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# Arthropod biodiversity loss and the transformation of a tropical agro-ecosystem

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The coffee (*Coffea arabica*) agro-ecosystem in the Central Valley of Costa Rica was formerly characterized by a high vegetational diversity. This complex system has been undergoing a major transformation to capital-intensive monocultural plantations where all shade trees are eliminated. In this study we examined the pattern of arthropod biodiversity loss associated with this transformation. Canopy arthropods were sampled in three coffee farms: a traditional plantation with many species of shade trees, a moderately shaded plantation with only *Erythrina poeppigeana* and coffee, and a coffee monoculture. An insecticidal fogging technique was used to sample both canopy and coffee arthropods. Data are presented on three major taxonomic groups: Coleoptera, non-formicid Hymenoptera, and Formicidae. Data demonstrate that the transformation of the coffee agro-ecosystem results in a significant loss of biological diversity of both canopy arthropods as well as arthropods living in coffee bushes. Percentage of species overlap was very small for all comparisons. Furthermore, species' richness on a per tree basis was found to be within the same order of magnitude as that reported for trees in tropical forests. If results presented here are generalizable, this means that conservation efforts to preserve biological diversity should also include traditional agro-ecosystems as conservation units.

*Keywords*: ants (Hymenoptera: Formicidae); beetles (Coleoptera); Hymenoptera; agricultural transformation; biodiversity.

## Introduction

Thirteen years ago a shocking hypothesis was presented – instead of the 1.5 million species of arthropods previously estimated to exist on Earth, there were perhaps 30 million species of insects alone (Erwin, 1982). The estimate was based on extrapolations from data on arboreal beetles collected by insecticidal fogging from the canopy of a Panamanian forest. This study, and others that followed (Adis *et al.*, 1984; Stork, 1987, 1988; Stork and Brendell, 1990; Hammond, 1990; Gaston, 1991, 1994; Kitching *et al.*, 1993), effected a change in the focus of biodiversity conservation. Rather than emphasizing the conservation of particular and usually highly visible or charismatic species, today there is more interest in the small organisms and the regions that are considered 'hot spots' of biodiversity.

More recently, the focus on undisturbed habitats has also been challenged. Attention has been called to the fact that 95% of contemporary terrestrial ecosystems are managed ones, including agricultural systems (Western and Pearl, 1989). Nevertheless, most biodiversity studies are conducted in what are considered undisturbed habitats, and in particular those that are believed to harbour the highest numbers of species (i.e. tropical rain forests) (Pimentel *et al.*, 1992). The conventional view is that agro-ecosystems are at best trivial with respect to biological diversity, and at worst reduce diversity to negligible levels. Although no one would maintain that a modern agro-ecosystem may have as much biological diversity as a rain forest, it is arguable that certain agro-ecosystems indeed have a very high diversity of plants (Room, 1971, 1975; Alcorn, 1981, 1984; Soemarwoto *et al.,* 1985; Gómez-Pompa *et al.,* 1987; Altieri and Hetch, 1990; Paoletti and Pimentel, 1992; Glissman, 1993; Hawkworth, 1993). How the modernization of those diverse agro-ecosystems affects arthropod diversity is not known, mainly because conservationists have largely ignored agro-ecosystems. Given the large expanses of land that are under agriculture the world over, and given that in tropical regions there is still much agricultural land under traditional management, it is imperative for conservation biologists to understand how agro-ecosystems may serve to maintain biological diversity and how biodiversity is affected by the process of transformation of traditional agro-ecosystems to modern ones.

In this study we present some preliminary data that support the assertion that traditional agro-ecosystems can contain a high biodiversity, and that this high diversity is significantly reduced when the system is modernized. Using an insecticidal fogging technique to sample arthropods in the canopy of shade trees and coffee bushes in coffee plantations in the Central Valley of Costa Rica, we quantify the species richness of beetles, ants and non-formicid hymenopterans, and compare three farms on a modernization gradient. In addition, we compare our results with those reported in studies of tropical forest canopies using similar methods.

