# Factors influencing pollinator abundance in Indigenous coffee farms of the Nilgiris, Western Ghats, India

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# Abstract

Wild pollinators are shown to be declining in many parts of the world where data and evidence exist; trends could be similar in other regions, but data and evidence are lacking. Land-use change is recognized as the top driver of biodiversity loss, including pollinator loss. In this study, we focused on coffee plantations in Indigenous land holdings in the Nilgiri Biosphere Reserve in the Western Ghats of India, where changing agricultural practices and reducing tree shade diversity and/or changing tree cover type may threaten pollinator communities. We assessed pollinator abundance, through scan sampling of flowers, in ten coffee farms — five of which had (*Grevillea robusta*) silver oak as shade trees and five of which had native tree species. We then evaluated the combined effect of (a) tree cover type, (b) distance from the forest edge, and (c) area under coffee cultivation on the abundance of four dominant coffee pollinators (*Apis dorsata, A. cerana, A. florea*, and *Tetragonula iridipennis*) and the abundance of *Xylocopa* sp., which is also known as a coffee pollinator. We found that the abundances of all five species were associated positively with the area under coffee cultivation. The abundance of *A. cerana* and *T. iridipennis* were also associated with the distance from the forest edge; the closer a farm to the forest, the more individuals of *A. cerana* and *T. iridipennis* were found visiting coffee flowers on the farm. Lastly, we found no statistically significant relationship between the abundances of the five species examined and tree cover type (either mixed native forest trees or silver oak (*G. robusta)*). The absence of a pattern may have been driven partly by our relatively small sample size since the abundances of *A. cerana, A. florea*, and *T. iridipennis* were on average higher in farms with native tree species. Our results suggest that maintaining forests near coffee systems increases insect pollinator abundance (i.e., delivery of pollination services) in the case of *A. cerana* and *T. iridipennis* and maintaining forest cover with native tree species composition plays a role in supporting pollinator habitats as well as providing foraging resources.

Implications for insect conservation

In working with Indigenous land holdings in India, our results show that forests and land use (area under cultivation) play a key role in maintaining bee pollinators in coffee agroecosystems and further investigation is needed to clarify the role of tree cover type and insect populations.


# Introduction

It is widely accepted that pollination services, provided by a diversity of pollinators, are important for global food security, ecosystem integrity, nutrition and health security, and human well-being (Chaplin-Kramer et al., 2014; Huttenhower et al., 2012; IPBES, 2016; Klein et al., 2018; Ollerton, 2021; Potts et al., 2016). Pollination is an indisputably critical ecosystem service, with approximately 90% of our wild-growing plant communities (Ollerton et al., 2011) and 75% of our leading global crop types dependent on pollinators, to varying degrees (IPBES, 2016; Klein et al., 2007). This is no exception for India, which, together with China and the USA, accounts for approximately 30% of the total global cropland (FAO, 2020); important crops for India include mangoes, fresh vegetables, tomatoes, soybeans, eggplant, cardamom, coffee, and others — which are all pollinator-dependent (Abraham et al., 2013; Agarwal et al., 2013; Basu et al., 2011; Bhattacharya & Basu, 2018; Cooley & Vallejo-Marín, 2021; Garibaldi et al., 2021; Huda et al., 2015; Krishnan et al., 2012).

Studies from various parts of the world have suggested that bees are on the decline (Biesmeijer et al., 2006; Cameron & Sadd, 2020; Gallai et al., 2009; IPBES, 2016; Koh et al., 2016; Orr et al., 2021; Potts et al., 2016). Yet, data and evidence are sparse from some regions. The largest drivers of biodiversity loss are land- and sea-use change, direct exploitation of nature, climate change, invasive alien species and pollution (IPBES, 2016), which unsurprisingly, match the drivers of pollinator decline (Dicks et al., 2021; Goulson et al., 2015). Dicks et al. (2021) found changes in land cover and configuration to be important drivers of pollinator loss in most regions worldwide; for the Asia-Pacific region, the study found pesticides to be among the top three drivers of pollinator loss, which differs from the global ranking of drivers for biodiversity loss overall (i.e., not the same relative rank of importance). In terms of land configuration, native forests are known to play a beneficial role in wild bee populations (Aizen & Feinsinger, 2003; Ghazoul et al., 1998; Schrader et al., 2018), largely because native trees and older trees provide suitable nesting substrates for bees such as *Apis dorsata* (Thomas et al., 2009) and *Tetragonula* species (Bhatta et al., 2019). Proximity to forests or semi-natural sites increases pollinator species richness and abundance within agricultural systems (Blanche et al., 2006; Blanche & Cunningham, 2005; Chacoff & Aizen, 2006; Free, 1993; Klein et al., 2003; Kremen et al., 2002, 2004; Morandin & Winston, 2006; Ricketts, 2004; Viswanathan et al., 2020, 2020; Widhiono & Sudiana, 2016). Natural forests and semi-natural plots play an important role for pollinators and their delivery of pollination services in several important cash crops, including coffee and spices.

