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COMPARISON OF INSECT BIODIVERSITY BETWEEN ORGANIC AND CONVENTIONAL PLANTATIONS IN KODAGU, KARNATAKA, INDIA

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Abstract: We undertook a comparative analysis of ground insects and fruit eating butterflies on 29 different plantations in Kodagu District of Karnataka which is one of the rich biodiversity zones of the Western Ghats. These included organic and conventional coffee and cardamom plantations using different levels of chemical fertilizers and pesticides. A total number of 457 ground insect species were collected using pit-fall traps which included 92 species of ants and 123 species of beetles, among other insect taxa that we measured. Similarly, 25 species of butterflies belonging to the family Nymphalidae were collected using bait traps. We found a clear negative effect on the ground insect species diversity (Shannon index) and evenness (Shannon evenness index) in pesticide treated plantations as compared to the organic plantations. A similar negative effect was observed for butterfly diversity in plantations using pesticides. Our results corroborate the value of organic plantations in supporting higher levels of biodiversity.

Keywords: Biodiversity, cardamom, coffee, conservation, insects, organic agriculture, pesticides, Western Ghats.

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INTRODUCTION

Agriculture is a dominant human activity and occupies about 40% of available land space globally (World Development Indicators online database, World Bank), even more in India (World Bank Report 2010). Therefore, the decisions that farmers make can dramatically affect biodiversity at all taxonomic levels. Modern farming practices (mechanization, mono-cropping, hybrid varieties and genetically modified GM crops) combined with the heavy use of agri-chemicals (fertilizers, pesticides and herbicides) have resulted in a loss of biodiversity in agricultural landscapes and surrounding areas (Andow 1983; Altieri & Letourneau 1984; Fuller et al. 1995; Krebs et al. 1999; Stoate et al. 2001; Benton et al. 2002, 2003). Agricultural ecosystems that are rich in biodiversity possess greater resilience and are, therefore, able to recover more readily from biotic and abiotic stresses such as drought, environmental degradation, pests, diseases, epidemics, among others (Wilsey & Polley 2002; Wittebolle et al. 2009). Clearly, higher community evenness—as found on organic plantations (Crowder et al. 2010)—enhances resistance to invasion and other forms of functionality under stress (Wilsey & Polley 2002; Wittebolle et al. 2009). Further, biodiversity conservation in agricultural landscapes also promotes higher species richness (Bengtsson et al. 2005) and facilitates metapopulation processes between habitat patches (Perfecto & Vandermeer 2010).

Insects have co-evolved with plants for millions of years and are of enormous importance for agriculture. Some insects can damage crops, but others also provide pollination and pest control services, or improve the fertility of the soil through feeding on and assisting the decomposition of organic matter. Conventional agricultural pest-management practices often lead to altered community structure (Macfadyen et al. 2009) and communities dominated by a few species, which contributes to pest outbreaks. Organic farming methods mitigate this ecological damage by promoting evenness among natural enemies (Crowder et al. 2010) which then contributes to a pest-predator balance. Hence, species evenness was considered an important response variable in the present study. While many studies in Europe, Australia and Mexico (Bengtsson et al. 2005; Horne 2007; MacFadyen et al. 2009) have demonstrated that organic plantations support a greater level of insect diversity, such studies are lacking in tropical zones which harbour similar biodiversity. Studies on biodiversity in coffee plantations in the Western Ghats have examined bird, mammal and butterfly diversity (Bali et al. 2007; Dolia et al. 2007; Anand et al. 2008) in plantations at varying distances from forests, but have not compared organic and conventional plantations. This study attempts to fill this gap in our understanding of agricultural systems by comparing ground insect biodiversity in organic and conventional plantations.

STUDY AREA AND METHODS

This study was carried out in the cardamom and coffee plantations of Kodagu District of Karnataka state, situated in the Western Ghats of southern India. The average annual rainfall in the area ranges from 1500–4000 mm and most of it occurs during the southwest monsoon between June and September. The temperature ranges from a minimum of 11^0C in winters to a maximum of 28^0C in summers. The natural vegetation cover is evergreen forest, which remains in the study landscape as fragments at varying levels of degradation. Both cardamom and coffee are cultivated under a two-tier mixed shade canopy comprising leguminous and non-leguminous evergreen shade trees. Coffee requires about 40% shade whereas cardamom requires 60% shade (Anonymous 1985). Therefore, in mixed systems coffee is generally grown on slopes with pepper as an intercrop while cardamom is grown in the moist valleys.