Traditional coffee plantations have been reported to contain up to 100 species of shade trees that are used to protect traditional coffee varieties from extremes in temperature and humidity, as well as to increase the nitrogen pool in the soil though nitrogen fixation and to diversify farm products (Espinoza, 1983; Babbar, 1993). The traditional system follows the common pattern of agroforestry, with a variety of shade tree species, frequently interspersed with fruit trees forming a 'canopy' above the coffee bushes. The more rustic of these plantations share many structural attributes normally associated with forests, including high plant diversity, multistrata structure, constant leaf-litter cover, and constant canopy cover which regulates microclimatic conditions in the understorey. Furthermore, some of these rustic plantations are established by simply cleaning the understorey of the forest and planting coffee under the canopy of the already established trees (Perfecto *et al.*, 1996).

In the early 1980s the Costa Rican government enthusiastically promoted the conversion of the diverse traditional plantations to either a system of monospecific shade, where a low density of only one species of shade tree is planted with the coffee, or to a system of coffee monoculture, where no shade trees are planted (Fig. 1) (ICAFE-MAG, 1989; Boyce *et al.*, 1994). This conversion was part of a programme of increasing the technification of coffee plantations, and consequently, increasing yields per hectare. By 1991, approximately 74% of all coffee farms in Costa Rica's Central Valley, the prime coffee producing region in the country, had been transformed (Boyce *et al.*, 1994). To a varying degree, the same process is occurring in other coffee producing regions of Latin America (Perfecto *et al.*, 1996).