One of the most important global agricultural commodities is coffee (Khoury et al., 2014), worth approximately $40 billion/yr in production value alone and significantly more when considering retail value (Rhiney et al., 2021); coffee prices reached an average of $190.82 US cents/lb (July 2022). The coffee industry involves upwards of twenty-five million coffee farmers and producers (Donald, 2004; Jha et al., 2011; Pham et al., 2019). Coffee production occupies over 10 million hectares of land (FAO, 2021). India is the seventh top coffee producer in the world (Sänger, 2018), making coffee an important cash crop for India (Bhattacharya, 2014), being the seventh top coffee grower in the world, India produces approximately 3% of the total global coffee export, equivalent to approximately 334,000 metric tons (estimated for 2020–2021, Coffee Board of India), which mainly comes from smallholder farmers (Chengappa et al., 2017; DaMatta et al., 2007; Ranjan Jena & Grote, 2017), some of whom are Indigenous forest-dwelling tribes. In the Western Ghats of India, coffee is traditionally grown under an agroforestry landscape with a diversity of native shade trees or intercropped with pepper, but in recent years, some coffee farms have shifted to a more intensified cultivation system (Chengappa et al., 2017). Specifically, in the coffee-growing slopes of Nilgiri Biosphere Reserve, which spans across the States of Tamil Nadu, Karnataka, and Kerala, the characteristic coffee agro-forest is densely planted with coffee bushes under an evergreen forest patch close to human habitation. However, some coffee growers have shifted to using an exotic fast-growing monocrop of silver oak (*Grevillea robusta*) trees (Bali et al., 2007) to shade their coffee crops. The impact of this shift on pollinator communities is unclear.

For coffee, fruit set is known to increase with cross-pollination by bees – as shown in the Indonesian coffee agroecosystems (Klein et al., 2003); fruit set increased by approximately 12.3% in *C. arabica* and 16% in *C. robusta* (Klein et al., 2003) with "open pollination" treatment where all insects could access coffee flowers compared to "control" where insect pollinators were excluded from the treatment. Pollination is important not only for the quantity of coffee production but also the quality; sufficient coffee pollination results in double-seeded full berries (fruit), while a pollination deficit leads to peaberries (i.e., the development of one ovule into a single-seeded fruit) (Classen et al., 2014; Ghazoul & Krishnan, 2012; Krishnan et al., 2012). Previous studies on pollinators and coffee production in other regions have shown that coffee fruit set increases when coffee is grown near rainforests, even fragments (De Marco & Coelho, 2004; Klein et al., 2003; Ricketts, 2004; Ricketts et al., 2004), since many wild bees nest in natural habitats – large tree branches and cavities, rocks, etc. (Aizen & Feinsinger, 2003; Cunningham, 2000; Ghazoul et al., 1998). In a recent global meta-analysis of *Coffea arabica* systems, Moreaux et al. (2022) found animal pollination to be important for increasing fruit set by approximately 18%, yet when looking at habitat features such as forest cover, distance to nearby forest and forest canopy density, the study found that forest cover and distance to open forest were not to be correlated to bee species richness and fruit set – which does not support previous research (e.g., Klein, 2009; Ricketts, 2004) highlighting the need for further research on this topic.

The Western Ghats of India is a biodiversity hotspot (Myers et al., 2000) and a UNESCO World Heritage Site with "high geological, cultural and aesthetic values" but has undergone extensive loss in forest cover and biodiversity owing to land-use change (Ambinakudige & Choi, 2009; Daniels et al., 1995; Gupta et al., 2014; Kale et al., 2016). Data has been documented the last 60 years for honey bee stocks (i.e., hives) for India and the trend has been increasing (approx. 5 million hives in 1961 to almost 13 million hives in 2021) at the same time, data are lacking on the status and trends of wild bees, which are important for coffee production (Pannure, 2016; Veddeler et al., 2008). Previous studies have cited *Apis dorsata*, the giant Asian honey bee, as the main pollinator of coffee in the Kodagu district (Karnataka); Krishnan et al. (2012) found *A. dorsata* individuals comprising almost 60% of floral visits recorded on coffee (*C. canephora*), which was associated with increased coffee fruit production by 50% (Krishnan et al., 2012).