We selected 29 plots in different parts of Kodagu District (Fig. 1). These included 12 in completely organic plantations that apply no pesticides or chemical fertilizers, five in plantations using only chemical fertilizers (NPK) but not pesticides, and 12 in conventional plantations that used NPK as well as chemical pesticides. Most (but not all) of the organic plantations had been certified by an international agency for an average of six years and conventional plantations had varying levels of pesticide use. We had originally intended to sample using the powerful randomised block design (Quinn & Keough 2002), but had to abandon this during the course of the study since we were unable to find clearly and meaningfully definable blocks. Because of this, pairs of plantations of different types (organic and conventional) are sometime located close together. However, we are confident that the overwhelming effect of treatments will justify statistical independence in such cases. The minimum distance between plantations of the same type is 1km. We collected ground insects and butterflies from the months April to May (before the onset of the monsoons) followed by collection from the months October to March (following the monsoon rains).

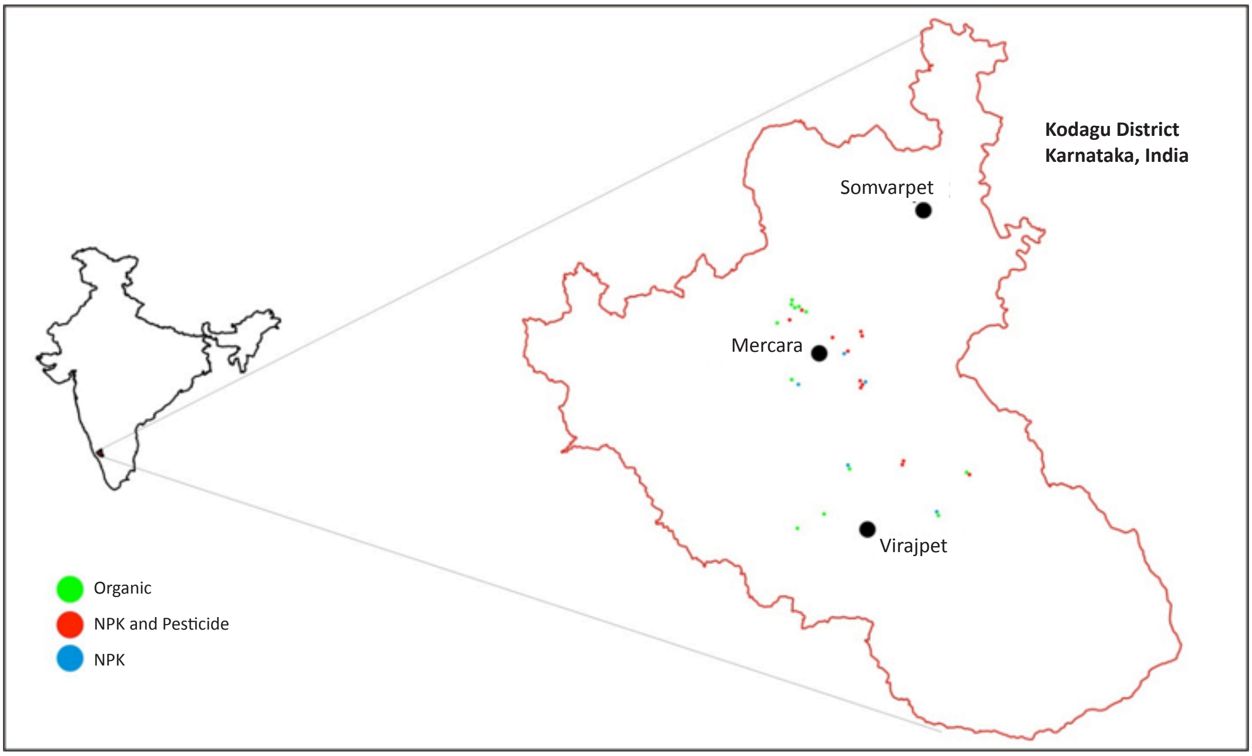

Figure 1. Location of sampled plots within Kodagu District, Karnataka, India. Inset shows location of Kodagu within India.