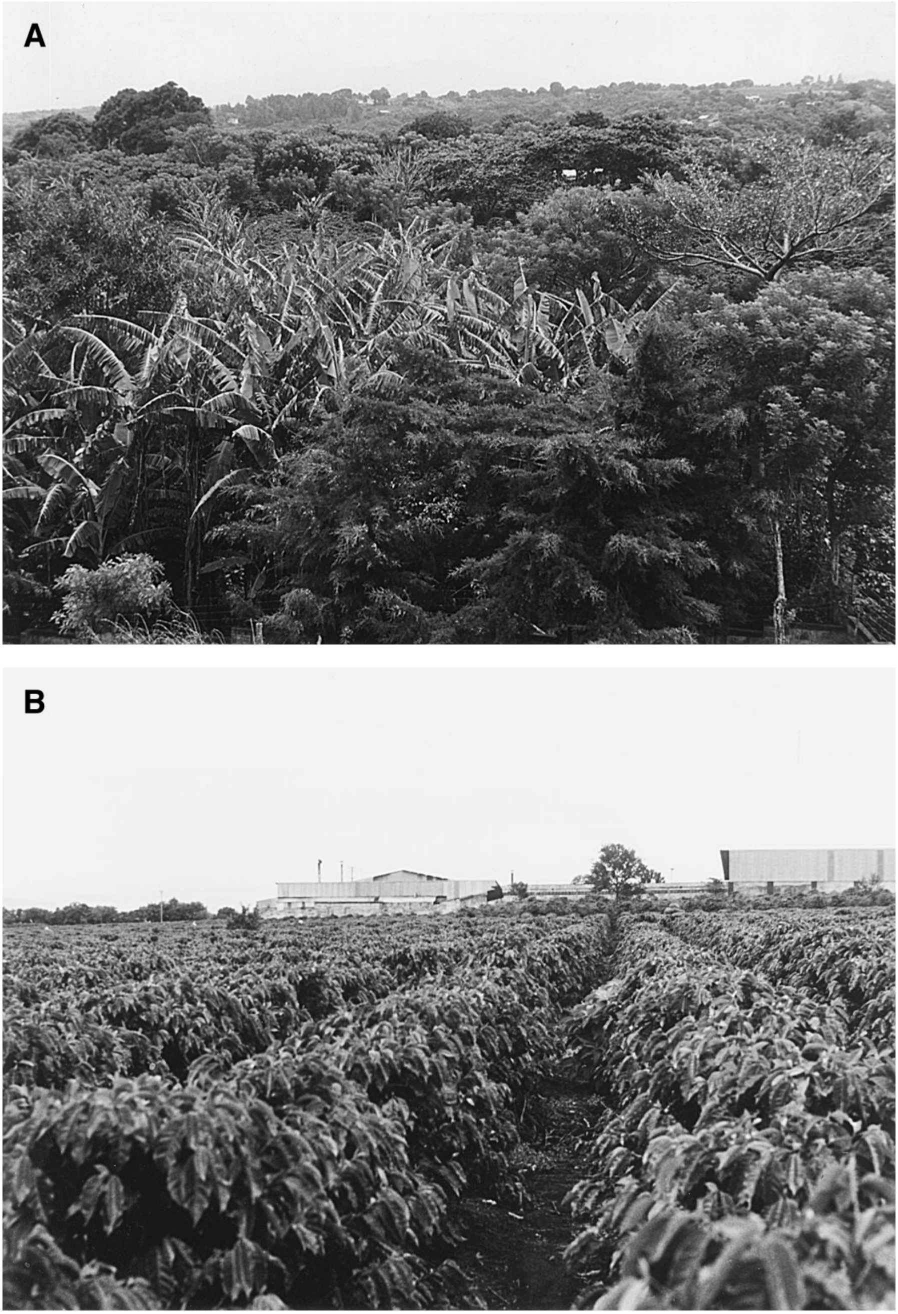


**Figure 1.** Photographs of two coffee plantations with different management systems in the Central Valley of Costa Rica (A) Traditional coffee plantation with a variety of shade and fruit trees (B) Unshaded coffee monoculture.

**Table 1.** Description of sampled farms

| Type | Size (ha) | Number of species of shade trees | Surrounding ecosystems |
|---|---|---|---|
| Traditional | 3.5 | ±20 | Coffee monocultures; moderately-shaded coffee pastures; semi-urban area |
| Moderately-shaded | 0.5 | 1 | Moderately shaded coffee |
| Coffee monoculture | 4.0 | 0 | Coffee monocultures; moderately-shaded coffee |

## Study site and methods

This study was conducted in three coffee farms located in Santo Domingo de Heredia in Costa Rica at an elevation of 1500 m, in an area that receives a mean annual precipitation of 2500 mm. Arthropods were sampled in three farms with different management systems: (1) a traditional farm with many species of shade trees, (2) a moderately shaded farm with only *Erythrina poeppigiana* as a shade tree, and (3) a coffee monoculture (Table 1). Three shade trees were selected for fogging in the traditional farm and one in the moderately-shaded farm. Table 2 describes the trees that were fogged in each farm. Selection of trees was based on species, accessibility and isolation of the canopy from other adjacent trees (to minimize the collection of arthropods from other trees). Different species of tree were selected in the traditional plantation specifically to examine interspecific overlap of arthropod species. In addition, two 10 × 10 m plots were randomly selected in each plantation, and five coffee bushes within each plot were randomly selected for fogging. The preparation of the shade trees for fogging consisted of tying down the understorey coffee bushes, and any other tall (≥ 1 m) understorey vegetation, in order to minimize the collection of arthropods living in these understorey plants. Lines were strung from the trunk of the selected tree and tied to adjacent trees in a radiating fashion at approximately 1.5 m height. Twenty-four collecting funnels (each with a collecting area equivalent to 1 $m^2$) were placed directly under the canopy (Fig. 2). The funnels were made of nylon with round bamboo frames. A 250 ml Nalgene bottle containing 70% alcohol was screwed to the bottom of the funnel. Fogging was conducted at sunrise to avoid strong winds. A hand-operated Dyna-fog machine containing 4 litres of Resmitrin (3%), a synthetic pyrethroid, was used for the fogging. Fogging lasted approximately 15 minutes or until the whole canopy was completely covered with the insecticidal fog. After 2 hours of drop-time, the material was collected and taken to a laboratory for further processing.

**Table 2.** Description of sampled shade trees

| Species (No.) | Type of farm | Height (m) | dbh[a] (cm) | Management |
|---|---|---|---|---|
| *Erythrina poeppigiana* (1) | Traditional | 18 | 44.9 | Unpruned |
| *Erythrina fusca* (2) | Traditional | 16.5 | 55.7 | Unpruned |
| *Annona chirimoya* (3) | Traditional | 13 | 27.7 | Unpruned |
| *Erythrina poeppigiana* (4) | Moderate | 11.5 | 34.1 | Pruned |

[a] diameter at breast height.

Arthropods in coffee bushes were sampled with the aid of two collecting funnels placed underneath each coffee bush. Coffee bushes were fogged with the Dyna-fog machine for approximately 5 minutes. Thirty minutes after the fogging was completed the plants were shaken to make sure that most insects fell into the collectors. The material collected from both funnels was combined into one sample and identified by farm, subplot, and plant number, and taken to the Entomology Laboratory of the National University of Costa Rica in Heredia, Costa Rica (UNA), where it was sorted to taxonomic order and morphospecies. The data presented here include those for the insect orders Coleoptera and Hymenoptera. In order to make possible comparisons with other studies, the order Hymenoptera was subdivided into ants (Formicidae) and others (non-formicid hymenopterans). Non-formicid hymenopterans were not identified in a manner that comparisons between trees and farms could be made. Therefore, estimates of species overlap were obtained only for beetles and ants.