There is a knowledge gap regarding the impacts of reducing shade tree diversity or changing tree cover type on bee pollinators and their pollination services to coffee crops in the Western Ghats. In a study in Kodagu, "a coffee-growing region where a high percentage of native tree cover is still intact to provide shade for coffee plants" (Bhagwat et al., 2005) shade tree diversity has been shown to enhance coffee production and quality of *C. canephora* while reducing incidences of the coffee berry borer *Hypothenemus hampei* (Nesper et al., 2017).

We assessed bee abundance in small holdings of *Coffea arabica* grown under two types of tree cover – native forest trees and silver oak (*G. robusta)*. Based on previous work (Barrios et al., 2018; Nesper et al., 2017; Prado et al., 2018), we predicted that coffee farms with native tree cover would offer better delivery of pollination services compared to those with only silver oak (*G. robusta)*; bee abundance was used as proxy indicator of pollination services. In order to determine bee abundance, only insect visitors observed foraging on pollen or nectar were considered potential pollinators. We quantified bee abundance as a function of (a) tree cover type, (b) distance from the nearest forest edge, and (c) area under coffee cultivation. We examined the influence of these three factors on abundance of *Apis dorsata, A. cerana, A. florea*, *Tetragonula iridipennis* and *Xylocopa* sp., the dominant pollinators of coffee. Although *Xylocopa* has been reported as a minor pollinator in several studies (Krishnan et al., 2012; Prado et al., 2019; Samnegård et al., 2016), their efficiency in pollination is believed to be high in comparison to social bees (Klein et al., 2003).

## Methods

# Study sites

The Nilgiri Biosphere Reserve (NBR) is one of the top twenty-five global hotspots of biodiversity in the world based on the level of endemic fauna and flora (Baskaran et al., 2012) and within India is the "largest protected ecologically sensitive areas" (Srinivasan et al., 2021) the NBR is composed of protected forests and human-dominated landscapes, including that of tea, coffee and eucalyptus plantations, orchards and vegetable farms. We chose ten coffee-growing farms (*Coffea arabica*) during the coffee flowering season of February to May (2014), which were part of the agricultural land belonging to the Irula and Kurumba Indigenous communities of the NBR (Fig. 1). These lands are located within evergreen and semi-evergreen forests composed of native tree species such as *Syzygium cuminii*, *Bombax* sp., *Dalbergia* sp., *Toona ciliata, Canarium strictum, Albizzia lebbeck, Lannea coromandelica, Sapindus emarginatus*, and *Anogeissus latifolia. Bombax* sp. and *Artocarpus* sp. (LR, pers. obs.) were more common closer to human settlements, having spread from planted trees. We based our study design on the protocol developed by FAO and Vaissière et al., (2011) for testing pollination deficits in crops. Tree cover type (mixed vs. silver oak) was the treatment tested. Half of the farms (n = 5) had coffee with only the silver oak (*G. robusta*) species for shade, and the other half of the farms (n = 5) had coffee with a composition of > 5 native tree species for shade. All of the latter (mixed) were similar to each other in terms of tree species composition. The area under coffee production ranged from 0.5 ha to 1 ha, and the sites were at a minimum distance of 210 m from each other and a maximum of 1097 m (average = 564 m; standard deviation = 312 m) to eliminate issues that could arise due to spatial autocorrelation. All sites were selected based on similar topography, soil, slope, and exposure; in addition, all sites were managed in a similar way, with the exception of the independent variable tested (tree cover type) to minimize the effects of confounding factors. There were no managed bee colonies or bee boxes in any of the study sites. Distances from the nearest forest edge and tree cover type were recorded at each crop site.

# Floral density and bee activity

Four trained samplers collected data from the ten sites in rotation. Floral density was measured and standardized in four random plots at each site during the coffee bloom. Floral density has been an important predictor of bee abundance (Hamblin et al., 2018; Mahon & Hodge, 2022) although other studies have not shown an effect of floral density on pollinator visits (Elliott & Irwin, 2009; Essenberg, 2012). In order avoid any effect of floral density on bees within plots, we estimated number of flowers per transect and made sure that each transect had approximately 250 flowers. Flowers were sampled on two random branches of two adjacent coffee bushes in a given plot. No plot was sampled twice. At each site, six transects were walked four times a day (0800h, 1000h, 1300h, 1500h), and scan sampling for bees visiting coffee flowers, or floral units (approximately n = 250 flowers per transect, using a counter) was carried out to assess pollinator density/abundance (Vaissière et al., 2011). To measure pollinator diversity and abundance, we sampled insects visiting flowers in 5-minute sampling slots and walked in transects that were roughly 20–25 m long. Sweep netting was also done to assess the diversity and abundance of insects. The diversity counts were done after density counts. Only visitors foraging on pollen or nectar were considered potential pollinators.