Wherever possible, one organic and one conventional plot were monitored simultaneously, as explained above.

Pitfall traps were used to capture ground-foraging insects. A 1.21 to 2.02 ha (3–5 acre) plot was selected on each plantation. The plot was selected by the field team so as to cover a representative part of the estate but also to ensure no edge effects from neighbouring plantations that may have been of a different type (e.g., pesticide runoff into an organic plantation, effects due to spatial dependence in the response variable). In each plot, five equally spaced transect lines 20m apart were demarcated with string and mapped using a global positioning system (GPS). Each transect measured 40m in length and five pitfall traps were placed 10m apart on each transect. Hence, a total of 20 pitfall traps were placed in each plot. Each pitfall trap consisted of a plastic disposable cup, measuring about 10cm in height and 6cm in diameter. The cups were buried at ground level and protected from rain by a plastic plate at a distance of about 2cm above the ground. Each cup contained 15ml of ethanol (50%) and 2–3 drops of glycerine to prevent evaporation. Trap contents were collected every 24h over four consecutive days, and preserved in ethanol (70%) before identification. Ants were separated from other insects for the purpose of identification.

We surveyed fruit-feeding butterflies using hanging traps baited with over-ripe, fermenting fruits (banana, apple, papaya). Each trap consisted of a cylindrical net with a conical head and a wooden plank hanging 2.5cm below the bottom of the net. The bait dish was placed on the wooden plank so that any butterflies visiting the bait were trapped within the net as they flew upwards. Three traps were randomly placed (equidistant from each other, approximately 30m apart) in the same plot used for the pitfall traps. The traps were emptied and the bait replaced every 24 hours over four consecutive days. The trapped butterflies were photographed, counted and released. The photographed butterflies were then identified using a field guide on butterflies of India (Kehimkar 2008).

Total ground insects and butterflies were identified to the lowest possible taxonomic level. These data were used to estimate mean species richness (not shown here), mean Shannon's diversity (which takes into account both species richness and evenness) and mean Shannon's evenness (data shown as evenness for each pitfall trap cumulative over four days. Evenness data is shown as it is considered an important response variable for effective pest control on organic farms (Crowder et. al. 2010).

The data were analysed using linear modelling (Quinn

& Keough 2002) in conjunction with a model selection approach (Burnham & Anderson 2002; Johnson & Omland 2004). We chose the model selection approach over the traditional null hypothesis testing as our data were derived from an observational study which lacked randomization of treatments and controls. We carried out separate analyses for the different response variables (species richness, diversity and evenness), using linear models with treatment (three levels: organic, NPK, pesticide) and crop type (cardamom or coffee) as the categorical predictors. We fitted models where the response variable was a function of only crop, only treatment, the additive effect of crop and treatment and the interaction between crop and treatment. The trap data were combined to the level of the plot (=estate) prior to statistical analyses, so random effects were not included in the models. Further, plantations were classified into four categories as 0P, 1P, 2P and 3P depending on the number of different pesticides used per year. (0P - No pesticide or NPK; 1P - 1–3 pesticide applications; 2P - 4–7 applications; 3P - 8–14 applications). All statistical analysis was carried out using the statistical programming package R (R Development Core Team 2008).

RESULTS

Pitfall traps

Total Ground Insects: Diversity: A total of 32,484 ground insects belonging to 467 different species, including 92 ant species and 123 beetle species, were collected using pitfall traps. The effect of treatment on the species diversity index was observed to be the best fit model (Table 1). Shannon's species diversity index (H') is clearly higher in organic (G) plantations compared to pesticide (P) plantations, while diversity in NPK (N) plantations overlaps with that of other treatments (Fig. 1). The role of treatment in determining Shannon's species diversity index (H') received further support from the next best model which included the additive effects of treatment and crops. (ΔAIC=1.19; Table 1). Here we see that there is a clear negative effect of pesticide treatment on Shannon's species diversity index (H') when compared with organic plantations in both coffee and cardamom plantations. There is no discernible effect of treatment on Shannon's species diversity index (H') in NPK plantations (Fig. 2).