## Results

The number of species recorded for all three groups was unexpectedly high given that samples were collected from plantations located in an agricultural and suburban zone that has been deforested for more than 50 years (Table 3). Furthermore, sample area relationships for all trees and coffee bushes sampled showed no sign of levelling off. The differences between species' richness in the traditional plantation, the moderately-shaded plantation and the coffee monoculture were dramatic for all three groups. The reduction of species was more dramatic for the species living in the tree canopies than for those collected from the coffee bushes. Nevertheless, beetles, ants and other non-formicid hymenopterans collected from coffee bushes were also reduced in the moderately shaded and unshaded plantations (Table 3).

A total of 65 species and 1992 individual ants were collected. Fifty-three species and 1682 individuals were collected from the canopy of the four fogged trees, and 21 species and 310 individuals were collected from the 30 coffee bushes sampled. The average number of ant species per tree collected from the traditional plantation (22 species) was reduced by 78% in the moderated plantation (five species). Since the monocultural plantation did not contain any shade trees we can assume that the exclusively arboreal species are completely eliminated from these plantations. A more realistic comparison can be made between ant

**Table 3.** Number of species (and individuals) of beetles, ants, and non-formicid hymenopterans in the canopy of shade trees and coffee plants in coffee farms

| Species (No.) | Type of farm | Beetles | Ants | Hymenoptera* |
|---|---|---|---|---|
| *Erythrina poeppigiana* (1) | Traditional | 126(401) | 30(333) | 103 |
| *Erythrina fusca* (2) | Traditional | 110(393) | 27(1,105) | 61 |
| *Annona chirimoya* (3) | Traditional | – | 10(179) | 63 |
| *Erythrina poeppigiana* (4) | Moderately shaded | 48(107) | 5(64) | 46 |
| *Coffea arabica* (10 plants) | Traditional | 39(76) | 14(135) | 34 |
| *Coffea arabica* (10 plants) | Moderately shaded | 29(82) | 9(128) | 31 |
| *Coffea arabica* (10 plants) | Unshaded | 29(92) | 8(47) | 30 |

*Not including ants; – = data not available.

