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ORIGINAL CONTRIBUTION

Relating shading levels and distance from natural vegetation with hemipteran pests and predators occurrence on coffee

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Abstract

The study was carried out to determine the effect of shading levels and/or distance from the natural alpine vegetation (NAV) on the occurrence of two insect functional groups: hemipteran herbivores and generalist predators in farmers' coffee fields in the Mt. Elgon region of Uganda. Three distance categories from the NAV, that is (i) 0–250 m; (ii) 250–1000 m and (iii) 1000–1500 m, were used to demarcate farms in the first stage of selection, and within each distance category, three levels of shading, that is (i) no shade, (ii) moderate shade and (iii) full shade, were used for final selection of coffee farms for the study. A total of 90 individually owned coffee fields were studied; 30 for each distance category, of which 10 represented each shading level. In two separate rounds, inventories of scale insects (*Coccus* spp.), antestia bugs (*Antestiopsis* spp.), root mealybugs (*Planococcus* spp.) and aphids (*Toxoptera aurantii*) on coffee plants were made for the hemipteran herbivores, whereas ants (Formicidae) and spiders (Araneae) were recorded for the predatory taxa. The results showed that the interaction between distance from the NAV and shading level consistently influenced the occurrence of the insects in both functional groups. For scale insects, root mealybugs and ants, it was closest to the NAV that shading-level effects were most discernible and generally limiting. To the contrary, the occurrence of aphids and spiders increased with the increase in the level of shading for plants furthest from the NAV. These results indicate that if inclusion of shade trees is to be a strategy in ecological pest management, the level of shading should be determined basing on the insect taxa as well as other pertinent factors in the landscape.

Introduction

Arabica coffee (*Coffea arabica* L.) generated approximately US$192 m of the foreign export value for Uganda in 2012 (Jassogne et al. 2013). The crop is mostly grown on the slopes of Mt. Elgon in eastern Uganda by smallholder growers who average yields of about 0.6 t/ha/year (FAO 2011). These coffee bean yield levels are very low when compared to the potential of 1.2 t/ha/year and above (Brando 2012). Pests account for a loss of over 50% in yields of Arabica coffee (Musoli et al. 2001). In Uganda, alongside the highly destructive Coleopterans *Hypothenemus hampei* and *Monochamus leuconotus*, hemipteran pests are of considerable importance on Arabica coffee (Le Pelley 1973; Karamura 1989; Rutherford and Phiri 2006; Erbaugh et al. 2008; Jassogne et al. 2013). For instance, in a field trial in the Mt. Elgon region, the root mealybug (*Planococcus* spp. Hemiptera: Pseudococcidae) killed 18.5% of the plants in the control plots (Kyamanywa et al. 2012). Incidences of 15–33% for *Planococcus* spp., 29–41% for *Coccus* spp.

(Hemiptera: Coccidae) and 19–30% for *Antestiopsis* spp. (Hemiptera: Pentatomidae) have been recorded on coffee farms (Kucel et al. 2006; Jassogne et al. 2013). Similar findings have been reported from neighbouring Kenya (Mugo et al. 2011). Yet, the group has received the least empirical attention.

The occurrence of coffee pests in general is under regulation by existing natural enemies (Hillocks 2000; Rutherford and Phiri 2006). Ants have been documented as effective generalist predators of *H. hampei*, stem borers, fruit fly, leaf miners and antestia bugs despite their mutualistic association with the Coccids (Armbrecht and Perfecto 2003; Jaramillo et al. 2006; Perfecto and Vandermeer 2006; Philpott and Armbrecht 2006; Armbrecht and Gallego 2007; Delabie et al. 2007; De la Mora et al. 2008). Spiders also commonly occur and regulate pests in coffee systems (Pinkus-Rendón et al. 2006; Hajian-Forooshani et al. 2013; Marín and Perfecto 2013). Natural enemies require complementing factors at local and landscape scales to be optimally functional in pest management. Such factors may be entrenched in farm management profiles and landscape structure in coffee-growing areas. For instance, Arabica coffee in the Mt. Elgon region is often grown under varying levels of shade, with the stocking levels of shade trees determined by individual households. Shade is a critical ingredient in Arabica coffee production; however, levels of shade intensity have been reported to affect different coffee pests differently. For example, *M. leuconotus* and *Habrochila* spp. are reported to be favoured by high levels of shade compared to *H. hampei* and *Leucoptera* spp. (Nestel et al. 1994; Beer et al. 1998; Guharay et al. 1999; Vega et al. 2002; Teodoro et al. 2008; Backlund 2012). Also, in this area, the forest cover and natural vegetation below an elevation of 2000 m has been converted into farmland to compensate for declining land productivity, and also due to high human population pressure (UWA 2000; NEMA 2006). As a result, most coffee farms are in simpler agricultural matrices, whereas a few are in close vicinity to the natural alpine vegetation that forms part of the gazetted Mt. Elgon National Park. Yet, distance from forests or complex natural vegetation has been also been shown to affect both natural enemies and insect herbivores in coffee agroforestry systems (Perfecto and Vandermeer 2002; Klein et al. 2006; Mariangie 2008). This study therefore set out to test the hypothesis that shading intensity at plot level and distance from the natural Mt. Elgon alpine vegetation, singly or interactively, can significantly influence the dynamics of hemipteran herbivores and generalist predators on coffee in the area.

