Tree diversity on sustainably certified and conventional coffee farms in Central America

Haggar, Jeremy[1]; Asigbaase, Michael[1]; Bonilla, Glenda[2]; Pico, Jose[3]; Quilo, Alma[4]

[1] Natural Resources Institute, University of Greenwich, Chatham, UK

[2] Universidad Nacional Agraria, Managua, Nicaragua

[3] Tropical Agricultural Research and Higher Education Center, CATIE, Costa Rica

[4] Centre for Biodiversity and Envionmental Studies, Universidad del Valle, Guatemala City, Guatemala

Abstract

Shade coffee agroforestry systems have the potential to support biodiversity. Sustainable certification of coffee has been promoted as a means to provide incentives to maintain these systems, but as yet there is little evidence if this is effective. We analyzed tree diversity on smallholder organic and conventional farms in buffer zones of three conservation areas in Costa Rica, Guatemala and Nicaragua (the later included some large-scale conventional and Rainforest Alliance certified farms). Organic farms had greater farm level tree species richness and Shannon diversity compared to conventional farms; estimated native tree species richness across the landscape was probably greater on organic farms than conventional in Nicaragua (48 versus 28 species respectively) and possibly in Guatemala (23 versus 15 species respectively). Organic farms had higher shade levels and more tree strata than conventional farms. In Guatemala and Nicaragua tree species composition was not closely related to whether farms were organic or conventional, although within composition clusters, organic farms tended to have greater diversity. In contrast, organic and conventional farms in Costa Rica mostly belonged to different tree species clusters. In Nicaragua most large-scale farms, and all Rainforest certified farms, formed a distinct species composition cluster with presence of old-growth forest species and within which Rainforest farms had greater diversity. Tree species composition of the shade seems to be mainly due to management history; but certification effectively differentiates those farms with greater tree diversity. Longer-term monitoring is required to determine whether certification can be an incentive to conserve or expand biodiverse coffee agroforestry systems within the buffer zones around conservation areas.

Key words: Agroforestry; organic; Rainforest Alliance; shade coffee; Shannon diversity index; species richness

Introduction

Faced with the current threats to biodiversity such as climate change, invasive species, deforestation, pollution, and disruption of migration paths by infrastructure and human settlements, protected areas are insufficient to preserve biodiversity (DeFries et al. 2005; Millennium Ecosystem Assessment 2005). Therefore agroecosystems, such as agroforestry systems, need to play a complementary role in the conservation of biodiversity (Vandermeer and Perfecto 2007; Harvey et al. 2008). Agroforestry has the potential to contribute to biodiversity conservation by creating habitat for species which are tolerant to some level of disturbance through preserving some native species (Harvey and Villalobos, 2007).

Agroforestry can be a tool for biodiversity conservation by having high plant diversity and increased structural complexity, incorporation of diverse native species and enhanced habitat and landscape heterogeneity. Gillison et al. (2004) found shade grown coffee (an agroforestry system) to have higher levels of biodiversity in comparison to sun coffee but lower when compared to secondary or primary forests. Diverse fauna and flora have been reported in various coffee systems including migratory birds such as the cerulean warbler (*Setophaga cerulean*) (Bakermans et al. 2009), orchids (Solis-Montero et al. 2005), rare bats (Estrada et al. 2006), ants (Armbrecht et al. 2005), other arthropods (Carlo et al. 2004) and amphibians (Santos-Barrera et al. 2011).

There is a significant overlap between major coffee production areas and biodiversity hot spots (Myers et al. 2000; Hardner and Rice 2002), such as in Mesoamerica, the Andean region and southern India. Agroforestry systems can serve as buffer zones, corridors, and as habitats for species that are tolerant to some level of disturbance (Donald 2004; Mas and Dietsch 2004). Moguel and Toledo (1999) concluded that coffee plantations in Mexico could serve as important corridors for flora and fauna, while Balia et al. (2007) found 28 mammal species including carnivores (such as tigers and leopards) and herbivores (such as elephants and deer) in 15 coffee plantations around the Bhadra Wildlife Sanctuary in Western Ghats of India. In some regions, because very little forest cover exists, much of the existing tree cover is provided by shade grown coffee. For example, shade coffee accounts for 80%-92% of forest cover in El Salvador (Rice and Ward 1996). Therefore, floristically and structurally diverse managed coffee plantations can contribute significantly to tree cover in the landscape.

Shaded coffee systems also provide a range of supportive, regulatory, and provisioning ecosystem services to farmers. Over time coffee agroecosystems conserve soil by increasing soil organic matter and reducing nutrient leaching (Siebert 2002; Tscharntke et al. 2011). The use of shade trees can positively affect pest management since shade trees host biological control organisms such as birds, lizards and predatory insects (Staver et al. 2001; Perfecto et al. 2004). Shade trees also provide products such as fruits, firewood and local construction material. Rice (2008) reported that the consumption and sale of all non-coffee products accounted for a fifth to a third of the total value realized from coffee farms in Peru and Guatemala.

Despite the potential to conserve biodiversity and provide socio-economic benefits, there has been considerable replacement of complex and floristically diverse shade coffee systems with simplified and less diverse, unshaded systems. This trend has been driven by the desire to increase yields to meet market demand for coffee (Polzot 2004; Castro-Tanzi et al. 2012). Gobbi (2000) estimated that 41% of the 2.7 million ha of coffee production lands in Latin America have been converted to unshaded or reduced shade plantations. Impacts of intensification included water pollution from agrochemical run-off, reduced forest cover and habitat loss, soil erosion and consolidation of plantations under large landowners (DaMatta 2004; Polzot 2004). When coffee prices fall, shaded coffee systems have been replaced with other land uses that offer fewer environmental benefits such as rubber plantations or pasture (Haggar et al. 2013).

Despite past intensification the majority of coffee in Central America is still grown in shade agroforestry systems; 98% is shade grown in Guatemala (ANACAFE 2008), 94% in Nicaragua (MAGFOR 2002), and 91% of the coffee area in Costa Rica has trees integrated into the plantation (CATIE 2002). Nevertheless, the nature of this shade varies considerably from heavily managed single species shade to highly diverse tree species assemblages (Moguel and Toledo 1999). Sustainable certifications have been developed that aim to provide market recognition of those coffee systems managed under sustainable practices including the maintenance of shade trees (Haggar et al. 2012). Under some certifications such as that of Rainforest Alliance, farmers gain points for having shade with a diversity of species (SAN 2010). Although organic certification standards do not require use of shade, most producers and certifiers see shade essential for organic production. Biodiverse shade systems studied in Chiapas have been mostly on organic farms (e.g. Perfecto and Vandermeer 2002, Soto-Pinto et al. 2001).

Sustainably certified coffee now represents 17% of global production and 8% of sales, with organic certification representing about 25% of certified coffee sold (Potts et al. 2010); 31% of organic coffee is grown in Central America and Mexico. Nevertheless, the predominant coffee shade systems within this region vary considerably from simple, mostly single species shade in Costa Rica to more diverse shaded systems in the rest of Central America and Mexico (Galloway and Beer 1997). The current study compares the shade tree biodiversity of smallholder organic and conventional farms in three regions of Costa Rica, Guatemala, and Nicaragua (plus some large-scale and Rainforest Alliance certified farms in Nicaragua) to evaluate whether certified farms have greater diversity of tree species than those without certification. Tree species richness and structure (e.g. canopy cover, number of strata) determine the forest as a habitat to host other native fauna and flora. Tree species richness and forest structure has been found to have close correlations with fruit and nectar feeding birds and fruit feeding butterflies (Schulze et al. 2004) or with diversity arthropod groups such as ants (Leal et al. 2012).

Methods

Description of study sites

Data were collected from farmer's coffee fields in three major coffee producing regions in Central America. All three locations are associated with protected areas and therefore the farming systems used are important for their potential value as buffer habitats or biological corridors. All locations are in the lower montane altitudinal range, whereas the forest of the protected areas is at higher altitude; thus the shaded coffee systems potentially represent an extension of forest-like habitat across a greater altitudinal range. Across Central America most protected forest is either lowland or higher montane, with lower montane forest being under-represented (e.g. CONAP 2009 for Guatemala).

Turrialba, Costa Rica is located at 9°53´44´´ N and 83°40´7´´ W and the biological corridor lies between the national parks of the central volcanic chain and the forests of the Talamanca mountain range. Annual precipitation is 2600-3200 mm with no marked dry season, and mean temperature is 22°C (Muschler 2001). Soils are of volcanic origin of different ages and degrees of weathering. The main land uses are coffee, sugar cane, pasture and forest fragments, with coffee grown at 700-1200 masl.