# Data Analyses

We used the abundance of each of the five pollinator species (*A. dorsata, A. cerana, A. florea*, *Tetragonula iridipennis*, and *Xylocopa* sp.) as the response variable and (a) tree cover type (native trees vs. silver oak), (b) distance from the forest edge, and (c) area under coffee cultivation, as the explanatory variables. To assess these variables' potential influence on each pollinator species, we ran a generalized linear mixed regression model with a Poisson error distribution. We used the identity of the sites as a random effect to account for the fact that each site was surveyed multiple times (n = 24) during the flowering season. We also used the date at which each survey was conducted as a random effect to account for any temporal similarities, e.g., due to weather conditions. To estimate the amount of variance explained by each model, we used the "r.squaredGLMM" function in the "MuMin" package in R; for each model, we calculated the corresponding marginal and conditional $R^2$ values. The marginal $R^2$ value represents the amount of variance explained by the explanatory variables (i.e., the fixed effects), while the conditional $R^2$ value corresponds to the amount of variance explained by the whole model, i.e., including the random effects. To confirm there was no collinearity, we used the "vif" function in the "car" package (Fox & Weisberg, 2019) to measure the variance inflation factor (VIF) of each of the three variables in our models. In all cases, VIF was < 2; therefore, we retained all variables in the analyses. To confirm that our data were not spatially autocorrelated, we used the "ape" package (Paradis & Schliep, 2019) to calculate the Moran's I value of each model's residuals. In all five models, the p-value was > 0.05, suggesting no spatial autocorrelation. All analyses were conducted using the R statistical software (R Core Team, 2022).

# Results

A total of 24 species of insects were documented visiting the coffee flowers in the NBR during scan sampling. This included those within the orders Hymenoptera (10 spp. of bees and one unidentified wasp), Diptera (5 spp. of Syrphid flies, one sp. in Bombyliidae, one sp. in Ulidiidae and one sp. unidentified), Coleoptera (1 sp. each in Cantharidae, Elateridae and Curculionidae) and Hemiptera (1 sp. of Pyrrhocoridae).

The abundances of *A. dorsata*, *A. florea*, and *Xylocopa* sp. were mostly associated with the size of the coffee farm, meaning that the larger the size, the more individuals were found visiting the coffee flowers (Tables 1 and 2). The abundances of *A. cerana* and *T. iridipennis* were associated with the size of the farm and the distance from the nearest forest (Fig. 3; Tables 1 and 2). The larger the farm and the closer it was to the forest, the more individuals of *A. cerana* and *T. iridipennis* were found visiting coffee flowers. The relationship between tree cover type and flower visitation was not statistically significant for any of the five species examined (Tables 1 and 2), although the abundances, from scan sampling of *A. cerana, A. florea*, and *T. iridipennis* were on average higher in farms with native tree species.

Table 1
Results of the generalized linear mixed models showing the relationship between the three variables examined and the abundances of *A. dorsata*, *A. cerana*, and *A. florea*. Statistically significant effects in bold.

| | ***Apis dorsata*** | | | ***Apis cerana*** | | | ***Apis florea*** | | |
|---|---|---|---|---|---|---|---|---|---|
| *Variables* | *β* | *std. Error* | *p* | *β* | *std. Error* | *p* | *β* | *std. Error* | *p* |
| (Intercept) | -5.42 | 2.04 | **0.008** | -1.34 | 0.72 | 0.065 | -6.49 | 1.77 | **< 0.001** |
| treecover [Silveroak] | 1.06 | 0.79 | 0.184 | -0.19 | 0.22 | 0.388 | -0.49 | 0.70 | 0.487 |
| Area | 4.99 | 2.53 | **0.049** | 3.91 | 0.72 | **< 0.001** | 9.37 | 2.26 | **< 0.001** |
| Dist | 4.56 | 2.59 | 0.079 | -3.79 | 0.84 | **< 0.001** | 1.10 | 2.31 | 0.633 |
| $R^2$ Marginal / $R^2$ Conditional | 0.141 / 0.997 | | | 0.236 / 0.983 | | | 0.319 / 0.995 | | |