Materials and Methods

Study site

The study was carried out in two rounds in June and December of 2012 in eastern Uganda on the south-eastern slopes of Mt. Elgon in the villages of Soono (00°51′N 34°25′E), Matokota (00°52′N 34°25′E) and Majanja (00°52′N 34°26′E) in Bumbo subcounty in Manafwa district. The district has a moist and cool agro-ecology favourable for growing Arabica coffee, with fertile volcanic soils (Isabirye et al. 2004). The mean annual precipitation in the area is around 1500 mm (Bamutaze et al. 2010). The precipitation shows a weak bimodal pattern. The onset and cessation of rainfall months are March and December, respectively. The two peak rainy months in the year are around May and August. The farmlands lay within an altitude range of 1512–1840 m above sea level. Coffee is the main economic crop in the area and is often grown within an agricultural matrix of other crops notably banana (AAA-EA), maize, beans and potatoes. The average coffee field size is 1.66 acres (0.67 ha). Coffee is mainly under moderate intensities of field management, and in this category, average coffee tree populations are 2231 per hectare; 74% of the farmers apply manure, 98% weed the plots and 91% prune the trees (van Asten et al. 2011). Chemical inputs are rarely used. In the area, coffee is grown with or without shade trees. Predominant shade tree species include *Markhamia lutea* (Bignoniaceae), *Grevillea robusta* (Proteaceae), *Milicia excelsa* (Meliaceae), *Albizia* spp. (Fabaceae), *Cordia millenii* (Boraginaceae), *Artocarpus heterophyllus* (Moraceae), *Mangifera indica* (Anacardiaceae), *Persea americana* (Lauraceae), *Carica papaya* (Caricaceae), *Psidium guajava* (Myrtaceae), *Syzygium cumini* (Myrtaceae), *Croton macrostachyus* (Euphorbiaceae), *Maesopsis eminii* (Rhamnaceae), *Ficus natalensis* (Moraceae), *Sesbania sesban* (Fabaceae), *Gliricidia* spp. (Fabaceae), *Acacia* spp. (Fabaceae), *Leucaena leucocephala* (Fabaceae), *Tephrosia vogelii* (Fabaceae), *Alnus* spp. (Betulaceae), *Calliandra* spp. (Fabaceae), *Inga* spp. (Fabaceae) and *Erythrina abyssinica* (Fabaceae) (EcoTrust 2012).

Experimental design

The study focused on two factors, distance of coffee fields from the natural alpine vegetation of Mt. Elgon National Park and level of tree shading; each at three levels. Coffee plantations located within 0–250 m, 250–1000 m, and 1000–1500 m of the natural area were selected for the study. Distance from the

Mt. Elgon alpine vegetation also had a characteristic altitude gradient (table 1) with altitude progressively decreasing away from the natural area. For each distance, 30 coffee plantations with differing shading level were studied. Shading levels were categorized as sunny, moderate shade and full shade (table 1). The levels were thus delineated using shade tree counts per unit area, and within plot microclimate variables: light intensity, temperature and relative humidity (table 1). Light intensity was measured using a foot-candle meter (model 3413F) following the guidelines of Bellow and Nair (2003). Temperature and relative humidity were measured using a thermo-hygrometer pen (model 3402). The microclimate readings were measured at different positions in the fields between 11 : 00 and 12 : 00 h. Ten plantations were selected for each shade category, and each plantation constituted a replicate. In all, 90 separately owned coffee fields were sampled.