Sierra de Las Minas Biosphere Reserve, Guatemala is located at 15°07´-15°21´ N and 89°18´-89°45´ W. The study focused on the Rio Hato water catchment on the south side of the mountain range between 700-1100 masl, with rainfall of between 1000-1500 mm and 2 to 4 months dry season. Soils are young, shallow inceptisols and derived from various sedimentary rocks. The main vegetation types are lower montane moist forest and cloud forest. Coffee farms are located in the buffer zone of the reserve assigned to agroforestry and agriculture production, below the forested core zone.

Peñas Blancas Massif Natural Reserve, Nicaragua is part of the Bosawas Biosphere Reserve located at 13°13´27´´ N and 85°35´25´´ W with a maximum altitude of 1745 masl and an annual rainfall range of 2000-2500 mm with a 4-8 week dry season from February to April (Cerdán et al. 2008). Depending on altitude, climate conditions are wet montane to humid sub-tropical. Vertisols and inceptisols soils are derived from the calcareous rocks of the Massif. Peñas Blancas, although a reserve area, has about 2000 ha of coffee located in the core zone with 94% being shade coffee and the remaining 6% sun coffee (MAGFOR 2002). Coffee is also an important land use in the buffer zone around the Reserve within a landscape mosaic of coffee, pasture, annual crops and forest fragments. Coffee is found from 800-1100 masl.

Survey design and data collection

Organic farms in each country were members of producer associations, in Guatemala and Nicaragua the smallholder conventional farmers were also members of the same associations; in Costa Rica the conventional farmers were not part of an association but from the same communities as the organic farmers. The coffee farms in each region were from a relatively small area (approximately 10 km × 10 km), and while covering a range in altitude (approximately 800 to 1100 masl), they had similar climatic and geological conditions. All the coffee fields studied were over 10 years old. Four plots per coffee field were sampled in Nicaragua and Costa Rica where fields were greater than 1 ha, while in Guatemala only one plot was sampled per field because most were less than 0.25 ha (Table 1). In each coffee farm, 20 × 25 m (500 m^2) plot(s) were established with a minimum of 10 m from the field edge and between plots. All plants that were taller than the coffee bushes and had a stem diameter over >5 cm dbh were considered shade trees and the number of individuals in the plot was registered. The number of tree strata was determined by visually estimating the presence of tree or shrub canopies within the strata of 0-5 m, 5-10 m, 10-15 m and over 15 m. The shade cover of each plot was estimated using a densiometer, a hemispherical mirror that reflects the tree canopy (Lemmon 1956). Four measurements were taken from the centre of each plot towards each cardinal direction, scoring the number of points on the matrix of the mirror that were covered by trees. The shade proportion and strata values of the four plots sampled were then averaged for each farm.

In addition to the small farms surveyed, in Nicaragua three large Rainforest Alliance certified farms and six large conventional farms were also surveyed for the purpose of comparing the effect of farm size, and a certification more typical of these farms, on tree composition and diversity. The data from these farms was only used in the cluster analysis of shade tree composition in Nicaragua.

Biodiversity calculations and statistical methods

Tree species diversity was estimated using species richness and the Shannon Diversity Index (Magurran 2004). The Shannon Index was calculated using the equation: $H = -\Sigma p_i*(\text{Ln } p_i)$ where p_i is the proportion of individuals found in the ith species and is calculated as n_i/N where n_i is the number of individuals in the ith species and N is the total number of individuals. The Shannon Index was chosen because it takes into account both evenness and species richness.

A two-way analysis of variance was used to compare the species richness, Shannon diversity and farm biophysical characteristics (tree strata, density and proportion of shade) between farm types and a Tukey Alpha test to compare between means of farm types. Species richness is highly dependent on sample size. Therefore, average plot values from Nicaragua and Costa Rica were used to give comparability with Guatemala, where only one plot was assessed per farm. All residuals from the data analyses were tested for normality using the Shapiro Wilks test, and all parameters complied with normality.

Tree species were divided in native and exotic species. Native species were further divided into those that were probably planted (fruit trees and shade trees) and forest tree and shrub species that were probably naturally present (Table 2 and Appendix). As different numbers of organic and conventional farms were sampled in Nicaragua and Guatemala, and the number of farms sampled also differed between countries, direct comparison of species richness across farms and countries is not possible. The rarefaction extrapolation function developed by Colwell et al. (2012) enables comparative estimation of species richness with uneven sample sizes using the extrapolation function to estimate to the same number of samples. This was done using the EstimateS programme (Colwell 2013), with number of farms extrapolated to 12 farms, double the smallest sample size (EstimatesS recommends that the extrapolation function is not used to more than double the number of samples). This enabled us to obtain an estimate of the number of native tree species across organic and conventional farms in the landscape, plus associated 95% confidence limits. Although it should be noted that Payton et al. (2004) considered that 95% confidence limits were much too conservative having calculated that for two normal distributions non-overlapping at 84% confidence was comparable to a $p<0.05$ probability of difference. This has been proposed to be applied to rarefaction curves by Gotelli and Colwell (2011), but as yet the calculation is not available on EstimateS.

Cluster analysis was used to assess the degree species composition was affected by farm certification. Dendrograms were produced by a hierarchical cluster analysis using Ward's minimum variance method based on a dissimilarity matrix based on the euclidean (square) distances between the sample vectors using the R package (R Development Core Team 2012). The bar charts show the distribution of species within each cluster – the y-axis scale is $\log_e$ (number of individuals of species+1). Species that only occurred once were excluded as they cannot contribute to an assessment of difference or similarity in species composition.

Results

Species richness and diversity

The average species richness (Fig. 1) was significantly higher (p = 0.002) on organic farms (4.83 per plot) than conventional farms (2.88 per plot). Shannon diversity was significantly higher (p = 0.008) on organic farms compared to conventional farms across all three countries (Fig. 2). Guatemalan farms had the highest plot mean species diversity (1.13), Costa Rican farms the least (0.61) and Nicaraguan farms were intermediate (1.04).

The estimated number of native tree species found across all farms were higher on organic than conventional farms, although the 95% confidence intervals overlapped in all cases (Fig 3). The largest estimated number of native tree species across farms was for Nicaragua with 48 species (S.D. = 8.36) for organic and 28 (S.D. = 4.6) for conventional (Fig. 3 c); and in Guatemala 23 species (S.D.=3.38) for organic and 15 (S.D. 2.66) for conventional. These differences could be significant if narrower confidence limits were used, as has been suggested by some authors (Payton et al. 2014, Gotelli and Colwell 2011). Furthermore, the species accumulation rates were still diverging between organic and conventional farms, with a higher rate of accumulation under organic farms. The differences were minimal and definitely non-significant between organic and conventional farms in Costa Rica (Fig. 3a). The percentage of tree species that were native ranged from 70-75% in Nicaragua and Guatemala to 50% in Costa Rica.

The composition of the species differed, however, with less than half of species found on both types of farm. Nevertheless, the predominant species were generally similar (See Appendix). In Costa Rica *Erythrina* spp., *Musa* spp. and *Cordia alliodora* were the most abundant species on both farm types, comprising 91% of the total number of trees on the conventional farms and 88% of those on organic farms. In Guatemala conventional farms were predominantly shaded by *Inga laurina*, *I. spuria*, *I. punctata* and *Musa* spp., which comprised 66% of trees, while on the organic farms *I. punctata, Musa* spp., *Chamaedorea tepejilote* and *Veronia patens* made up 44% of individuals. The majority of the native species in Guatemala were planted shade or fruit tree species, while in Nicaragua a majority of the native species were naturally occurring forest trees and shrubs. The most abundant species on conventional farms in Nicaragua were *Musa* spp., *I. oerstediana*, *Juglans olanchana* and *Erythrina poeppigiana*, making up 80% of the total number of trees; while on the organic farms, *Musa* spp., *I. oerstediana*, *Cordia alliodora*, *I. punctata* comprised 77% of the individuals. Forty percent of the native forest tree species (13 species total) were only represented by one individual.

3.2 Vegetation structure of shade

The average number of shade tree strata was marginally significantly higher on organic farms than on conventional farms (p=0.076) when compared across all three countries (Table 3).

Percentage shade cover was higher on organic (63%) than on conventional farms (47%) (*p*=0.0013), and in general was higher in Nicaragua and Guatemala than Costa Rica. Overall mean tree densities were about 25% higher on the Costa Rican farms than on the Nicaraguan and the Guatemalan farms but there were no differences between organic and conventional farms. The higher tree density in Costa Rica was largely due 50% of tree species being *E. poeppigiana* which is pollarded twice yearly thus restricting the development of the tree but requiring higher tree densities to achieve a certain shade cover.

