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Front and back covers: Rustic coffee production in Chiapas, Mexico. (Photos courtesy of John Vandermeer.)

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CHAPTER 6

The Coffee Agroecosystem in the Neotropics: Combining Ecological and Economic Goals

Ivette Perfecto and Inge Armbrecht

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THE SOCIOPOLITICAL AND ECONOMIC LANDSCAPE OF COFFEE

In Latin America, a region of rich and diverse natural resources and intensifying anthropogenic pressures upon them, policy makers, economists, and conservationists struggle to balance economic development with environmental conservation. The interest in combining conservation and development has resulted in more attention being paid to managed agroecosystems, in particular those that incorporate high levels of planned biodiversity (Vandermeer and Perfecto, 1997). Among the agroecosystems that have received considerable attention recently is the coffee agroforest. It has been argued that coffee production in Latin America, if managed with a diverse canopy of shade trees, presents the opportunity to generate economic benefits, conserve biodiversity, and enhance the livelihood of small producers (Perfecto et al., 1996; Rice and Ward, 1996). This chapter examines the agroecology of the shade coffee agroecosystem, focusing on its biodiversity and the potential that this system presents for combining economic and conservation goals in Latin America.

Economic Importance of Coffee

Coffee, along with petroleum and cotton, is one of the world's most traded commodities (McLean, 1997; International Coffee Council, 2001). Approximately 34% of the world's coffee production and 30% of the world's coffee area is based in northern Latin America, an area that extends from Mexico to Colombia and includes the Caribbean (Rice, 1999). As early as the mid-1800s, coffee had been economically linked to the countries of the region, becoming one of their main export crops. Until the mid-1980s, when production declined due to the civil war and adverse policies, coffee accounted for more than 50% of total exports in El Salvador (Consejo Salvadoreño del Café, 1997). In Mexico over the past few decades, coffee has become one of the most important exports, generating 36% of the agricultural export value (Nolasco, 1985; Nestel, 1995); and in Peru, coffee is the single most important export crop in terms of value (Greenberg and Rice, 2000). Furthermore, the coffee produced in this region belongs to varieties of *Coffea arabica*, which produces a higher-quality coffee and demands higher prices in the international market than varieties *of C. robusta* grown in Brazil and in lower elevations in the region. In Colombia, coffee constitutes around 66% of permanent crops in the country (Rice and Ward, 1996) and traditionally has been the dominant agricultural activity of the country, with 20% of the value of agricultural production (Sanint, 1994).

The 2001 Coffee Crisis

The economic importance of coffee for northern Latin America transcends figures of export value. The great demand for labor that is generated from this commodity ensures that a large sector of the agricultural labor force is involved in coffee (Rice and Ward, 1996). Until the most recent coffee crisis, this crop was an important and reliable source of income for many small producers in Latin America. This began to change with a remarkable drop in price as a consequence of overproduction on a global scale. By the end of 2001, coffee prices had reached a 30-year low. In just 4 years, from 1997 to 2001, coffee prices went from $3.00/lb to $0.42/lb (De Palma, 2001), causing widespread poverty, desperation, and conversion of coffee farms to other types of agriculture. By the harvest season of 2001, many coffee producers were abandoning their farms, setting up shanty towns near large cities, waiting in line for food handouts, and in the case of Mexican and Central American producers, trying to make their way north to find jobs in the U.S. (Oxfam, 2002).

To a large degree, the coffee crisis stems from an excess of coffee production. In the past 5 years, coffee demands have remained constant, but in the same time period production has increased by nearly 7%. Much of the overproduction stems from a general intensification of coffee production over the past 30 years. Though coffee is traditionally grown as an understory crop under a diverse shade canopy, many producers have opted for higher-yielding varieties that are grown on farms with little or no shade and high chemical input levels, largely to boost per-farm productivity. As a result, coffee yields in Central America were at an all-time high. Furthermore, increases in coffee production in Vietnam flooded the world market with cheap coffee. In the 1990s, Vietnam was producing little coffee, but then a massive project funded by the World Bank and the Asian Development Fund promoted intensive coffee production. By 2001, production levels had skyrocketed, placing Vietnam in second place among world coffee-producing countries, second only to Brazil (Oxfam, 2002).