Table 2
Results of the generalized linear mixed models showing the relationship between the three variables examined and the abundances of *Tetragonula iridipennis* and *Xylocopa* sp. Statistically significant effects in bold.

| | ***Tetragonula iridipennis*** | | | ***Xylocopa* sp.** | | |
|---|---|---|---|---|---|---|
| *Variables* | *β* | *std. Error* | *p* | *β* | *std. Error* | *p* |
| (Intercept) | -6.01 | 0.97 | **< 0.001** | -13.36 | 4.22 | **0.002** |
| treecover [Silveroak] | -0.19 | 0.33 | 0.558 | 0.30 | 1.60 | 0.854 |
| Area | 9.84 | 1.21 | **< 0.001** | 12.04 | 5.20 | **0.020** |
| Dist | -2.83 | 1.32 | **0.033** | 1.91 | 5.60 | 0.733 |
| $R^2_{Marginal}$ / $R^2_{Conditional}$ | 0.578 / 0.994 | | | 0.306 / 0.949 | | |

# Discussion

Changes in land cover and configuration, land management, and pesticides have been identified as the top three drivers threatening pollinator communities across all regions of the world (Dicks et al., 2021). Surrounding natural or semi-natural landscapes are important for the preservation of nature and related ecosystem services (also referred to as nature's contributions to people (Díaz et al., 2018) such as pollination (Julier & Roulston, 2009; Millennium Ecosystem Assessment, 2005; Ricketts, 2004). This is supported by most studies examining the impacts of habitat fragmentation and isolation on pollinator richness and abundance (e.g., (Aizen & Feinsinger, 1994a, 1994b; Blanche et al., 2006; Carvalheiro et al., 2010; Klein et al., 2003; Klein et al., 2003; Perfecto & Vandermeer, 2002; Ricketts, 2004; Steffan-Dewenter & Tscharntke, 1999) but not all (Moreaux et al., 2022).

Our study contributes some empirical evidence that forest fragments are important for pollinators including bees. Forest areas and riparian strips (both small and large) provide potential nesting sites for some bee species. Krishnan et al., (2012) while studying coffee farms (*Coffea canephora*) in Kodagu, South India, demonstrated adjacent forest fragments (0.3–20 ha) positively impacted the number of insect pollinators, dominated by *Apis dorsata*. They found in their study that the giant honey bee *Apis dorsata* – known to nest in forested areas, was the main pollinator of coffee (58% of the total coffee flower visitors). In our study, there was a weaker link between nearby or adjacent forests and *A. dorsata*, although proximity from the forest was correlated to *A. cerana* and *T. iridipennis* bee species abundances. This may indicate that our study required another study period (i.e., more than one sampling season) or more replicates of study sites. Future research may wish to collect insect specimens to be able to identify them to species level, beyond morphospecies identifications, in order to determine diversity of insect visitors to each farm. In addition, future research to monitor insects could consider standardized or multiple methods in order to determine pollinator communities more accurately. For example, our study used pollination scan sampling to determine pollinator density, meaning "an insect will be recorded or not depending on whether it is present at the time a given flower is first seen" (FAO, 2011) and we complemented this with sweep net sampling, however the sweep net sampling results were not used in our analysis. Other studies use slightly different methods to monitor pollinators on coffee such as flower visits consisting of bees observed to both carry pollen and contact the coffee flower stigma (Boreux et al., 2013) or pollinator observations on selected branches/flowers (Krishnan et al., 2012) – this difference in insect pollinator monitoring precludes a direct comparison of pollinator communities in coffee systems. Our study did support, in part, the findings of the meta-analysis done by Moreaux et al. (2022), where forest proximity was not a strong factor in determining bee richness or in our case, *A. dorsata, A. florea*, and *Xylocopa* sp bee abundance. Further research is needed to study the importance of distance from forest fragments, forest fragment size, and forest fragment/habitat quality in influencing nearby pollinator communities for coffee agroecosystems. These factors are hard to isolate (Boreux et al., 2013).

Lastly, the importance of natural forest fragments to coffee agroecosystems and coffee pollinators may be diminished if the shade tree diversity within coffee farms is sufficient in providing nesting sites to pollinators – this relationship has not been sufficiently studied within Indian coffee systems. Shade coffee systems grown under traditional or rustic management have shown potential to have the capacity to house equivalent levels of biodiversity compared to those of adjacent forests (e.g., arthropods) in other regions such as Latin America (Perfecto et al., 1996; Philpott et al., 2008 etc.). Not only can diversity (heterogeneity) of shade trees be of importance but the type (species) of shade tree can also be important for maintaining insect or other faunal diversity in those systems.