Total ground insects: Evenness: The additive effect of crop and treatment on the Shannon's species evenness index (E) was observed to be the best fit model (Table 2). Shannon's species evenness index (E) is clearly higher in organic (G) plantations compared to pesticide (P) plantations (Fig. 3). The role of treatment in determining Shannon's species evenness index (E) received further support from the next best model which included only treatment (ΔAIC=1.36; see Table 1 and Fig. 3). The evenness index for NPK (N) plantations is intermediate, overlapping both organic and pesticide plantations.

Table 1. Model selection results for factors affecting diversity of overall ground insects and nymphalid butterflies. The best model is included in boldface font.

Shannon's Diversity Index (H')	Pitfall trap (Ground insects)		Bait trap (Nymphalid butterflies)	
	Δ AIC	AIC weight	Δ AIC	AIC weight
Treatment	0.0	0.569	0.0	0.665
Crop	6.885	0.018	6.620	0.024
Crop + Treatment	1.198	0.312	1.788	0.272
Crop * Treatment	3.485	0.099	5.716	0.038

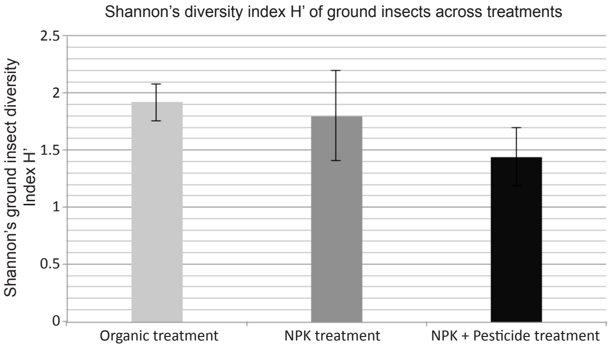

Figure 2. Bar plot for ground insects shows the mean Shannon's diversity index H' for all treatments with their 95% confidence intervals (CI). Note the 95% CI for treatments organic (G) and NPK + pesticide (P) do not overlap.

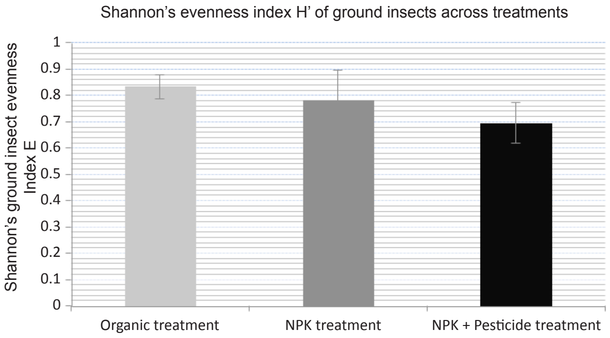

Figure 3. Bar plot for ground insect shows mean Shannon's species evenness index (E) for all treatments with their 95% confidence intervals (CI).

Table 2. Model selection results for factors affecting evenness of overall ground insects and nymphalid butterflies. The best model is included in boldface font.

Shannon's Evenness Index (E)	Pitfall trap (Ground insects)		Bait trap (Nymphalid butterflies)	
	Δ AIC	AIC weight	Δ AIC	AIC weight
Treatment	1.366	0.292	0.0	0.478
Crop	7.175	0.016	0.976	0.293
Crop + Treatment	0.0	0.579	1.960	0.179
Crop * Treatment	3.303	0.111	4.588	0.048

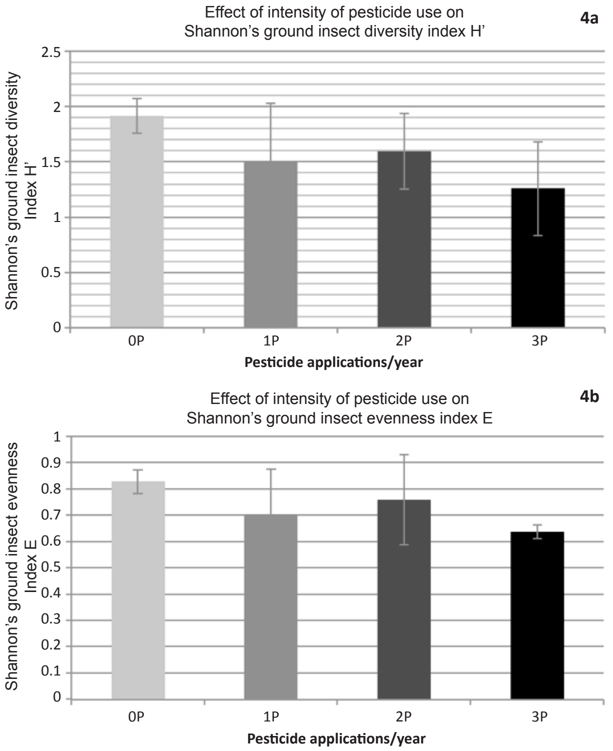

Figure 4. The bar graph shows the effect of increase in chemical pesticides on ground insect species diversity (Fig. 4a) and evenness (Fig. 4b) with their 95% confidence intervals (CI).