Data collection

Each of the selected coffee plantations was sampled twice, once in June and later in December in 2012. These months fall in different fruiting cycles of coffee in the area. In each field, ten trees were randomly selected following methodologies by Magina (2007). For aphids, scale insects and antestia bugs, the entire canopy of each sampled tree was carefully examined and any infestations recorded. Both immatures and adult insects were counted. For the root mealybug, the occurrence was estimated using a score of 1–5, where 1 = no plant symptoms and no infestation; 2 = no plant symptom but infestation present; 3 = mild stunting and infestation present; 4 = stunting, leaves beginning to yellow and infestation present; 5 = leaves yellow, wilting and infestation present. Incidence was confirmed by scrapping off a small amount of soil around the collar to expose the whitish infestation mass. Severe root mealybug damage manifests as yellowing and wilting of foliage, which falls off gradually (Rutherford and Phiri 2006; Barrera 2008). When such plants are uprooted, the mealybug colonies are often found around the roots. To sample for the predators (ants and spiders) in coffee trees, the vegetation beating method was used, where the insects were collected by tapping the vegetation with a heavy stick while holding a collecting white cloth underneath for insect sampling (Coddington et al. 1996; Sørensen et al. 2002). The occurrence of the pests and natural enemies was recorded as counts/scores per plant sampled.

Table 1 Characteristics of the different shading levels and distance from Mt. Elgon National Park

Parameter shading level	Mean shade tree counts/Ha	Average light intensity (Foot candles)	Average temperature (°C)	Average relative humidity (%)
Shade level 1 (no shade)	0	2559	26.7	55.6
Shade level 2 (moderate)	23	1851	26.5	56.2
Shade level 3 (full)	92	535	24.5	63.2

Parameter distance from Mt.Elgon alpine vegetation	Distance (m)	Mean elevation (m.a.s.l)
Distance 1 (near)	0–250	1783
Distance 2 (intermediate)	250–1000	1634
Distance 3 (far)	1000–1500	1537

Data analysis

Data were transformed (when appropriate) to achieve homogeneity of variance, using square-root transformation $(X + 0.5)^{1/2}$ for insect counts and scores. Data were analysed using the GenStat computer package, Release 13.1 PC/Windows 7 (Lawes Agricultural Trust, Rothamsted Experimental Station 2010), and a statistical package for social scientists (SPSS) version 16.0, for Microsoft Windows (© 2010, University of Bristol, Bristol, UK) to generate analysis of variance (ANOVA) and means. Individual treatment effects and interaction effects were investigated using a two-way ANOVA (GLM) with distance from a natural area and shading level as the fixed factors with elevation included as a covariate. Means were separated by the least significant difference (LSD) at 5%. Additionally, for ants and spiders, the hemipteran variables were used as covariates; and vice versa, in the GLM. The Pearson two-tailed correlations were carried out to test for relationships among the dependent variables.

Results

Effect of distance from a natural area and shading level on hemipteran insect pests

Distance from a natural area, shading level and the interaction between distance from the natural area and shading level significantly affected the occurrence of scale insects (*Coccus viridis*, *C. alpinus*, Hemiptera: Coccidae), mealybugs (*Planococcus* spp., Hemiptera: Pseudococcidae) and aphids (*Toxoptera aurantii*, Hemiptera: Aphididae) on coffee (all $P \leq 0.001$; table 2a). The highest scale insect populations were on coffee plants closest to the natural alpine vegetation (0–250 m) compared to the other further distances, whose counts were not significantly different (fig. 1). With regard to shading levels, the highest populations of scale insects were found on no-shade coffee plants when compared to the moderate and full shade plants, whose scale insect loads were not significantly different (fig. 1). It was at the nearest distance to a natural area that shading-level effects were most discernible (fig. 1). The trend of mean mealybug damage scores was similar to that of scale insect counts with highest mean scores of mealybug damage recorded on coffee plants nearest to the natural alpine vegetation and grown under unshaded conditions (fig. 2). Although there was a significant and positive correlation between scale insects and ants counts ($r = 0.661^{**}$; $N = 180$), shading level and distance from the natural area, singly or interactively, affected the occurrence of the scale insects (and mealybugs) even after ants were included as covariates in the GLM (table 2b). The trend for aphid infestation was different and not as clear; generally, the highest infestation was on coffee plants at distances further from a natural area (intermediate and far) compared to that on plants closest to the natural area; and lowest on no-shade plants compared to shaded ones (fig. 3). Uniquely, for plants furthest from the natural area, the level of infestation increased with the increase in the level of shading (fig. 3). Data for Antestia bugs are not presented due to unusually low infestation levels during the study.