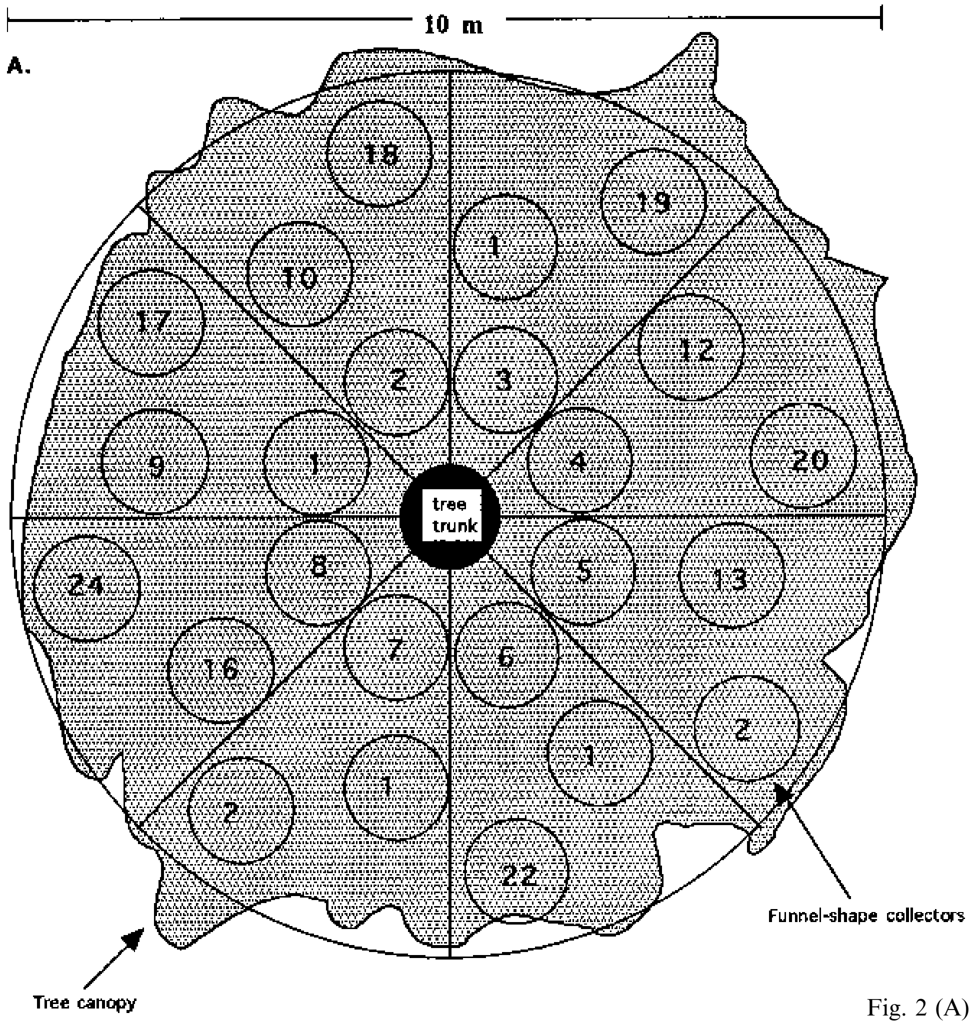


Fig. 2 (A)

species in coffee bushes since the same number of plants were sampled in each farm. Ant species collected from coffee bushes were reduced by 36% and 43% in moderately shaded and non-shaded plantations, respectively.

Average ant abundance (number of individuals) per shade tree was 539 individuals in the traditional plantation. This was reduced by 88% to 64 in the moderately shaded plantation. However, it should be pointed out that the only tree sampled in the moderately shaded plantation had been pruned and the amount of foliar biomass was much smaller than that of unpruned trees in the traditional plantation. The total number of individual ants in coffee bushes showed the same pattern as that of shade trees, although not as dramatic. The total number of individuals in coffee bushes in the traditional plantation (135) was reduced by 5.2% in the moderately shaded plantation (128) and by 65.2% in the coffee monoculture (47).

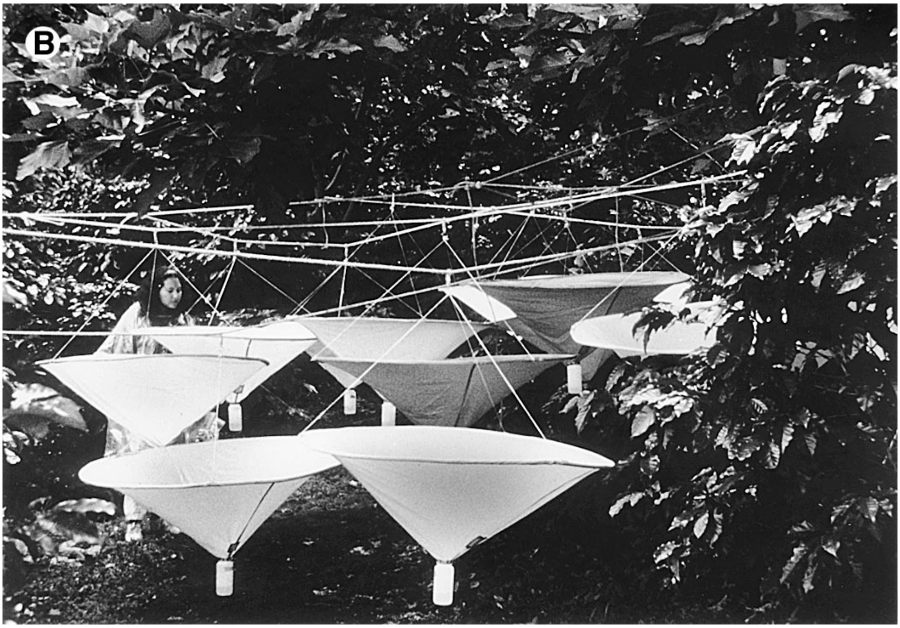


**Figure 2.** (A) Technique used for collecting arthropods from fogged tree canopies – bird's eye view. Each small circle indicates a collecting funnel (surface area = 1 $m^2$), and the shaded area represents the tree canopy. (B) Photograph of the funnels in the field as canopy arthropods are being collected.