<u>Effect of chemical pesticides on ground insect species diversity and evenness indices:</u> Clear differences were seen in Shannon's species diversity index (H') (Fig. 4a) between pesticide-free (0P) plantations and heavily sprayed (3P) plantations (95% confidence interval [CI] for pesticide free (0P) and heavily sprayed (3P) do not overlap).

Similar results were observed for Shannon's species evenness index (H') (Fig. 4b) where there is a clear difference between pesticide-free (0P) plantations and heavily sprayed (3P) plantations.

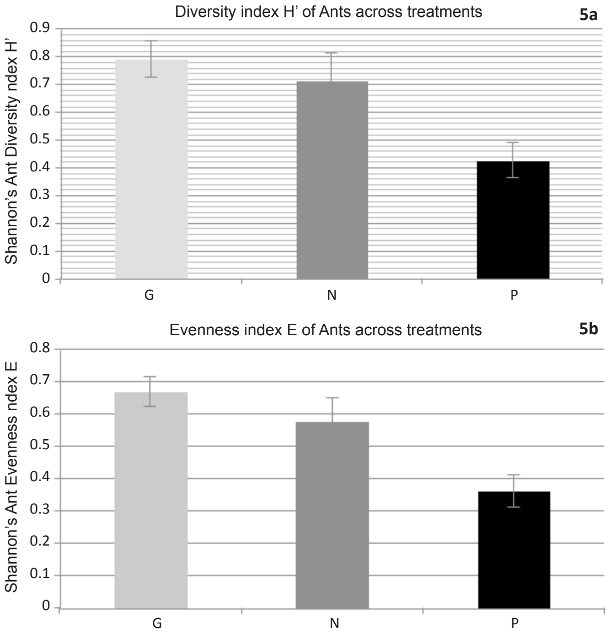

Figure 5a. Bar plot for ant species shows the mean Shannon's diversity index H' for all treatments with their 95% confidence intervals (CI); Figure 5b. Bar plot for ant species shows mean Shannon's evenness index E for all treatments with their 95% confidence intervals (CI). Note the 95% CI of treatments organic (G) and NPK + pesticide (P) do not overlap in either plot.

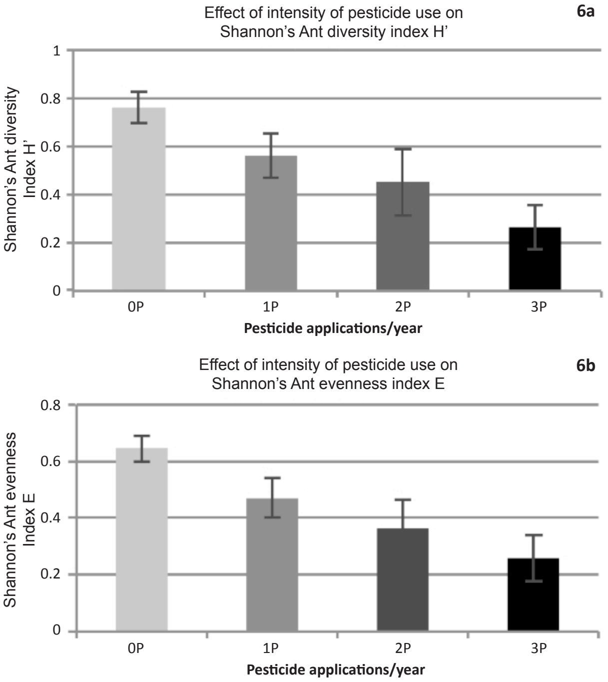

Figure 6. Bar plot shows the effect of increase in chemical pesticides on ant species diversity (Fig. 6a) and evenness (Fig. 6b) indices with their 95% confidence intervals (CI).