Effect of distance from a natural area and shading level on the generalist predators

Distance from a natural area, shading level and the interaction between distance from a natural area and shading level had a significant effect on the occurrence of ants (Hymenoptera: Formicidae – *Pheidole megacephala*, *Plagiopsis* spp. and *Cataulacus* spp.) on cof-

Table 2 Results of analysis using a two-way ANOVA; F-statistics for the combined analysis of the effect of distance from a natural area and shading level with (a) elevation as a covariate on hemipteran pest infestation and natural enemies' occurrence on coffee (b) ants as a covariate on hemipteran pest infestation on coffee (c) hemipteran pests as covariates on ants' occurrence on coffee

		F-statistics				
Source	d.f.	No. scale insects/plant	No. aphids/plant	Mealybug scores/plant	No. ants/plant	No. spiders/plant
(a)						
Elevation	1, 170	0.040	0.628	1.408	0.216	0.489
Distance from natural area	2, 170	11.151***	02.259	10.618***	15.321***	1.681
Shading level	2, 170	09.977***	07.830***	07.785***	18.889***	7.365***
Distance from natural area × Shading level	4, 170	05.518***	11.112***	05.791***	11.050***	7.104***

		F-statistics		
Source	d.f.	No. scale insects/plant	Mealybug scores/plant	No. aphids/plant
(b)				
Ants counts/plant	1, 170	62.968***	49.655***	3.244
Distance from natural area	2, 170	3.001*	52.540***	10.114***
Shading level	2, 170	2.993*	24.632***	7.823**
Distance from natural area × Shading level	4, 170	2.686*	16.142***	8.739***

Source	d.f.	F-statistics No. ants/plant
(c)		
No. scale insects/plant	1, 168	57.639***
Mealybug scores/plant	1, 168	1.351
No. aphids/plant	1, 168	3.168
Distance from natural area	2, 168	1.580
Shading level	2, 168	4.718**
Distance from natural area × Shading level	4, 168	5.041***

Values with asterisks indicate significance: ***0.001; **0.01; *0.05, whereas values without asterisks indicate no significance.

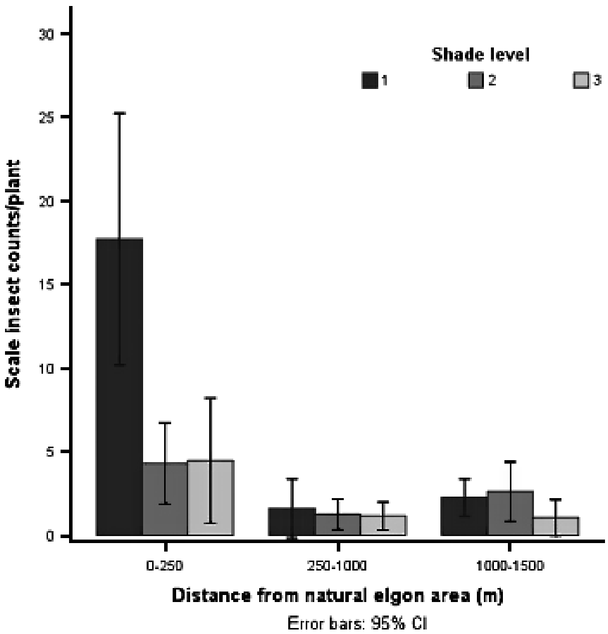

Fig. 1 Scale insects' counts (means and 95% confidence intervals) on coffee plants at different distances from a natural area and shading levels (where shade level 1 = no shade; 2 = moderate shade; and 3 = full shade).