The consequences of the coffee crisis are manifold. Rural poverty and unemployment have increased astronomically in coffee-growing regions, and coffee farmers and workers in many areas are faced with poverty and hunger. Reports from Guatemala claimed 40% rural unemployment in 2001; in Nicaragua, thousands of jobless workers set up camps along the highways, begging for food (Jordan, 2001; González, 2001), and in Colombia, more than 2 million people were displaced from several regions including the coffee-growing regions (Human Rights Watch, 2001).* Furthermore, many small coffee producers chose to either abandon their largely shade-grown coffee farms or convert them to subsistence crops or cattle pasture. In South America, many farmers turned to growing more lucrative crops such as coca (Wilson, 2001). By 2001, in Peru, 10,000 of the 180,000 small coffee producers had already converted to coca production (Human Rights Watch, 2001).

The environmental and political ramifications of such land conversions are many. It is within this sociopolitical and economic landscape that we discuss the agroecology of coffee production in northern Latin America and explore the possibility of

* These problems, although not a direct result of the coffee crisis, have been accentuated by the crisis.

combining economic goals with conservation and social justice goals for coffee producers in the region.

Ecological Importance of Coffee

Globally, coffee is cultivated on 26,000 square miles, which is equivalent to a strip 1 mile wide around the equator. In northern Latin America, coffee farms cover 3.1 million hectares of land (FAO, 1997). However, the ecological importance of coffee is not as much with the extension of land that its covers, but on the particular locations where coffee is grown. In Latin America, coffee is important in countries that have been identified as megadiverse, such as Colombia, Brazil, and Mexico (Mittermeier et al., 1998). *Coffea arabica* is grown primarily in mid-elevation mountain ranges and volcanic slopes where deforestation has been particularly high. The northern Latin American region has three of the five countries with the highest rates of deforestation in the world (FAO, 2001). In some countries of the region, traditional coffee plantations are among the few remaining forested areas, especially in the medium-to-high elevation ranges. An extreme example of the ecological importance of coffee can be found in El Salvador, one of the most deforested countries of this hemisphere. El Salvador has lost more than 90% of its original forests; however, 92% of its coffee is shade grown (Rice and Ward, 1996). Shaded coffee has been estimated to represent about 80% of the nation's remaining forested areas (Panayotou, Faris, and Restrepo, 1997; Monro et al., 2001). High levels of biodiversity and endemism also characterize tropical mid-elevation areas. In Mexico, the main coffee-growing areas coincide with areas designated by the national biodiversity agency (CONABIO) as priority areas for conservation because of the high numbers of endemic species they contain (Moguel and Toledo, 1999).

BIODIVERSITY CONSERVATION IN SHADE COFFEE

Coffee is produced under a wide range of cultivation technologies. However, the traditional and, until the late 1970s, most common way of producing coffee was under the diverse canopy of shade trees (Perfecto et al., 1996). In some cases, farmers would cut the original vegetation and establish agroforestry systems of shade trees, fruit and timber trees, and coffee shrubs. But the most traditional way of establishing a coffee plantation was by removing the understory of a forest, leaving most of the original trees intact, and replacing the understory with coffee plants (Perfecto et al., 1996; Moguel and Toledo, 1999) (Figure 6.1). This rustic coffee represents an agroforestry system that maintains many of the environmental functions of an undisturbed forest (Rice, 1990; Fournier, 1995; Perfecto et al., 1996; Moguel and Toledo, 1999). Other management systems consist of planted shade trees with varying degrees of floristic diversity, height, and density of shade trees (Figure 6.2). The most technified plantations are coffee monocultures, also called sun coffee (Figure 6.3), where newer varieties of coffee replace the older varieties and agrochemicals are used to replace the functions of shade trees such as weed suppression and nitrogen fixation.