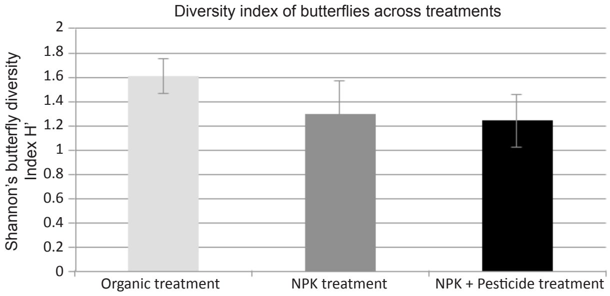

Figure 7. Bar plot for butterflies shows mean Shannon's diversity index values H' for all treatments with their 95% confidence intervals (CI).

Pitfall Traps

Ants: Diversity and Evenness: A total of 6695 ants comprising 92 species were collected from the pitfall traps. Similar to overall ground insect data, we analysed patterns for just ants by fitting and comparing the same set of models. The results for ant species diversity and evenness are similar to those obtained for all ground insects and they confirm that pesticide treatment (P) has a considerable and clear negative effect on Shannon's ant species diversity (Fig. 5a) and evenness (Fig. 5b) indices compared to both organic (G) and NPK (N) plantations. As for total ground insects, Shannon's ant species diversity and evenness indices are not clearly different between organic and NPK treatments.

Effect of number of pesticide applications on ant species diversity and evenness indices: Large differences are apparent in both Shannon's ant species diversity (Fig. 6a) and evenness (Fig. 6b) indices even between pesticide-free (0P) plantations and very low pesticide (1P) sprayed plantations. In highly pesticide sprayed plantations (3P), the reduction in both Shannon's ant species diversity and evenness indices is very drastic.

Butterfly Bait Trap

Nymphalid butterflies: Diversity: A total of 1,259 butterflies comprising 25 species from the family nymphalidae were collected using bait traps. The effect of treatment on the species diversity was observed to be the best fit model. Shannon's butterfly species diversity index (H') is highest in organic (G) plantations (Fig. 7) and clearly lower in pesticide (P) plantations. The role of treatment in determining Shannon's butterfly species diversity index (H') received further support from the next best model which included the additive effects of treatment and crops (Δ AIC=1.78). The data show a clear decrease in the nymphalid butterfly diversity in plantations sprayed with pesticides but patterns in nymphalid butterfly evenness are unclear.

All species data will be published separately as a Data Paper.

DISCUSSION

The intensification of agriculture has been associated with a substantial loss of biodiversity along with many important ecosystem services which include crop production, pest control, pollination and decomposition processes, and soil properties (Lal 1988; Daily 1997; Altieri 1999; Schläpfer et al. 1999; Tilman et al. 2002; Wilby & Thomas 2002). The decline of biodiversity affects ecosystem functioning and yield (Russell 1989; Daily 1997). Local intensification may affect biological pest control (Russell 1989; Matson et al. 1997; Thies & Tscharntke 1999; Östman et al. 2001; Symondson et al. 2002; Barbosa 2003; Donald 2004; Perfecto et al. 2004; Tylianakis et al. 2004), grassland production (Bullock et al. 2001; Loreau & Hector 2001), pollination (Nabhan & Buchmann 1997; Kremen et al. 2002; Klein et al. 2003a,b) and resistance to plant invasion (Lyons & Schwartz 2001; Kennedy et al. 2002; Levine et al. 2004; Zavaleta & Hulvey 2004). During the last decades, worldwide losses of biodiversity have occurred at an unprecedented scale and agricultural intensification has been a major driver of this global change (Matson et al. 1997; Tilman et al. 2001; Kremen et al. 2004). Hence, there is considerable concern that intensive modern agriculture is not compatible with the conservation of biodiversity (Robinson & Sutherland 2002).