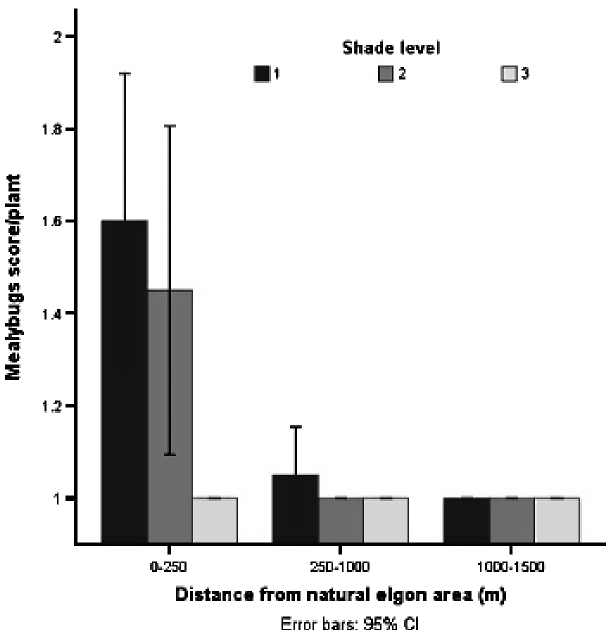

Fig. 2 Mealybug infestation scores (means and 95% confidence intervals) on coffee plants at different distances from a natural area and shading levels (where shade level 1 = no shade; 2 = moderate shade; and 3 = full shade).

fee (table 2a). The occurrence of the ants generally decreased with increasing shade levels and distance from the natural area. The effect of level of shading

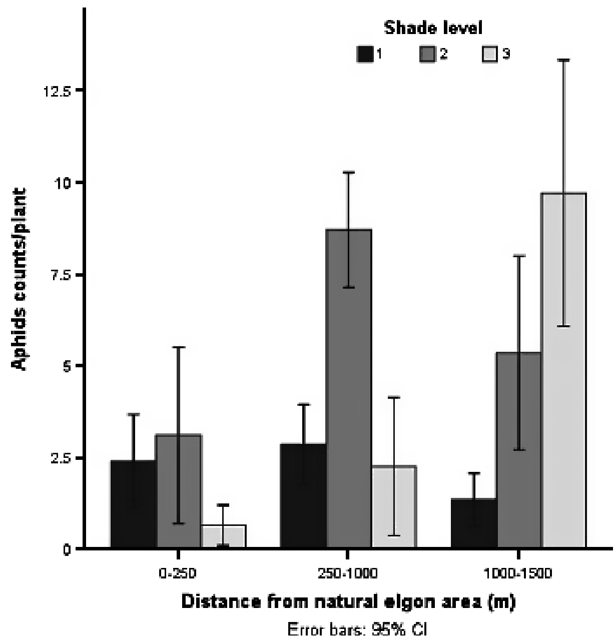

Fig. 3 Aphid counts (means and 95% confidence intervals) on coffee plants at different distances from a natural area and shading levels (where shade level 1 = no shade; 2 = moderate shade; and 3 = full shade).

was most distinct on coffee trees nearest to the natural area (fig. 4). The highest counts of ants were on coffee plants with no shade but nearest to the natural area (fig. 4). When each of the hemipteran pests (scale insects, mealybugs and aphids) was used as a covariate in the GLM, shading level and the interaction between shading level and distance from the natural area still significantly affected the ants' occurrence (table 2c). In the case of spiders (Araneae: Lycosidae, Oxyopidae and Salticidae), shading level and the interaction between distance from a natural area and shading level significantly affected the occurrence ($P \leq 0.001$; table 2). Spiders were not as distinct as ants in their response to the studied factors; populations were generally highest on plants under partial shade level as compared to the two extremes, except at the furthest distances where the increase in shade level led to an increase in spider occurrence (fig. 5). There was no discernible main effect of distance from a natural area on spider abundance (fig. 5; table 2a). The Pearson two-tailed correlation was significant and positive between aphids counts and spider occurrence ($r = 0.288$**; $N = 180$).

Discussion

The highly significant interaction between level of shading and distance from the natural area of coffee