As reported in other studies, beetle diversity was much higher than that of ants (Stork, 1988). A total of 241 species belonging to 48 families, and 901 individuals were collected from three sampled trees (No. 1, 2, and 4). Additionally, 84 species belonging to 38 families, and 250 individuals were collected from the 30 coffee bushes sampled. A similar pattern of species reduction was observed for beetles in both tree canopies and coffee bushes. The average number of beetle species per tree collected from the traditional plantation (118 species) was reduced by 59% in the moderated plantation (48 species). Beetle species collected from coffee bushes in the traditional plantation were reduced by 26% in both the moderately shaded and non-shaded plantations. In other words, there was no reduction in the number of species going from the moderately shaded plantation to the coffee monoculture, even though the actual species found in each plantation differ significantly.

The average beetle abundance per shade tree was 397 individuals in the traditional plantation and 107 in the moderately shaded plantation, a 73% reduction. Beetle abundance in coffee bushes showed the reverse pattern of either the ants or the beetles in the canopies. The total number of individuals in coffee bushes in the traditional plantation (76) increased by 7% in the moderately shaded plantation (82) and by 17% in the coffee monoculture (92).

More telling than the actual number of species on a per tree basis (alpha diversity) was the low overlap of species for both ants and beetles, even within the same farms (Table 4). For example, none of the samples collected from canopies of trees overlapped more than 19% (for the comparison between ant species in tree No. 1 and 2 in the traditional plantation) and was as low as 3.23% (for the comparison between ant species in tree No. 4, in the moderately shaded plantation and tree No. 3 in the traditional plantation). It should

**Table 4.** Percentage of species overlap for beetles and ants among sampled shade trees and coffee plants

(A) Ants

| Shade trees | | | | | Coffee bushes | | | |
|---|---|---|---|---|---|---|---|---|
| Tree No. | 1 | 2 | 3 | 4 | Coffee Management. | Trad.[a] | Mod.[b] | Monoc.[c] |
| 1 | 100 | 18.7 | 11.1 | 6.1 | Tand. | 100 | 21.0 | 29.4 |
| 2 | | 100 | 8.8 | 3.2 | Mod | | 100 | 30.8 |
| 3 | | | 100 | 7.1 | Monoc. | | | 100 |
| 4 | | | | 100 | | | | |

(B) Beetles

| Shade trees | | | | Coffee bushes | | | |
|---|---|---|---|---|---|---|---|
| Tree No. | 1 | 2 | 4 | Coffee Management | Trad.[a] | Mod.[b] | Monoc.[c] |
| 1 | 100 | 14.0 | 3.6 | Trad. | 100 | 9.6 | 18.1 |
| 2 | | 100 | 9.7 | Mod. | | 100 | 11.5 |
| 4 | | | 100 | Monoc. | | | 100 |

[a] Traditional coffee plantation, [b] Moderately shaded coffee, [c] Coffee monoculture.

be noted also that the distance between the sampled trees within the traditional plantation was no more than 200 metres, that the farm was only 3.5 hectares in size, and that it was surrounded by coffee monocultures, pastures and the town of Santo Domingo itself. These low overlap figures suggest that the diversity of ants and beetles, and perhaps other arthropods, contained in these shaded plantations could be much higher than that reported here.

Because the study area had long ago been completely deforested, it was not possible to include trees from a forest for comparative purposes. However, we were able to compare our figures for ants and beetles with those reported in other studies using similar methods. Table 5 shows the similarity of the species' richness reported in this study with that reported for the canopy of tropical forest trees. As can be seen from the table, the number of ants and beetles collected from the canopy of single trees in this study fall within the same order of magnitude as those reported for tropical forest trees.

## Discussion

This study illustrates the dramatic loss of arthropod diversity concomitant with the transformation of traditional coffee plantations to coffee monocultures. The data presented here also demonstrate that the traditional coffee agro-ecosystem contains high arthropod diversity that, at least on a tree-by-tree basis, is roughly comparable to the diversity of arthropods found in tropical forest tree canopies. The case of coffee is particularly important because in many countries it is the only 'forested' habitat left at mid-elevation (Perfecto *et al.*, 1996).