3.3 Tree composition across farm types

Cluster analysis of the tree species composition on the organic and conventional farms in Costa Rica revealed three clusters (Fig 4 a). Cluster 1 was found mostly on organic farms and included the exotic legume shade tree *I. edulis* plus the root crop *Manihot esculenta* (managed as a perennial shrub), a high incidence of fruit trees such as *Musa* spp. *Psidium guajava* and *Theobroma cacao,* and two native forest species, *C. alliodora* and *Cedrela odorata*. Cluster 3 was found mostly on conventional farms and shade was dominated by two species, one exotic shade tree - *Erythrina poeppigiana* and one exotic fruit crop *Musa* spp. Cluster 2 consisted of one organic and one conventional farm and was differentiated by the presence of the native fruit-producing palm *Bactris gasipaes*. Guatemalan farms had four tree clusters (Fig 4b). Three included both organic and conventional farms, while the fourth cluster comprised just one organic farm with a unique species composition including the cultivated native palm *C. tepejilote*. Among the others, Cluster 3 was distinguished by a higher presence of exotic fruit *Citrus* spp. and *Prunus persica* trees, while Clusters 2 and 1 differentiated in the presence or absence of several species of lower frequency. No significant differences were found in species richness or Shannon diversity between the clusters in either country.

For Nicaragua, cluster analysis was conducted combining the large and small-scale farms. The species cluster analysis revealed four main vegetation types (Fig 4 c). The elements common to all were some kind of leguminous tree usually *Inga* spp. combined with the presence of *Musa* spp. Cluster 1 was differentiated by native successional shrub and tree species such as *Lippia myriocephala*, *Lonchocarpus* spp., *Senna atomaria* and *Urera caracasana* as well as planted temporary shade species such as *Ricinus communis.* Cluster 2 consisted of largely planted shade legumes trees (*Inga* spp., *Gliricidia sepium*) and native timber species (e.g. *Tabebuia rosea, J. olanchana).* Cluster 3 was composed of largely native forest species but all providing specific products (e.g. *Pimienta dioica* - allspice, *Brosimum alicastrum* - breadnut) as well some native forest species (e.g. *C. alliodora* and *Lonchocarpus minimiflorus*) more typical of secondary forest. Native mature forest trees such as *Ocotea yeraquensis*, *Spondias mombin*, *Hyeronima alchorneoides* and *Pouteria sapota* were observed only in Cluster 4. Two farm types, organic and conventional, comprised Cluster 1 and 2, Cluster 3 was made up of only organic farms and Cluster 4 was made up of large-scale conventional and Rainforest certified farms.

Difference in species richness between clusters was only significant to p=0.066, but farm type (certification × farm size) had a significant effect (p=0.016). Organic farms recorded higher numbers of species (5.8 species) compared to conventional farms (2.8 species) averaged across clusters (Fig. 5a). Rainforest farms also had greater species richness than conventional farms in the same cluster (Fig. 5a).

Shannon diversity was significantly affected both by farm type (p=0.011) and vegetation cluster (p=0.052). The diversity of trees species was generally higher on the organic farms compared to the conventional farms (Fig. 5b; Shannon index = 0.67 for conventional farms vs. 1.24 for organic farms), while Rainforest Alliance farms also recorded higher Shannon diversity values compared to conventional farms of the same cluster (Fig. 5b; Shannon index = 0.82 for Rainforest farms vs. 0.55 for conventional farms).

4.0 Discussion

4.1 Influence of certification on shade tree composition

The results show a definite trend in all countries to higher tree species richness and diversity on certified compared to conventional farms, despite the variety of shade composition found across and within the countries. Species diversity was accompanied by more diverse canopy structure (i.e. more vertical stratification) and higher levels of shade, but interestingly it was not associated with a higher density of trees. Thus the organic systems maintain a higher diversity of species with the same number of trees. The presence of native tree species was higher on the organic than the conventional farms in Guatemala and Nicaragua, but not in Costa Rica.

In the only other study of this kind, Philpott et al. (2007) reported a significant difference in mean numbers of tree species on organic farms (12.89 ± 0.49) compared to organic and Fairtrade coffee farms (10.14 ± 0.46). Previous studies have not looked at how species are associated or how these associations may be related to certification. Actually, the species clusters showed only a weak correlation with the certifications status of the farms, although at least for Nicaragua species diversity was higher on certified than non-certified farms within clusters. Thus the species composition would appear to be responding to other factors rather than certification. Analysis of the ecology and utility of the species composition of the clusters indicates that some clusters have more young secondary forest species (e.g. cluster 1 in Nicaragua), other mature forest species (e.g. cluster 4 Nicaragua) or others are differentiated by exotic, native fruit trees or other species of value to the farmers (e.g. Cluster 3 in Guatemala and Nicaragua). These different tree species compositions would appear to relate to different land use histories, management and production objectives of the farmers independent of whether they are certified or conventional. The certifications would appear to have arrived subsequently and then favoured or been favoured by those with more diverse shade systems.

4.2 The role of shaded coffee for biodiversity conservation

It has been claimed that the creation, maintenance and conservation of diverse multi-purpose shade trees can maintain high levels of both flora and fauna in agroforestry systems (Tscharntke et al. 2011). Noble and Dirzo (1997) suggested that about 50-80% of species from regional species pools could survive in agroforestry systems. In Chiapas, Mexico, Soto-Pinto et al. (2000) documented 61 tree species, the majority of which were native trees. Lopez-Gomez et al. (2008) reported 107 tree species, 83 of which were native species, in central Veracruz, Mexico. In this study overall 55 species were found in Nicaragua of which 80% were native; species richness and proportion of native species were lower in the other two countries. How many of these native species are found in native forest can be quite small, for example Mendez et al. (2007) documented 123 shade tree species in El Salvador of which just 16% were also found in adjacent forest. In this study, although no comparison was made with adjacent forest, 60% of the tree species found in Nicaragua were considered to be native forest species; including species from early succession (e.g. *Cecropia obtumifolia, Guazuma ulmifolia),* mid succession (e.g. *Juglans olanchana, Ocotea yeraquensis)* and old growth species (e.g. *Hyeronima alchorneiodes, Platymiscium pinnatum*).

Additionally, the cluster analysis facilitates some interpretation of the ecology of the species composition. For example in Nicaragua cluster 1 was characterised by early successional species while cluster 4 was characterised by tree species more characteristic of the mature forest. Another differentiation could be between species that are planted or occur naturally (although both native); overall it was found that about half the native species were probably planted being fruit trees or preferred shade trees for coffee (usually legumes). This does not mean that farmers don't plant forest species, indeed the *Inga* spp. planted in coffee often also occur in adjacent forest, and in Nicaragua Cluster 3 was characterised by the presence of native fruit, nut, timber and spice trees that farmers had planted. Thus defining which tree species are indigenous to the site is not straightforward.

Furthermore, it must be recognized that the dominant legume trees also make an important contribution to the biodiversity sustaining capacity of shaded coffee. For example, compared to full sun coffee, *Inga* spp. shade hosted greater bird diversity (Greenberg et al. 1997), and *Erythrina* spp. shade favoured higher ground ant diversity (Perfecto and Snelling 1995). Indeed the Rainforest Alliance certification criteria (SAN 2010) promote restrictions on the management of the predominant shade trees in the northern winter to sustain their capacity to support migrants. Thus, the ecology of the specific shade tree species and especially those dominating the system has a strong influence on the value of the systems for sustaining biodiversity. Nevertheless, under appropriate management, such as promoted under certification, shaded coffee may be an effective way of conserving tree biodiversity since it acts as reservoirs for native species expanding the populations in remnant forest patches.

4.3 Costs and benefits to farmers maintaining high diversity shaded coffee

Highly managed systems tend to be less diverse, and the profitability of commodities such as coffee tends to restrict the adoption of highly diverse systems in large-scale plantations (Noble and Dirzo 1997; Harvey and Villalobos 2007). While Soto Pinto et al. (2000) observed that tree density did not affect coffee yields in Chiapas, Mexico; Haggar et al. (2013) found that the diverse shade species coffee systems in neighbouring Guatemala had lower productivity than shaded coffee with just one shade species.

Nevertheless, particularly for organic farmers, there may be ecological benefits to maintaining high tree diversity. Soto-Pinto et al. (2002) studying shade coffee in Mexico reported that there was no correlation between pests, diseases and weeds with percentage shade cover, yield, stand age, light, aspect, coffee density and basal area. Therefore, the authors concluded that mixed shade-tree systems with high diversity and structural complexity maintain a healthy production system. It may be expected that organic farmers who cannot use agrochemicals for soil fertility and pest management would benefit more from these ecosystem services and thus favour more diverse shade systems. Economic surveys in the Nicaraguan study site indicated that organic and Rainforest Alliance certified farms received higher prices for their coffee than conventional farms, but net income although slightly higher was not significantly different from conventional farms (Haggar et al. 2012).