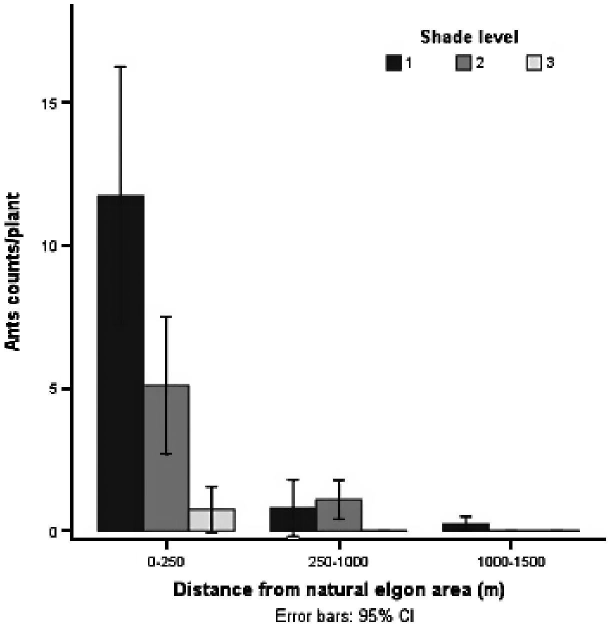

Fig. 4 Ant counts (means and 95% confidence intervals) on coffee plants at different distances from a natural area and shading levels (where shade level 1 = no shade; 2 = moderate shade; and 3 = full shade).

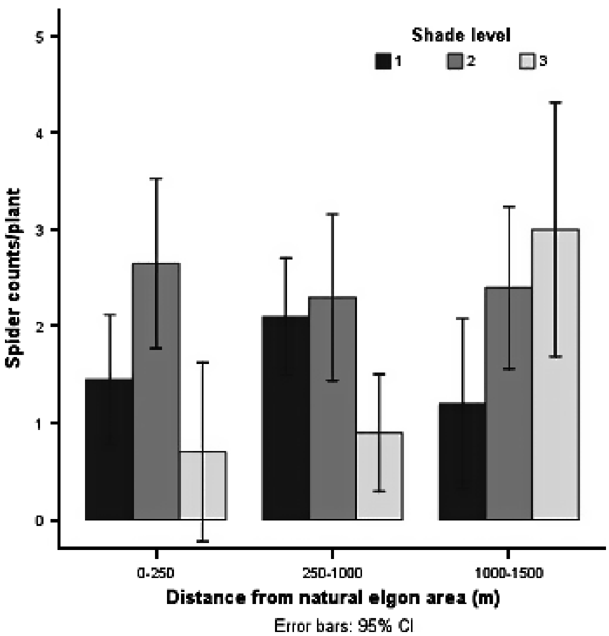

Fig. 5 Spider counts (means and 95% confidence intervals) on coffee plants at different distances from a natural area and shading levels (where shade level 1 = no shade; 2 = moderate shade; and 3 = full shade).

plantations for all the five studied insect taxa indicates that the effect of tree cover in the Mt. Elgon region is dependent on distance from the natural area, which was correlated to altitude ($r = -0.829$; $P < 0.001$, $N = 180$). These results support other reports that recommend that insect occurrence be viewed at the landscape scale, because most species respond to their environment on this level (Tscharntke et al. 2005, 2008; Clough et al. 2007; Vandermeer and Perfecto 2007; Coll 2009; Chaplin-Kramer et al. 2011; Backlund 2012) including spillover across managed systems and natural habitat (Hedlund et al. 2004; Tscharntke et al. 2005, 2008; Vandermeer and Perfecto 2007). Backlund (2012) working in Kenya also found strong interactions between in-field shading and landscape complexity on abundance of aphids, lace bugs and leaf miners on coffee. As such, in implementing habitat management for pest management in coffee at farm level, due consideration should be given to the landscape context. Woltz et al. (2012) also reached a similar conclusion. The interaction affected the different insect pest taxa differently; in the case of scale insects and mealybugs, the highest occurrence was on coffee trees with no shading but close to the natural area while the reverse was true for aphids, where the highest incidence was on coffee plants under full shade furthest from the natural area. Because scale insects and mealybugs are more important than aphids in coffee production in this area and in sub-Saharan Africa in general (Hillocks et al. 1999; Damon 2000; Hillocks 2000; Jaramillo et al. 2006; Bigirimana et al. 2012; Jassogne et al. 2013), farms far from natural area and at lower altitude would benefit most by increasing the level of shading on their farms. Incidentally, spiders that were found to be associated with aphids in this study were most common in highly shaded coffee far from the natural area and at low altitude.