There is evidence that a diversity of native tree cover for shade helps maintain floral and faunal diversity (Badrinarayanan et al., 2001; Bhagwat et al., 2005; Dolia et al., 2008; Kapoor, 2008) and within coffee agroecosystems, this diversity supports pollinator communities (Belavadi, 2020). In a recent study, 107 species of shade trees were found in coffee systems in the Kodagu district (Belavadi, 2020). Trees such as *Schefflera venulose* and *S. wallachiana* have their flowering season following coffee; this sequential blooming supports pollinators with a stable source of nectar and pollen (i.e., provisioning of foraging sources during non-flowering season) with added benefits of providing microclimates for better fruit maturation (Krishnan et al., 2017). Planting indigenous tree species such as *Dalbergia latifolia, Ficus racemosa*, and *A. fraxinifolius* could have multiple benefits (Maheswarappa et al., 2022; Nath et al., 2016) including those for soil (e.g., improved soil quality through litter fall or reduced soil erosion (Dhanya et al., 2014), timber, firewood, and birds and pollinators. In the coffee-growing areas of Kodagu, Karnataka, there are 280 tree species which could be used as native shade tree species (Ambinakudige & Sathish, 2009; Maheswarappa et al., 2022), yet larger-scale coffee farmers tend to prefer the exotic silver oak species (*G. robusta*) within their coffee farms (Maheswarappa et al., 2022). There are incentives to use *G. robusta* (Nath et al., 2011), as it is fast-growing and holds the lure of timber market. There have also been cited negative aspects to having *G. robusta* as shade trees such as their impact on berry dry weight and coffee quality (Boreux et al., 2018). In our study, having only silver oak (*G. robusta)* was correlated with decreased abundance for three of the five pollinator species (Tables 1 and 2), albeit not statistically significant, suggesting that their abundance was, on average lower in silver oak-covered coffee crops compared to those sites that had native shade trees. As noted above, a larger sample size with more replicates may have shown a stronger significant relationship between pollinators and tree cover type. We recommend that future studies investigate this relationship further. As landscape elements (size of farm and proximity to forest) were shown in this study to have impacts on key pollinator abundances, these factors should be of importance to farming communities. Our study encourages coffee growers in the region to consider diverse native shade trees for tree cover rather than the non-native silver oak (*G. robusta*) for coffee systems, and to support forest conservation within the Reserve.

In general, more research, funding, and attention are needed in areas where pollinators and pollination are understudied, such as Asia. Coffee production (quality and quantity) is important for farmers within the Western Ghats and across India. Improving and stabilizing coffee production will in turn improve the livelihoods and well-being of farmers and their families and communities. While it is recognized that countries within Asia lack pollination studies compared to other regions such as North America and Europe (Archer et al., 2014; Klein et al., 2018; Orr et al., 2021; Teichroew et al., 2017) there are some initiatives starting that could help promote and support more pollinator and pollination-related research in Asia, including India. The Indian Pollinator Initiative, established in 2021, is run by academics in the field of pollination ecology. The Indian Pollinator Initiative has three main objectives: 1) to advance and promote studies on pollinators and pollination, 2) to provide a platform to exchange findings, ideas, methods and concepts to enhance collaboration, and 3) to encourage and promote education related to pollinators or pollination (more information can be found on https://inpollin.com/). There have been several attempts to start an Asian Pollinator Initiative – which is not yet formally established due to the COVID-19 pandemic and the disruption in international travel. A continuation of these efforts is envisioned, and a second meeting is planned to take place in early 2023. This endeavor aimed to have pollinator ecologists from the region meet to discuss how the Asian network could be established, connected, and further developed. The Indigenous Pollinator Network (IPN), supported by the Indigenous Partnership for Agrobiodiversity and Food Sovereignty has various organizations such as the Keystone Foundation (India), Slowfood International (Italy, Kivulini Trust (Kenya), and the Ogiek Peoples Development Project (Kenya) as part of it; this initiative hopes to expand its operations in the coming years (more information can be found at https://www.theindigenouspartnership.org/pollinators-network). Future research and support for such initiatives could increase the understanding of pollinators' role in important productive systems and, ultimately, their conservation.