Within each country farms that were sustainably certified generally had greater tree diversity, although diversity of native tree species was probably only greater on certified farms in Nicaragua and possibly Guatemala. The certifications do not recognize the difference between native and exotic tree species, nor that the Nicaraguan farms were estimated to support five times more native tree species as Costa Rican farms. In terms of contributing to biodiversity conservation, the range of tree native species found on organic Nicaraguan farms (26 species) could be expected to support many native forest species of fauna and flora and act as effective extensions of the protected reserve area, while the less diverse Costa Rican farms (both organic and conventional) would probably only host species associated with the agricultural landscape. The composition the tree species appears to respond to farmers' selection of species for their utility or as remnant species from the pre-existing land-use. What remains to be seen is whether the sustainability certification will help to conserve that diversity or even be an incentive for others to revert to more tree-diverse systems. While sustainable certification may help to support conservation of biodiverse land-uses on farms in conservation buffer zones, it is probably just one of many factors influencing farmers' decisions. Longer-term monitoring of the changes in certified farms is required to determine whether certification provides an effective incentive to conserve or expand species diverse shaded coffee.

Acknowledgements

This research was supported by the EC funded project "CAFNET: Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India" EC Contract number EuropeAid/ENV/2006/114-382/TPS which had no involvement with the design or analysis of the research, and the DEFRA/Darwin Initiative funded project 19-018 "Agroforests: a critical resource for sustaining megadiversity in Guatemala". Elias de Melo and Gabriela Soto of the Tropical Agricultural Research and Higher Education Centre (CATIE) in Costa Rica coordinated the CAFNET project in Central America and supervised parts of this research. Cesar Tot of Fundacion Defensores de la Naturaleza, and Luis Cuadra and Urbina Alvarado students at the National Agrarian University supported the implementation of the research in Guatemala and Nicaragua, respectively. We thank Stephen Young for his advice on the statistical analysis.

References

ANACAFE (2008). Green Book: Guatemalan coffees. ANACAFE, Guatemala City. http://www.guatemalancoffees.com/ index.php/greenbook. Accessed 12 February 2014

Armbrecht I, Rivera L, Perfecto I (2005) Reduced diversity and complexity in the leaf-litter ant assemblage of Colombian coffee plantations. Cons Bio 19:897-907.

Bakermans MH, Vitz AC, Rodewald AD, Rengifo CG (2009) Migratory songbird use of shade coffee in the Venezuelan Andes with implications for the conservation of the cerulean warbler. Biol Conserv 142:2476-2483.

Balia A, Kumarb A, Krishnaswamy J (2007) The mammalian communities in coffee plantations around a protected area in the Western Ghats, India. Biol Conserv 139:93-102.

Carlo TA, Collazo JA, Groom MJ (2004) Influences of fruit diversity and abundance on bird use of two shaded coffee plantations. Biotrop 36:602-614.

Castro-Tanzi S, Dietsch T, Urenaa N, Vindasa L, Chandler M (2012) Analysis of management and site factors to improve the sustainability of smallholder coffee production in Tarrazú, Costa Rica. Ag Ecosys and Enviro 155:172–181.

CATIE (2002) Sistema geografica sobre area cafetalera de Costa Rica. Informe final al Instituto de Café de Costa Rica, Turrialba.

Cerdán C, Lamond G, Pagella T, Soto G, Sinclair FL (2008) Local knowledge of coffee productivity and ecosystem services in coffee plantations surrounding Macizo Peñas Blancas Reserve, Jinotega-Matagalpa Departments, Nicaragua: a guide to using the CAFNET-Nicaragua knowledge base. CATIE, Nicaragua.

Colwell RK (2013) EstimateS: Statistical estimation of species richness and shared species from samples. Ver 9. Persistent URL <purl.oclc.org/estimates>

Colwell RK, Chao A, Gotelli NJ, Lin S-Y, Mao CX, Chazdon RL, Longino JT (2012) Models and estimators linking individual-based and sample-based rarefaction, extrapolation, and comparison of assemblages. J Plant Ecol 5:3-21.

CONAP (2009) IV Informe Nacional de cumplimiento a los acuerdos del convenio de Diversidad Biológica ante la Conferencia de la Partes -CDB. Consejo Nacional de Áreas Protegidas, Guatemala, 135p.

DaMatta FM (2004) Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crop Res 86:99-114.

DeFries R, Hansen A, Newton AC, Hansen MC (2005) Increasing isolation of protected areas in tropical forests over the past twenty years. Ecol Appl 15:19-26.

Donald PF (2004) Biodiversity impacts of some agricultural commodity production systems. Conserv Biol 18:17-37.

Estrada CG, Damon A, Hernandez, CS, Soto Pinto L, Nunez GI (2006) Bat diversity in montane rainforest and shaded coffee under different management practices in southeastern Chiapas, Mexico. Biol Conserv 132:351-361.

Galloway G, Beer J (1997) Opportunidades para fomentar la silvicultura en cafetales de America Central. CATIE, Turrialba, Costa Rica. Informe técnico, No 285, 166p.

Gillison AN, Liswanti N, Budidarsono S, van Noordwijk M, Tomich TP (2004) Impact of cropping methods on biodiversity in coffee agroecosystems in Sumatra, Indonesia. Ecol Soc 9:7-13.

Gobbi J (2000) Is biodiversity-friendly coffee financially viable? An analysis of five different coffee production systems in western El Salvador. Ecol Econ 33:267-281.

Gotelli NJ, Colwell RK (2011) Estimating species richness. Pages 39-54 in Magurran AE, McGill BJ eds. Frontiers in measuring biodiversity. Oxford University Press, New York

Greenberg R, Bichier P, Cruz Angon A, Reitsma R (1997) Bird populations in shade and sun coffee plantations in Central Guatemala. Conserv Biol 11:448-459.

Haggar J, Medina B, Aguilar RM, Munoz C (2013) Land use change on coffee farms in southern Guatemala and its environmental consequences. Environ Manage 51:811-823.

Haggar J, Jerez R, Cuadra L, Alvarado U, Soto G (2012) Environmental and economic costs and benefits from sustainable certification of coffee in Nicaragua. Food Chain 2:24-41

Hardner J, Rice R (2002) Rethinking green consumerism. Sci Am 286:88–95.

Harvey CA, Komar O, Chazdon R, Ferguson BG, Finegan B, Griffith DM, Martinez-Ramos M Morales, Nigh H, Soto-Pinto R, Van Breugel L, Wishnie M (2008) Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot. Conserv Biol 22:8-15.

Harvey CA, Villalobos JAG (2007) Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. Biodivers Conserv 16:2257-2292.

Leal IB, Filgueiras J, Gomes L, Iannuzzi A (2012) Andersen. Effects of habitat fragmentation on ant richness and functional composition in Brazilian Atlantic forest. Biodivers Conserv DOI 10.1007/s10531-012-0271-9.

Lemmon P (1956) A spherical densitometer for estimating overstory density. Forest Sci 2:314-320.

Lopez-Gomez AM, Williams-Linera G, Manson RH (2008) Tree species diversity and vegetation structure in shade coffee farms in Veracruz, Mexico. Agr Ecosyst Environ 124:160–172.

MAGFOR (2002) Elaboración del mapa de cultivo de café en Nicaragua. Ministerio de Agricultura Ganadería y Forestal, Managua.

Magurran AE (2004) Measuring biological diversity. Blackwell Publishing, Oxford.

Mas AH, Dietsch TV (2004) Linking shade coffee certification to biodiversity conservation: butterflies and birds in Chiapas, Mexico. Ecol Appl 14:642-654.

Mendez VE, Gliessman SR, Gilbert GS (2007) Tree biodiversity in farmer cooperatives of a shade coffee landscape in western El Salvador. Agr Ecosyst Environ 119:145-159.

Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Moguel P, Toledo VM (1999) Biodiversity conservation in traditional coffee systems in Mexico. Conserv Biol 13:11-21.

Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Noble IR, Dirzo R (1997) Forests as human-dominated ecosystems. Science 277:522-525.

Payton ME, Greenstone MH, Schenker N (2004) Overlapping confidence intervals or standard error intervals: What do they mean in terms of statistical significance? J Insect Sci 3:34

Perfecto I, Vandermeer JH, Bautista GL, Nunez GI, Greenberg R, Bichier P, Langridge S (2004) Greater predation in shaded coffee farms: The role of resident neotropical birds. Ecology 85:2677-2681.

Perfecto I, Vandermeer J (2002) The quality of the agroecological matrix in a tropical montane landscape: ants in coffee plantations in southern Mexico. Conserv Biol 16:174-182.

Perfecto I, Snelling R (1995) Biodiversity and the transformation of a tropical agroecosystem: ants in coffee plantations. Ecol Appl 5:1084– 1097.

Philpott SM, Bichier P, Rice R, Greenberg R (2007) Field-testing ecological and economic benefits of coffee certification programs. Conserv Biol 21:975-985.

Polzot C (2004) Carbon storage in coffee agroecosystems of Southern Costa Rica: Potential applications for the Clean Development Mechanism. MSc. Thesis, Faculty of Environmental Studies, York University, Toronto, Ontario.

Potts F, van der Meer J, Daitchman J (2010) The State of Sustainability Initiatives Review 2010: Sustainability and Transparency. IISD, IIED, Aid Environment, UNCTAD and ENTWINED.