Organic farming is often thought of as a solution to the problems associated with biodiversity conservation in intensive agricultural landscapes. Our study shows that there is greater level of insect diversity (ground insects and butterflies) on organic plantations when compared to the conventional (chemical fertilizers and pesticide-sprayed) plantations. Our study supports the contention that organic farming enhances biodiversity (Paoletti et al. 1992; Schönning & Richardsdotter-Dirke 1996, Bignal & McCracken 1996; Plachter 1999; Sutherland 2002a,b). Conventional agricultural pest-management practices often lead to altered food web structure and communities dominated by a few common species, which together contribute to pest outbreaks. Organic farming methods mitigate this ecological damage by promoting evenness among natural enemies (Crowder et al. 2010) which then contributes to a pest-predator balance. Hence, species evenness was considered an important response variable in the present study. Our results confirm the hypothesis that organic farming promotes species evenness of total ground insects.

The data generated and analyzed here clearly show that pesticide treatment has a significant negative effect on insect biodiversity as measured by Shannon's diversity and evenness indices. A comparative effect of treatment on mean Shannon's diversity index H' for ground insects within each crop type clearly indicates that organic (and NPK) cardamom plantations have higher levels of biodiversity than corresponding coffee plantations. This is expected because cardamom is a native crop and grown under denser forest shade canopy than coffee. However, pesticide-treated cardamom plantations show the lowest levels of insect biodiversity. This can be explained by the very high levels (6–12 sprays per year) of pesticide use in conventional (chemical) cardamom plantations as compared to 1–2 sprays in conventional coffee plantations. There is no clearly observable difference in insect diversity between organic and NPK plantations. This result is probably because NPK treatment is limited to once per year and most of the plantations in the district show high plant (weed) diversity and good canopy cover. This produces a heavy build up of mulch and ground leaf litter, and this combined with heavy rainfall provides a good buffering capacity to the negative impacts of limited applications and quantities of fertilizers.

One of the interesting results of this study is that ants show a similar response to pesticide use as total insects but the magnitude of the effect is much greater: 50% reduction in diversity compared to 20% for total insects in organic versus pesticide-sprayed plantations. For total ground insects, a significant difference was observed between pesticide-free (0P) plantations and heavily pesticide-sprayed (3P) plantations, but not with low or moderate pesticide treatment. For ants, a significant difference was observed between pesticide-free (0P) plantations and even lightly pesticide-sprayed (1P) plantations. These results indicate that ants are sensitive and rapid responders to plantation management practices and hence are good biological indicators (Campbell & Tanton 1981; Majer 1983; Andersen 1990). This is especially significant in light of the fact that tropical regions support very high levels of insect diversity, which, combined with incomplete taxonomic work (Narendran 2001), makes identification a difficult task. This may account for the lacuna of other studies on total ground insects. Ants, on the other hand, have been extensively studied and their taxonomy is well understood (Narendran 2001). Moreover, ants are functionally important at different trophic levels (Alonso 2000) and play critical ecological roles in soil turnover and structure (Humphreys 1981; Lobry de Bruyn & Conacher 1994), nutrient cycling (Levieux 1983; Lal 1988), plant protection, seed dispersal and seed predation (Ashton 1979; Beattie 1985; Christian 2001). Hence we propose, based on our results, that such future studies can be carried out more cost-effectively by simply considering patterns in ant diversity.

Despite the clear patterns in our results, we recognize that biodiversity in agricultural landscapes is affected by many factors other than the farming system. Fallow areas, such as field margins, habitat islands, hedgerows, natural pastures, wetlands, ponds and other small habitats are important refuges and source areas for many organisms. Maintenance of biodiversity in agricultural landscapes will depend on the preservation, restoration and management of such habitats (Corbett & Rosenheim 1996; Stopes et al. 1995; Baudry et al. 2000; Tscharntke et al. 2002, 2005). Landscape structure and heterogeneity also contributes to biodiversity in agricultural areas (Marino & Landis 1996; Fahrig & Jonsen 1998; Krebs et al. 1999; Weibull et al. 2000; Berg 2002; Steffan-Dewenter et al. 2002; Benton et al. 2003; Dauber et al. 2003, Ricketts et al. 2004).

Our study shows that organic plantations support greater diversity of ground insects and nymphalid butterflies, and that ants are a good indicator taxon for ground insects. The number of pesticide applications was seen to have a strong effect on both ant and overall ground insect diversity. A better understanding of how species interact within a community and how communities function at the landscape level could be keys to the maintenance and utilization of biodiversity in agri-ecosystems. Therefore, there is a crucial need to conduct further similar research studies, at multiple spatial and temporal scales, especially from tropical regions dominated by agriculture.

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