The level of shading had a large effect on both insect pests and the predators. The results revealed reduced infestations of scale insects and mealybugs on coffee plants that were under shade. Staver et al. (2001) also reported that mealybugs have higher abundances in less shaded agroforestry systems. The relatively lower insect pest levels in shaded coffee production systems can be attributed to complex insect communities and food webs (bottom-up or top-down effects) that are a result of high species diversity in such systems (Altieri 1999; Bianchi et al. 2006); the high biodiversity coupled with watershed services may also reduce pest incidence and damage in shaded coffee polycultures (Perfecto et al. 1996; Moguel and Toledo 1999; Schroth et al. 2000; Pérez-Nieto et al. 2005; Dossa et al. 2008). Non-crop diversity within plots was not measured in this study; however, it has been reported that the increased canopy cover in shaded coffee systems modifies the soil quality and plant microclimate that may directly affect different processes of the pest life cycles as well as enhance plant defence mechanisms against pest infestation (Beer et al. 1998; Rao et al. 2000; Schroth et al. 2000; Staver et al. 2001; Avelino et al. 2004; DaMatta 2004; Varon et al. 2007; Lott et al. 2009). In this study, we found that coffee farms with different levels of shade had variable light intensity, relative humidity and temperature readings. Shade has been documented to reduce sap flow of coffee shrubs, a fact that can affect hemipteran pests (van Kanten and Vaast 2006). Mariangie (2008) also found shade to negatively affect leafhopper (Hemiptera: Cicadellinae) abundance in coffee polycultures in Costa Rica. The lower incidences of pests in shaded systems may, in part, be due to the effect of natural enemies; generalist predators such as spiders and ants have been noted to be favoured by shaded coffee polycultures (Perfecto et al. 1996; Armbrecht and Gallego 2007). The fact that high shade in this study did not favour ants was probably due to the fact that ants were mostly driven by the presence of scale insects which preferred unshaded conditions. However, the results show that the trend of low pest infestations in shaded coffee agroforestry may not always hold (Staver et al. 2001; Teodoro et al. 2008). In fact, aphids responded contrary to this paradigm in this study. This may not be in isolation as Singh Rathore (1995) showed that most aphids prefer shady conditions in warm climates. Also, during a survey in the Trans-Nzoia region of Kenya, Backlund (2012) found the abundance of aphids to be higher in shaded plantations when the proportion of semi-natural habitat surrounding the sites was lowest.

Distance from a natural area was found to affect the occurrence of scale insects, mealybugs, aphids and ants. This effect held true after the inclusion of altitude as a covariate in the analysis. The presence of natural enemies as a result of proximity to a natural area could also have played a role. A number of studies have reported that the proximity of a near-natural habitat can result in increases in natural enemy abundance (Duelli et al. 1990; Dyer and Landis 1997; Tscharntke et al. 1998; Chaplin-Kramer et al. 2011) and diversity (Clough et al. 2005). In this study, ants were mostly found on coffee plants in fields near the natural Mt. Elgon alpine area. These results on ants are comparable with the findings of Bianchi et al. (2006) who found that diversity and abundance of natural enemies decline with increasing distance from a natural area; and of Perfecto and Vandermeer (2002) as well as Armbrecht and Perfecto (2003) who reported that natural enemies such as ants exhibit a decline in species richness with increasing distance from a forest. Several studies have indeed demonstrated that natural enemies tend to disperse and aggregate to natural resources, in search of resources other than prey (Corbett and Rosenheim 1996; Grafton-Cardwell et al. 1999; Pontin et al. 2006). For habitat generalists that use non-crop habitats, spatial and temporal patterns of resource use and dispersal will play a large role in determining their distribution and activity within crop fields, and it will depend greatly on the quality, quantity and proximity of non-crop habitat in the landscape (Cronin and Reeve 2005; Bianchi et al. 2006). In this study, the pattern for spiders was not quite as distinct as that of ants with regard to distance from a natural area, but the highest counts were in fully shaded coffee plants at the furthest distance from the natural area. Stenchly et al. (2012) also found the abundance of a cocoa tree canopy-dwelling spider *Thorelliola ensifera* (Salticidae) to be enhanced with distance to a forest. Shackelford et al. (2013) also reported spiders to be positively influenced by landscape heterogeneity. In the case of our study, the trend may be partly explained by the occurrence of aphids, which had a similar trend and were found to be positively correlated with spider occurrence.

Conclusion

The results showed main and interactive effects of factors at local plot (level of shading) and the landscape level (distance from a natural area) on insect abundance and suggest that efforts should be directed beyond plot-level shade management to effectively manage insect pests of coffee agroforestry systems. The effects of shading on pests and natural enemies were found to be both highly taxon specific and dependent on distance from natural area. Thus, the optimal shade tree management for pest control will depend on the pests that are of most concern and on the environmental conditions at a specific coffee plantation.

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