R Development Core Team (2012) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/.

Rice RA (2008) Agricultural intensification within agroforestry: the case of coffee and wood products. Agr Ecosyst Environ 128:212-218.

Rice RA, Ward JR (1996) Coffee, conservation and commerce in the western hemisphere. Smithsonian Migratory Bird Center, Washington, DC.

SAN (2010) Sustainable Agriculture Standard. Sustainable Agriculture Network, San Jose, Costa Rica. http://www.rainforest-alliance.org/agriculture/documents/sust_ag_standard_july2010.pdf

Santos-Barrera G, Urbina-Cardona JN (2011) The role of the matrix-edge dynamics of amphibian conservation in tropical montane fragmented landscapes. Revista Mexicana de Biodiversidad, 82:679-687.

Schulze CH, Waltert M, Kesler PJA, Pitopang R Shahabuddin, Veddeler D, Muehlenberg M, Gradstein SR, Leuschner C, Steffan-Dewenter I, Tscharntke T (2004) Biodiversity indicator taxa of tropical land-use systems: comparing plants, birds and insects. Ecol Appl, 14:1321–1333.

Siebert SF (2002) From shade- to sun-grown perennial crops in Sulawesi, Indonesia: implications for biodiversity conservation and soil fertility. Biodivers Conserv 11:1889-1902.

Solis-Montero L, Flores-Palacios A, Cruz-Angon A (2005) Shade-coffee plantations as refuges for tropical wild orchids in central Veracruz, Mexico. Conserv Biol 19:908-916.

Soto-Pinto L, Perfecto I, Caballero-Nieto J (2002) Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico. Agroforest Syst 55:37-45.

Soto-Pinto L, Romero-Alvarado Y, Caballero-Nieto J, Warnholtz GS (2001) Woody plant diversity and structure of shade-grown-coffee plantations in Northern Chiapas, Mexico. Rev Biol Trop 49:977-987.

Soto-Pinto L, Perfecto I, Castillo-Hernandéz J, Caballero-Nieto J (2000) Shade effects on coffee production at the Northern Tzeltal zone of the State of Chiapas, Mexico. Agric. Ecosyst. Environ 80:61-69.

Staver C, Guharay F, Monterroso D, Muschler RG (2001) Designing pest-suppressive multistrata perennial crop systems: shade-grown coffee in Central America. Agroforest Syst 53:151-170.

Tscharntke T, Clough Y, Bhagwat SA, Buchori D, Faust H, Hertel D, Holscher D, Juhrbandt J, Kessler M, Perfecto I, Scherber C, Schroth G, Veldkamp E, Wanger TC (2011). Multifunctional shade-tree management in tropical agroforestry landscapes – a review. J Appl Ecol 48:3, 619-629.

Vandermeer J, Perfecto I (2007) The agricultural matrix and a future paradigm for conservation. Conserv Biol 21:274-277

Table 1. Number of farms (and plots per farm) sampled at each site

Farm Size	Small scale (<35 ha)		Large scale (>50 ha)	
Certification	Organic	Conventional	Rainforest	Conventional
Nicaragua	6 (4)	8 (4)	3 (4)	6 (4)
Guatemala	9 (1)	10 (1)		
Costa Rica	6 (4)	6 (4)		

Table 2. Number of native forest trees and shrubs, native planted shade and fruit trees, and exotic tree and shrub species on organic and conventional farms in each country (note number of farms is not the same for each country and certification).

Country	Certification	Native species			Exotic	Total	% native
		Forest	Planted	Total			
Costa Rica	Conventional	3	2	5	5	10	50
	Organic	4	3	7	8	15	47
Guatemala	Conventional	2	12	14	5	19	74
	Organic	9	12	21	9	30	70
Nicaragua	Conventional	14	8	22	8	30	73
	Organic	18	8	26	8	34	76

Table 3. Mean tree density (tree dbh >5 cm), shade cover and strata of farm types in each study area

Study Area	Tree Density (per ha)		Shade cover (%)		Number of Strata	
	Conventional	Organic	Conventional	Organic	Conventional	Organic
Costa Rica	163a	135a	31a	45a	2.11a	2.67a
Guatemala	92a	95a	44a	70b	2.30a	2.67a
Nicaragua	85a	92a	63ab	75b	2.34a	2.63a

Different letters indicate significant difference between country/farm type combinations ($p<0.05$)

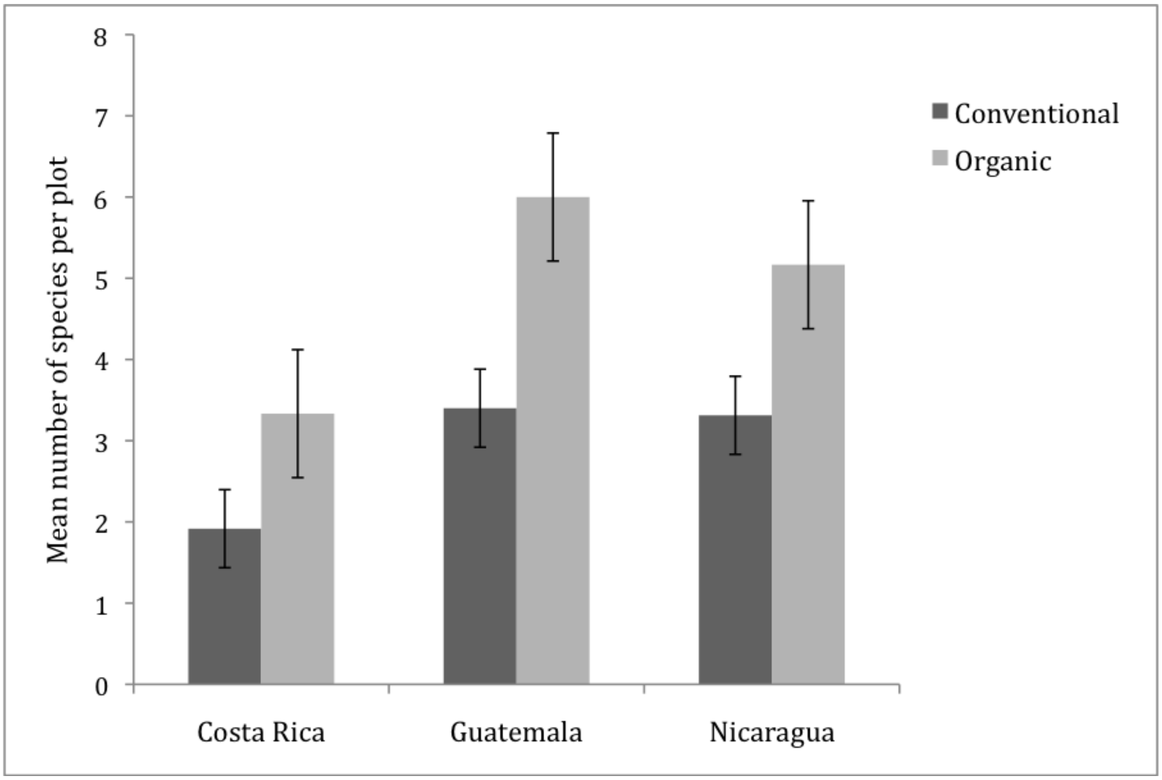


Figure 1. Species richness per plot (500m^2) on organic and conventional farms across countries (error bars are least significant differences between means $p<0.05$)