This study suggests that tropical agro-ecosystems are more important for the conservation of biological diversity than previously thought. It also calls attention to the

**Table 5.** Number of species of ants (Hymenoptera: Formicidae) and beetles (Coleoptera), collected by insecticidal fogging from the canopy of trees in coffee plantations in the Central Valley of Costa Rica, and tropical forests in Panama, Peru, and Brazil

| Taxon | Tree species | Habitat | Country | Number of species | Source |
|---|---|---|---|---|---|
| Coleoptera | 1 *Luehea seemannii* | Moist seasonal forest | Panama | 335 | Erwin and Scott (1980)* |
| | 1 *L. seemannii* | Moist seasonal forest | Panama | 191 | Erwin and Scott (1980) |
| | 1 *L. seemannii* | Moist seasonal forest | Panama | 115 | Erwin and Scott (1980) |
| | 1 *L. seemannii* | Moist seasonal forest | Panama | 171 | Erwin and Scott (1980) |
| | 1 *L. seemannii* | Moist seasonal forest | Panama | 147 | Erwin and Scott (1980) |
| | 1 *Erythrina poeppigiana* | Traditional coffee plantation | Costa Rica | 126 | |
| | 1 *Erythrina* sp. | Traditional coffee plantation | Costa Rica | 110 | |
| | 1 *E. poeppigiana* | Moderately shaded coffee plantation | Costa Rica | 48 | |
| Formicidae | 2 unidentified trees | Upland rain forest | Peru | 62 | Wilson (1987) |
| | 2 unidentified trees | Upland rain forest | Peru | 47 | Wilson (1987) |
| | 2 unidentified trees | Upper flood plain forest | Peru | 37 | Wilson (1987) |
| | 2 unidentified trees | Swamp forest | Peru | 19 | Wilson (1987) |
| | 1 unidentified tree | Young upland forest | Peru | 38 | Wilson (1987) |
| | 1 unidentified tree | Secondary floodplain forest | Peru | 43 | Wilson (1987) |
| | 1 *Ficus* sp., and 2 *Pseudobombax munguba* | White-water inundation forest | Brazil | 25 | Adis *et al.* (1984) |
| | 1 *Erisma calcaratum*, and 2 *Aldina latifolia* | Black-water inundation forest | Brazil | 26 | Adis *et al.* (1984) |
| | 1 *Dipterix alata,* and 2 *Eschweilera* cf. *odora* | Upland rain forest | Brazil | 38 | Adis *et al.* (1984) |
| | 1 *Erythrina poeppigiana* | Traditional coffee plantation | Costa Rica | 30 | |
| | 1 *Erythrina fusca* | Traditional coffee plantation | Costa Rica | 27 | |
| | 1 *Annona chirimoya* | Traditional coffee plantation | Costa Rica | 10 | |
| | 1 *E. poeppigiana* | Moderately shaded coffee plantation | Costa Rica | 5 | |

*The data presented here correspond to the wet season sampling period, approximately the same period in which our data were collected.

potential for significant biological diversity loss with the increasing trend of transforming traditional agro-ecosystems into high-input monocultural systems. It also suggests that management practices in agro-ecosystems can have an impact on the ability of natural lands to sustain biological diversity at a landscape level. This is the case because natural areas are usually embedded in a matrix of natural and managed lands. A thorough understanding of how management practices affect biodiversity in agro-ecosystems will enable managers to incorporate agricultural lands into more comprehensive conservation and restoration strategies.

Although conversion from primary forest to some sort of agro-ecosystem has been demonstrated to be very damaging for biodiversity (Terborgh and Weske, 1969; Sayer and Whitmore, 1991; Verhaagh, 1991), it may not necessarily be the case that all conversions will result in a dramatic decimation of biodiversity. As this study shows, some diverse agro-ecosystems have the capacity to maintain a high diversity of arthropods. More careful attention should be focused on designing of agro-ecosystems in general, but particularly in areas adjacent to highly diverse natural systems. Agro-ecosystems that maintain similar microclimate to that of the natural areas, as well as contain high planned biodiversity (i.e. the diversity of the plants that the farmer chooses to include in the system) can provide abundance and diversity of food, nesting-living, and hiding places for arthropods. Such habitats could help maintain arthropod biodiversity in areas that are undergoing transformation.

This study, as well as others on biodiversity in agro-ecosystems (Paoletti and Pimentel, 1992; Hawksworth, 1993), suggests that agro-ecosystems could be compatible with conservation objectives. Furthermore, careful planning of the mosaic of agro-ecosystems that surround natural preserves is not only recommended but perhaps necessary for the future preservation of biodiversity in the tropics.

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