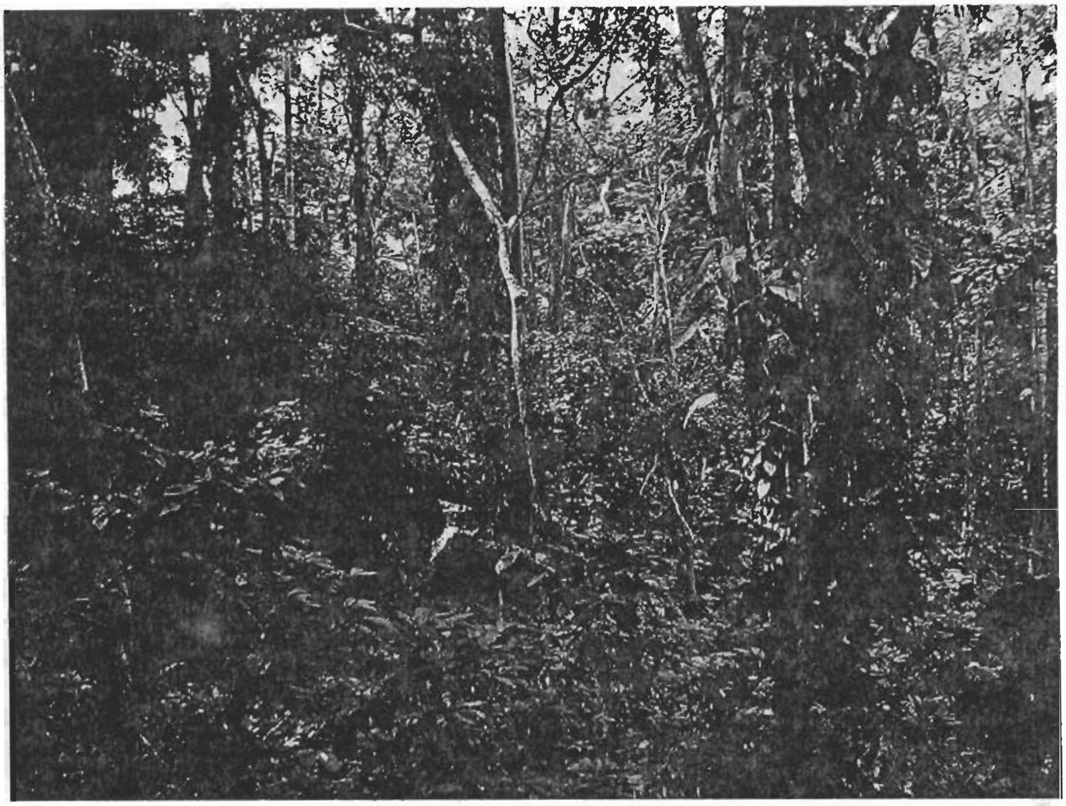

Figure 6.1 A rustic coffee plantation in Chiapas, Mexico.

In recent years, conservationists have focused their attention on shaded coffee as an agroecosystem where biodiversity can be conserved (Perfecto et al., 1996; Moguel and Toledo, 1999; Botero and Baker, 2001). This interest arises from many studies conducted over the past 20 years that demonstrate that shaded coffee plantations contain high levels of biodiversity, sometimes comparable to those in forests. These studies have also demonstrated the significant ecological role of shaded coffee in the region. From their erosion-suppression qualities (Rice, 1990), to their importance as habitat and refuge for biodiversity (Perfecto et al., 1996; Moguel and Toledo, 1999) and for carbon sequestration (Fournier, 1995; Márquez-Barrientos, 1997; DeJong et al., 1995, 1997), shaded coffee, and in particular rustic coffee, has been demonstrated to behave in a similar fashion to natural forests.

Birds and Other Vertebrates

Regional large-scale and detailed local surveys of birds in the Caribbean, Mexico, Central America, and northern South America revealed that coffee plantations support high diversity and densities of birds, and in particular some species that depend on closed canopy forest (Aguilar-Ortíz, 1982; Robbins et al., 1992; Wunderle and Wide, 1993; Vennini, 1994; Wunderle and Latta, 1994, 1996; Greenberg, Bichier, and Sterling, 1997b; Johnson, 2000). Coffee plantations have also been cited as an important habitat for migratory birds, which can be found in coffee agroforests in higher densities than in natural forests (Borrero, 1986; Greenberg, Bichier, and

Figure 6.2 A coffee plantation with a shade canopy dominated by *Inga* sp. in Chiapas, Mexico.

