nearest forest across irrigated and rain-fed sites. Filled circles represent rain-fed agro-forests, while empty circles represent irrigated agro-forests.

2. Materials and methods

2.1. Study area

The study was carried out in the district of Kodagu, south India, along the Western Ghats. The main agricultural product in Kodagu is coffee, grown mainly on hill slopes and covering 33% of the district's land area, with *Coffea canephora* Pierre ex Froehner comprising three quarters of the coffee cultivated area, the remaining being *C. arabica* L. Other major land uses include rice fields (21% of land area) in valley bottoms, and 'forests' (46%) (Elouard, 2000; Garcia et al., 2010), the designation of which is ambiguous. Two-thirds of the forested area (accounting for 30% of land area) is government-owned 'reserve forests' located in large blocks at the edge of the district political boundaries. About 16% of total land area is composed of over a thousand forests fragments scattered within the coffee and paddy matrix, the size of most being less than 1 ha to around 20 ha (Kalam and Thanuja, 2000).

The original vegetation in this area consisted of moist-deciduous to evergreen forests. The coffee agro-forests are shaded by either native trees (e.g. *Aporusa lindleyana* (Wt.) Baill, *Artocarpus heterophyllus* Lam., *Syzygium cumini* (L.) Skeels., *Dalbergia latifolia* Roxb., listed in declining order of abundance), or a mixture of native and exotic trees (the latter being mainly *Grevillea robusta* A. Cunn. ex R. Br.). Most coffee farmers grow pepper vines as a secondary crop and shade trees are often used as a trellis for pepper vines. *Grevillea robusta* is a fast growing exotic tree species which provides a better trellis for pepper vines than most native shade tree species and can also be harvested for timber. Prior permission from the government is not required to harvest this tree species since it is a non-native species. In light of these perceived benefits coffee farmers are gradually replacing native tree species with *G. robusta*, hence reducing shade tree species diversity within coffee agro-forests (Garcia et al., 2010).

2.2. Characteristics of the coffee agro-forests

In 2008, we selected 126 coffee agro-forests for our study. We used the size and distance from the edge of the nearest forest to quantify the impact of forest on coffee pollination (see Fig. 1). The