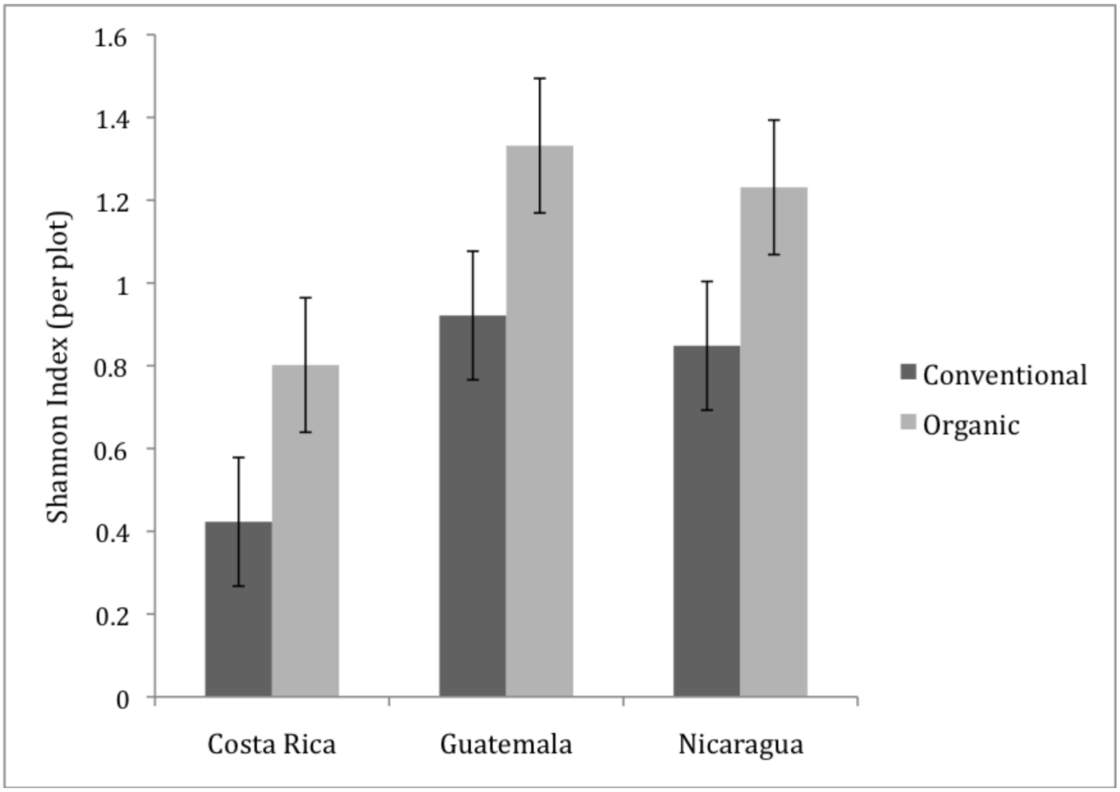
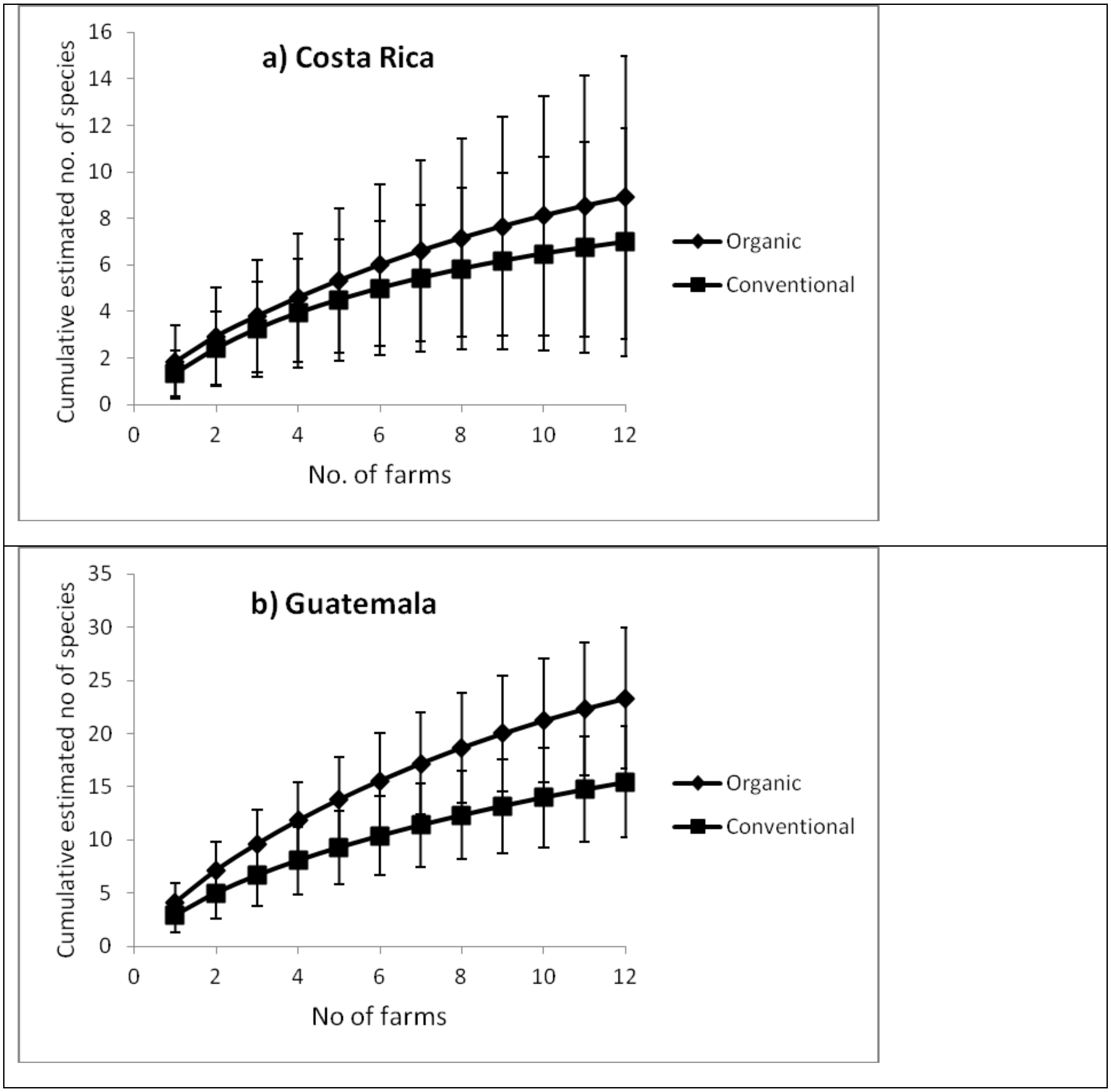


Figure 2. The Shannon diversity index per plot ($500m^2$) of shade tree species on organic and conventional farms across countries (error bars are least significant differences between means $p<0.05$)



a) Costa Rica
Cumulative estimated no. of species
No. of farms
Organic
Conventional
b) Guatemala
Cumulative estimated no of species
No of farms
Organic
Conventional