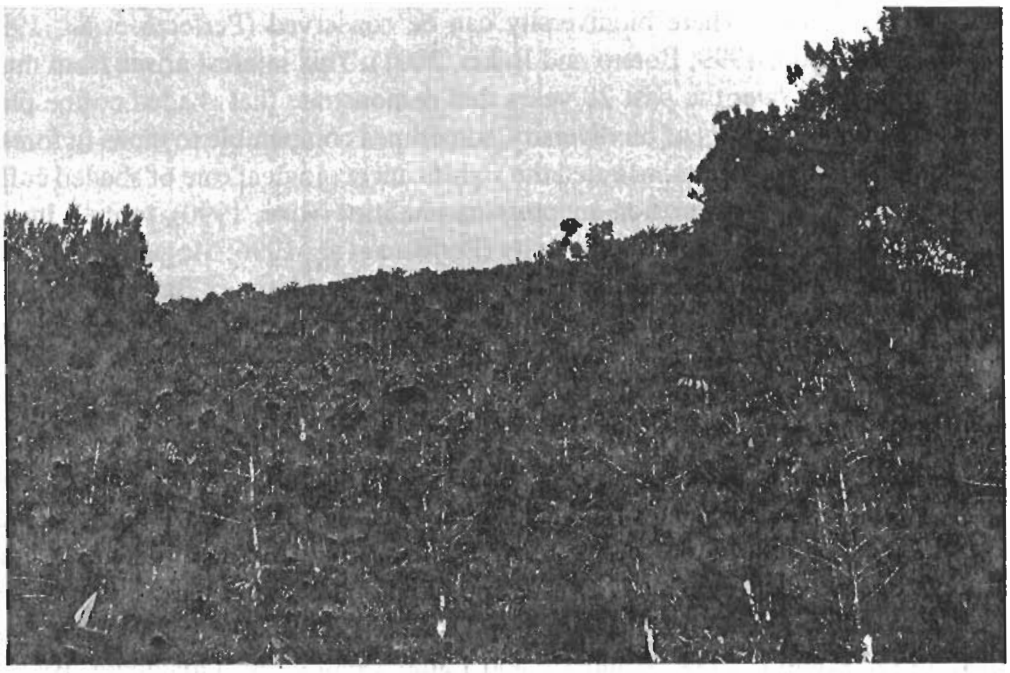

Figure 6.3 A sun (unshaded) coffee plantation in Chiapas, Mexico.

Sterling, 1997b). Shade coffee plantations may serve as dry-season refugia for birds at a time when energetic demands are high and other habitats are food poor (Wunderle and Latta, 1994, Johnson, 2000). Certain tree species that are used as shade trees can provide important nectar and insect resources to birds in coffee plantations. For example, it has been documented that trees in the genus *Inga* support large numbers of arthropods and that birds tend to be in higher abundances in areas dominated by this shade tree (Johnson, 2000). Wunderle and Latta (1998) also described how birds in Dominican coffee plantations dominated by *Inga* and *Citrus* spp. foraged primarily in the shade tree canopy. *Inga* also provides abundant nectar resource for nectivores (Koptur, 1994; Celedonio-Hurtado, Aluja, and Liedo, 1995; Greenberg et al., 1997a).