# Declarations

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### Contributions

M. V. Sharma, B. Gemmill-Herren, R. Leo and H. T. Ngo designed the project and field sampling. P. Viswanathan and R. Leo implemented the field sampling and monitoring. M. V. Sharma and H. T. Ngo wrote the main manuscript text. C. Mammides carried out the majority of statistical analyses and reviewed the entire manuscript and added invaluable discussion and guidance to the manuscript.

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### Ethics declarations

### Conflict of interest

The authors have no conflicts of interest.

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# Figures

**Figure 1**

Map of study area and farm sites. The Nilgiri Biosphere Reserve (NBR) and the ten coffee-growing farms (*Coffea arabica*) belonging to the Irula and Kurumba Indigenous communities of the NBR.

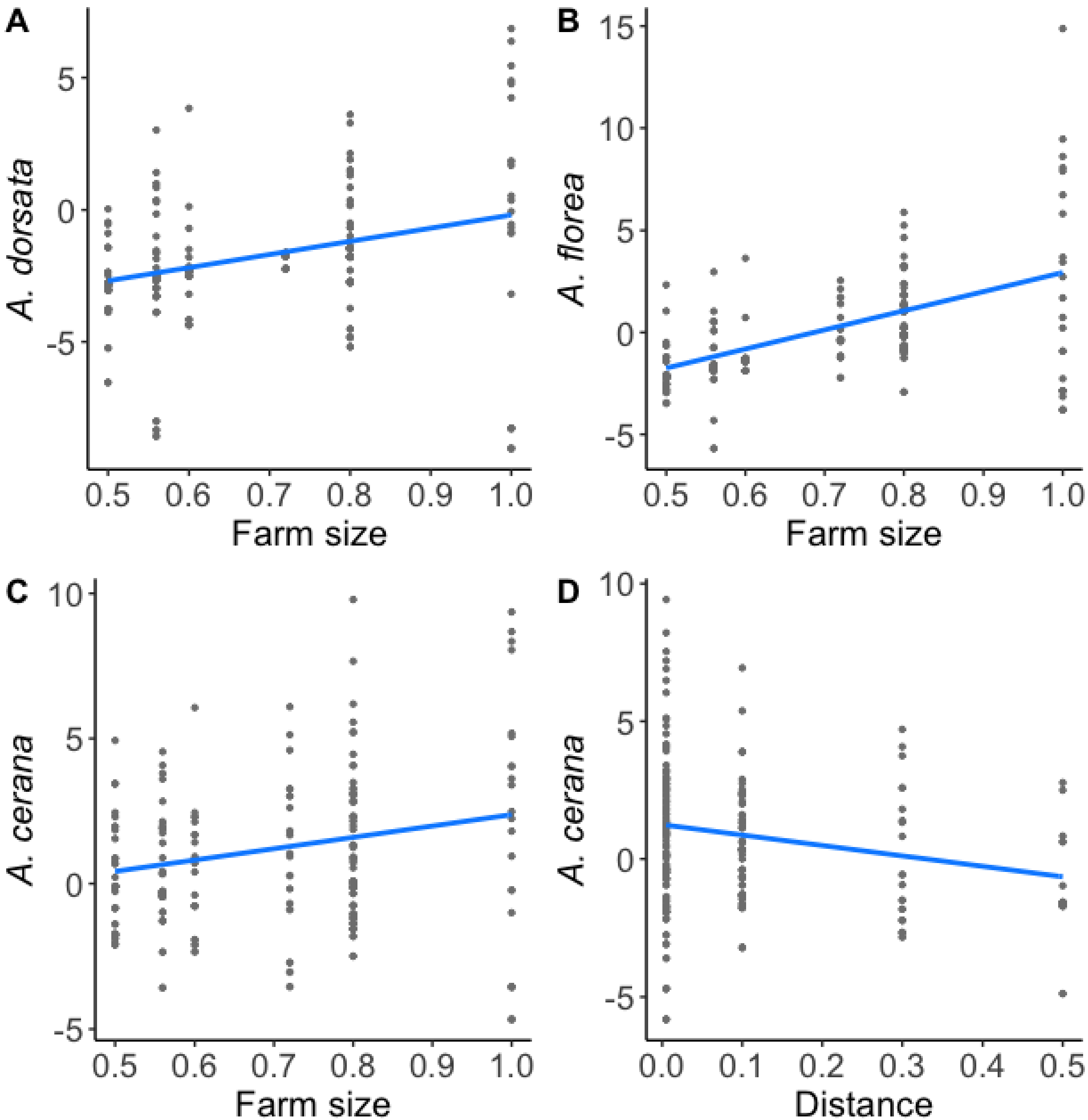


**Figure 2**

The abundances of *A. dorsata* and *A. florea* were associated with the size of the farm, while the abundances of *A. cerana* were associated with the size of the farm and the distance from the nearest forest edge.