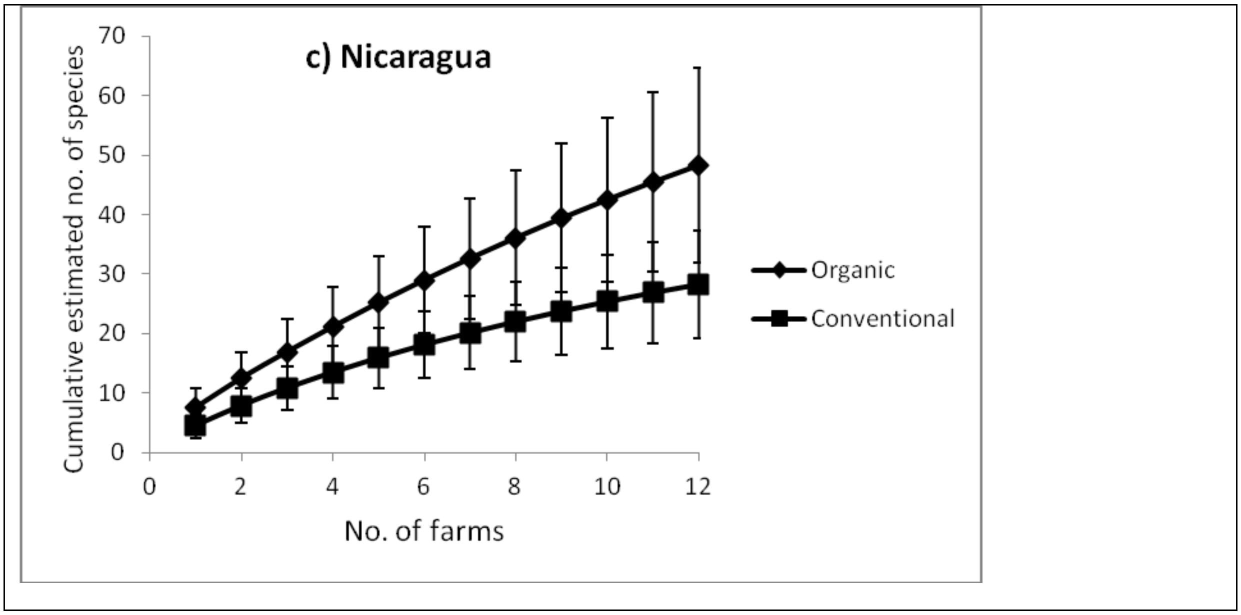
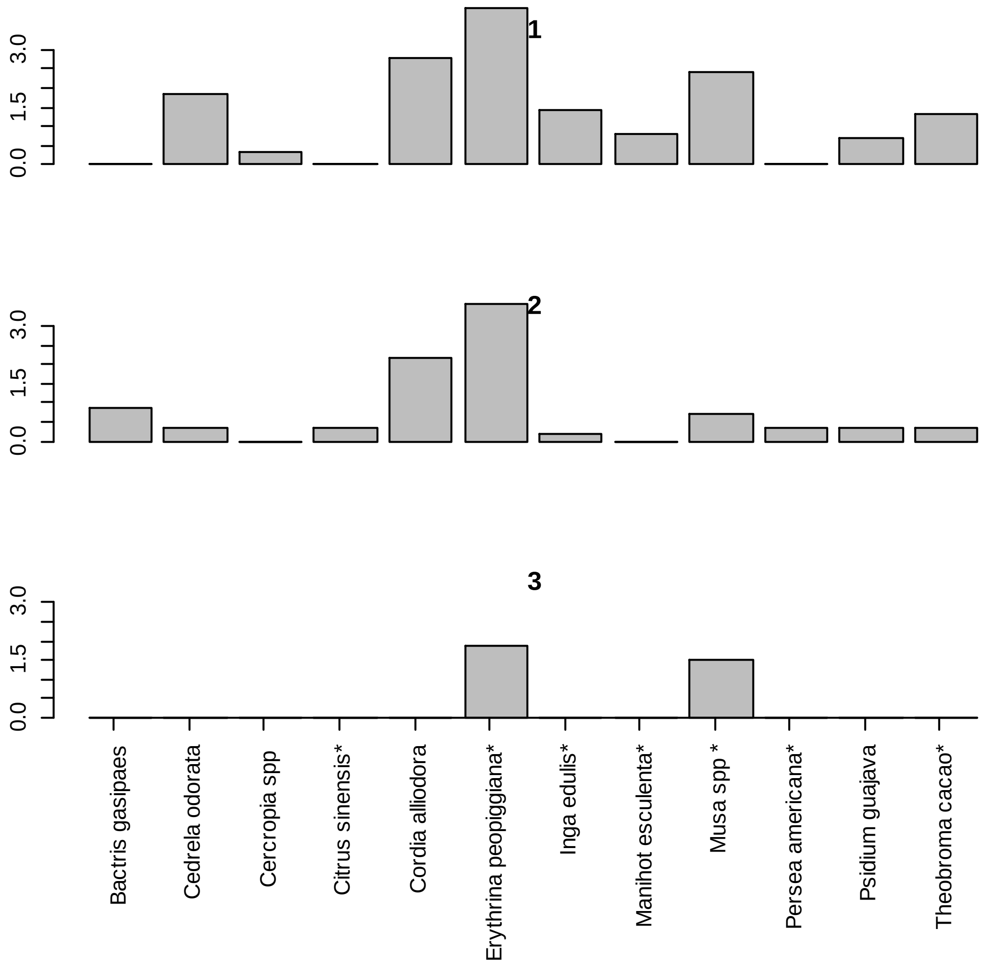
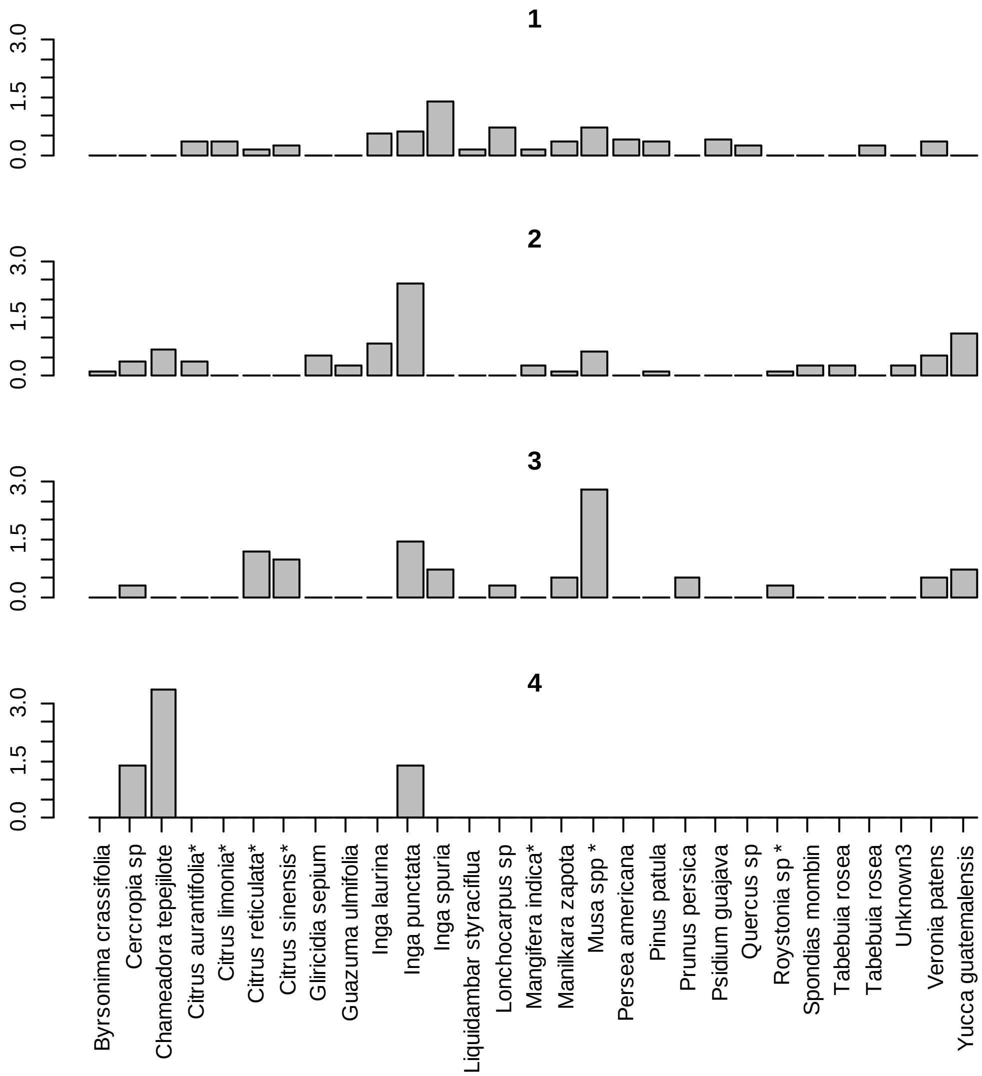


Figure 3. Species accumulation curves for native trees on organic and conventional farms (error bars are 95% confidence limits around estimate)


1
2
3
0.0
1.5
3.0
Bactris gasipaes
Cedrela odorata
Cercropia spp
Citrus sinensis*
Cordia alliodora
Erythrina peopiggiana*
Inga edulis*
Manihot esculenta*
Musa spp *
Persea americana*
Psidium guajava
Theobroma cacao*

a) Costa Rica


1
2
3
4
0.0
1.5
3.0
Byrsonima crassifolia
Cercropia sp
Chameadora tepejilote
Citrus aurantifolia*
Citrus limonia*
Citrus reticulata*
Citrus sinensis*
Gliricidia sepium
Guazuma ulmifolia
Inga laurina
Inga punctata
Inga spuria
Liquidambar styraciflua
Lonchocarpus sp
Mangifera indica*
Manilkara zapota
Musa spp *
Persea americana
Pinus patula
Prunus persica
Psidium guajava
Quercus sp
Roystonia sp *
Spondias mombin
Tabebuia rosea
Tabebuia rosea
Unknown3
Veronia patens
Yucca guatemalensis

b) Guatemala

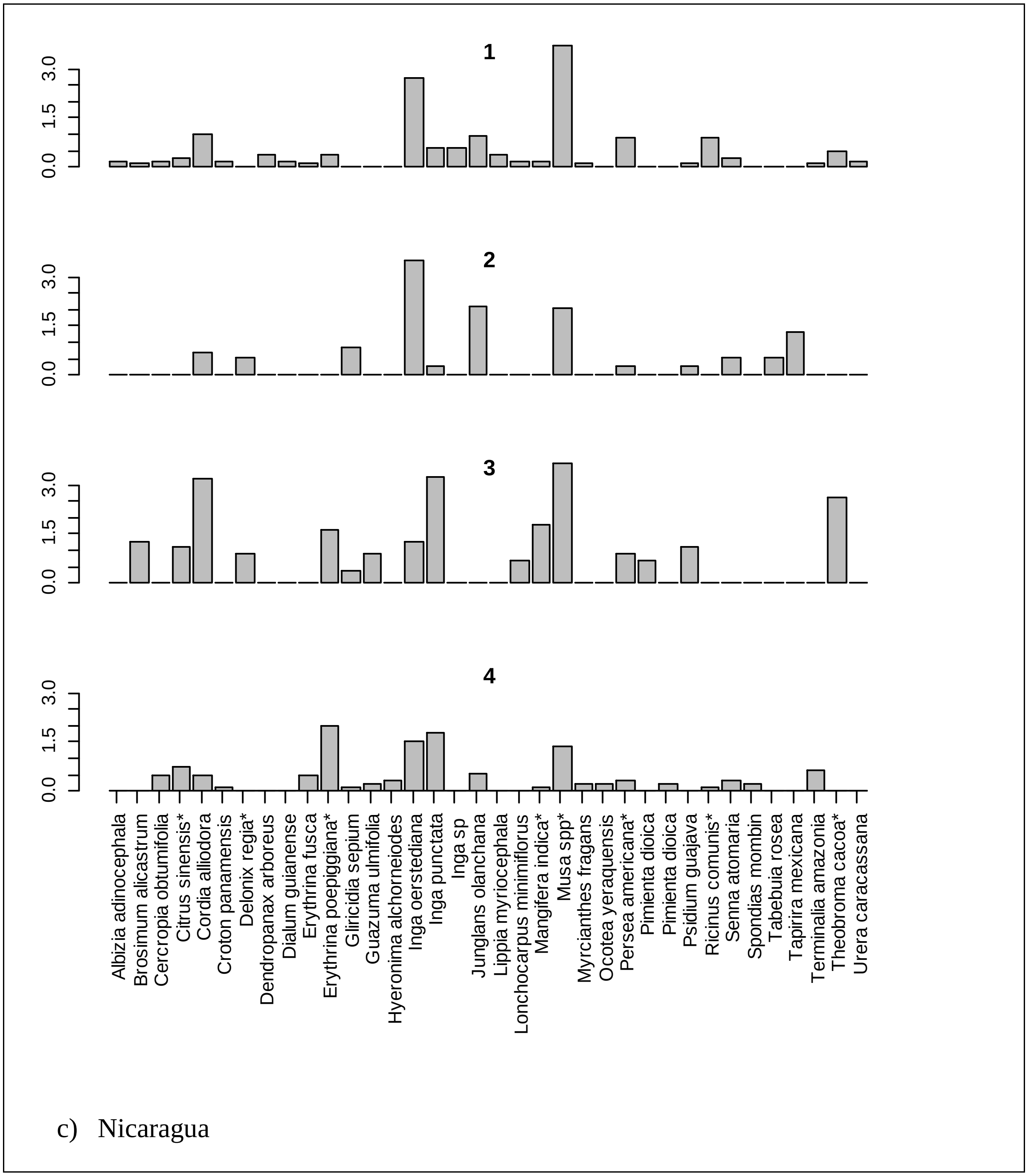


Fig 4. Clusters of farm tree species composition in each country where y axis is $\log_e$ of species abundance. Species only represented by one individual in a country are not included in the cluster analysis. Species marked with * are exotic to the country sampled.

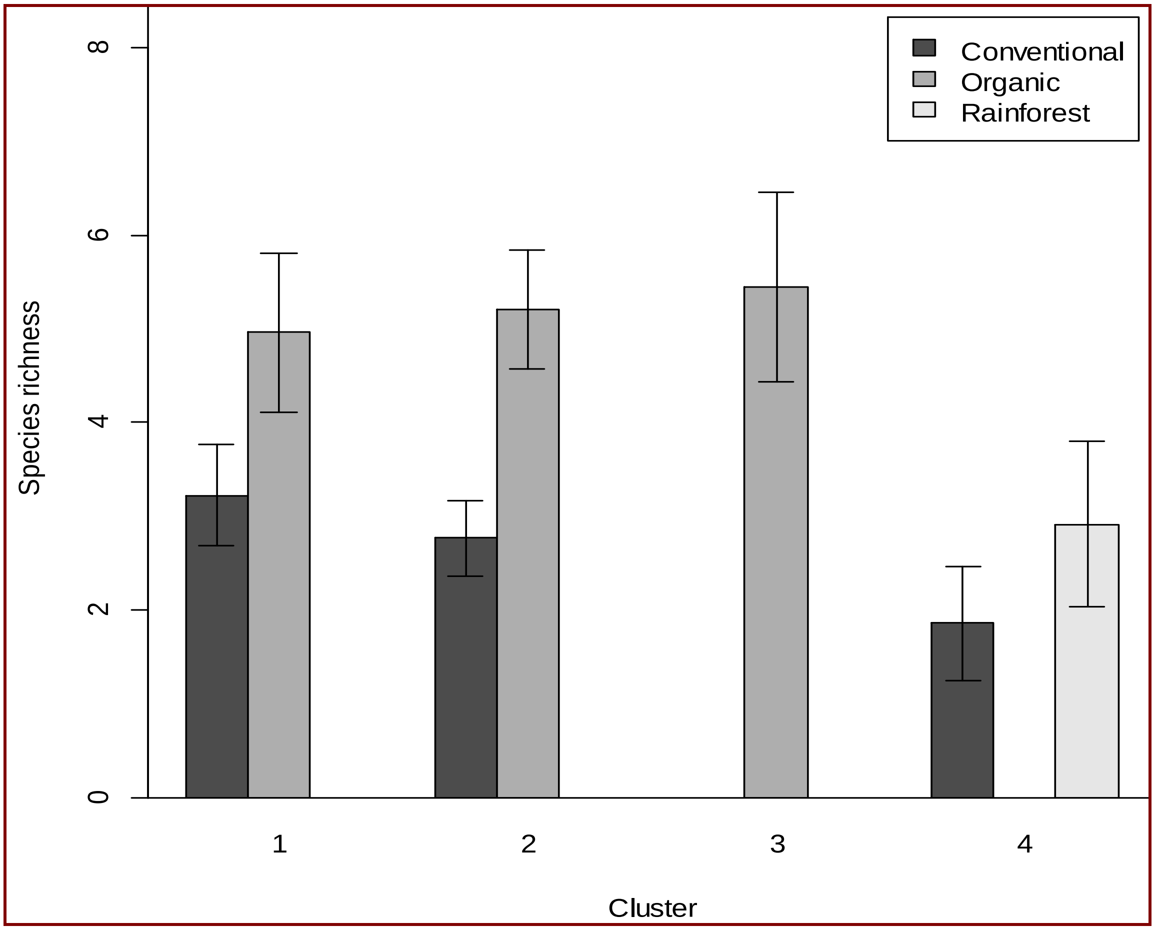


Figure 5a. Species richness (per plot $500m^2$) in farm types and clusters in Nicaragua

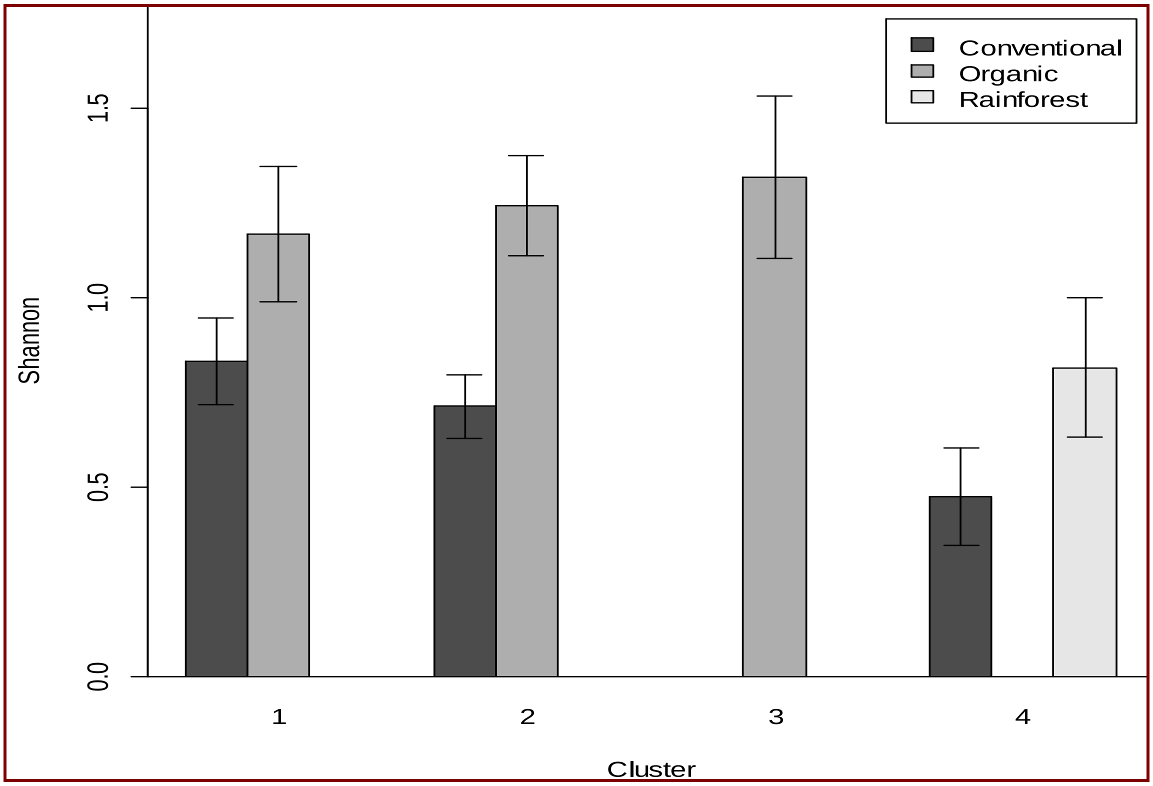


Fig. 5b Tree species Shannon diversity index between farm types and clusters in Nicaragua