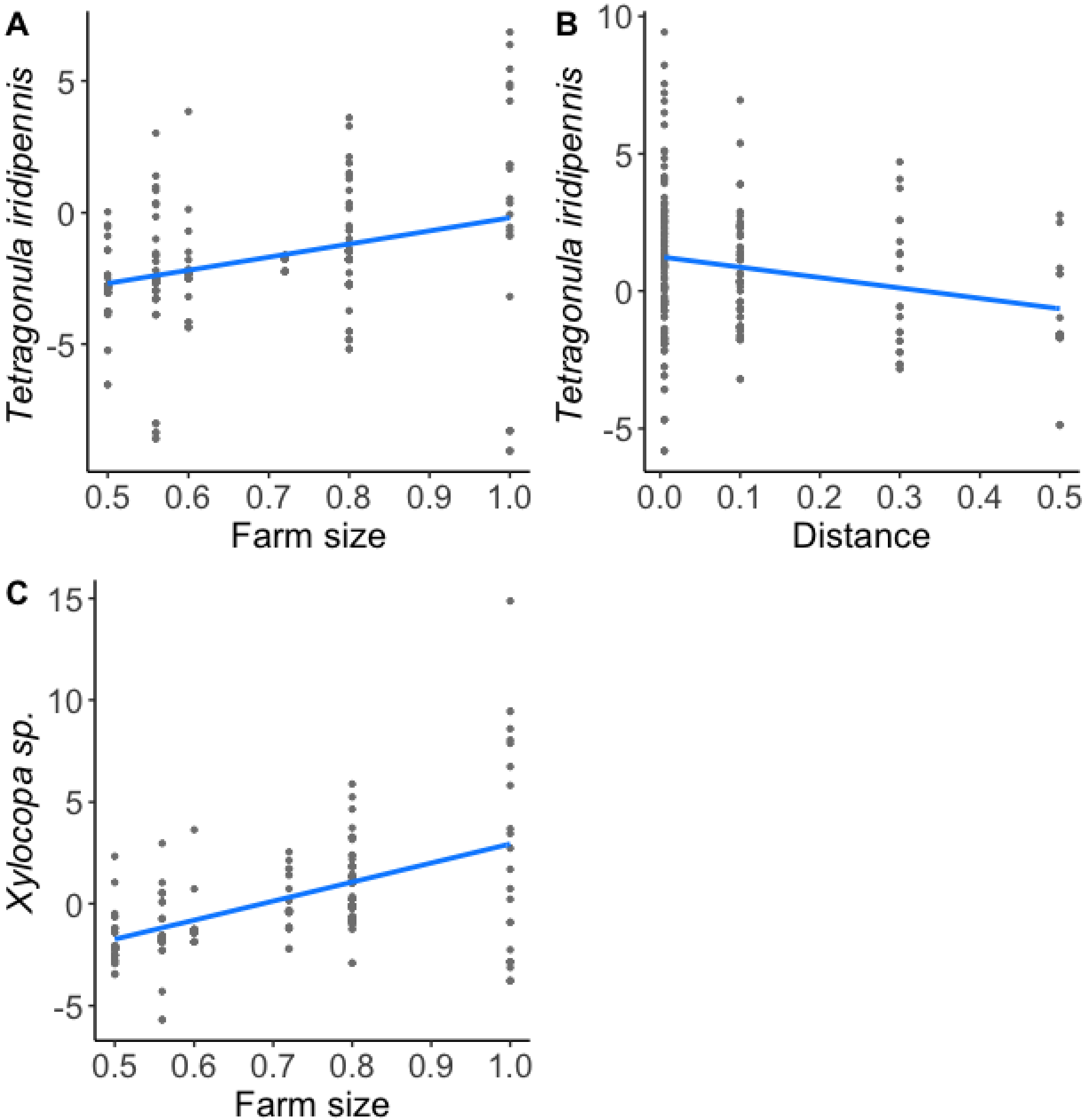


**Figure 3**

The abundances of *Tetragonula iridipennis* were associated with the size of the farm and the distance from the nearest forest edge, while the abundances of *Xylocopa* sp. were only associated with the size of the farm.