A large percentage of the birds found in coffee plantations are canopy omnivores and partial nectivores (Wunderle and Latta, 1996; Greenberg, Bichier, and Sterling, 1997b). Although some studies have found similar levels of bird species richness in shaded plantations when compared to adjacent forests (Aguilar-Ortíz, 1982; Corredor, 1989; Greenberg, Bichier, and Sterling, 1997b; Dietsch, 2000), the species composition tends to be different. According to Greenberg et al. (1997b), many forest-edge and second-growth species contribute significantly to the high diversity of birds in coffee plantations. Being more generalists than residents, migrants seem to fare better in coffee plantations. Forest residents that have very specific foraging and nesting requirements may be more affected by the habitat modifications that take place even in rustic plantations. In addition, larger resident birds may be more susceptible to hunting pressure in coffee plantations than in isolated large tracts of forests. However, in areas where forests have been highly fragmented or depleted, coffee agroforests seem to offer an adequate habitat for the conservation of many bird species. It is because of this high potential that the Smithsonian Migratory Bird Center, as well as many conservation organizations, has taken special interest in the conservation of shade coffee plantations in northern Latin America, especially along the main migration routes.

Other vertebrates have not received as much attention as birds from the scientific community, and therefore many of the accounts are anecdotal. However, the few studies that have been published suggest that shaded plantations, especially the rustic systems (which preserve most of the canopy species from the original forest), support a diverse medium- and small-sized mammalian fauna (Gallina, Mandujano, and González-Romero, 1992, 1996; Estrada, Coates-Estrada, and Merrit, 1993; Estrada, 1994). Estrada, Coates-Estrada, and Merrit (1993) reported a high diversity and abundance of bats in shaded coffee as compared to other agricultural habitats. The majority of the bats found in coffee plantations are partially frugivores and nectivores, deriving most of their diet from the fruits and flowers produced by shade trees (Estrada et al., 1993). Likewise, nonflying mammals have been reported to be richer in species and biomass in coffee plantations than in other agricultural habitats (Estrada, 1994; Gallina, Mandujano, and González-Romero, 1992, 1996; Horváth, March, and Wolf, unpubl. data). Nonflying mammals are primarily omnivores, but Gallina et al. (1992) reported that some specialized mammals, such as small cats and otters, have been observed in coffee agroforests in Veracruz, Mexico.

There are also accounts of regular observations of howler monkeys in the same region (Estrada, 1994). Although no large mammals such as deer and large cats have been officially recorded in coffee, some rare and threatened species such as the chupamiel (*Tamandua mexicana*), the nutria (*Lutra longicaudis*), and the viztlacuache (*Coenduc mexicanus*) can be observed in diverse coffee agroforests (Moguel and Toledo, 1999). The diversity and richness of small- and medium-sized mammals have been found to be associated with horizontal plant diversity and vertical foliage diversity (Estrada, 1994), as well as with the vegetation structure of coffee plantations (Gallina et al., 1992).

A limiting factor for mammals in coffee agroforests could be the availability of food (seeds, fruits, insects) throughout the year, which suggests that shaded plantations dominated by one or a few shade tree species might not be sufficiently diverse to provide the ample and continuous food resources needed to maintain a diverse mammalian community. Although most studies have found coffee agroforests to fare better than other agricultural habitats with respect to mammals, they have also found lower mammal diversity in coffee agroforests than in closed-canopy forests (Estrada et al., 1993; Estrada, 1994; Horváth, March, and Wolf, unpubl. data). However, in a study comparing a forest fragment with coffee plantations under different shade levels, Witt (2001) reported higher species richness and densities of small rodents in the agroforests than in the forest fragment. This study reported a total of three small rodent species in the forest fragment and five in the more diverse coffee plantations, which included the three found in the forests (Witt, 2001). This study suggests that, in the absence of a large reserve or continuous original forests, which is the case in most of the midelevation regions in northern Latin America where coffee is grown, coffee agroforests could provide a matrix of suitable habitat for medium- and small-sized mammals, if not for permanent colonization, at least as a safe travel route from one forest fragment to another (Witt, 2001).

Studies documenting populations of amphibians and reptiles in coffee agroforests are even scarcer than those for mammals, and results are contradictory. Although Lenart et al. (1997) documented that all five species of *Norops* (formerly *Anolis*) lizards reported locally in a region of the Dominican Republic were also found in three-tiered coffee plantations, Seib (1986) and Rendón-Rojas (1994) documented much lower numbers of reptiles and amphibians in coffee plantations than in natural forests. Komar and Domínguez (2001) sampled 24 coffee plantations in El Salvador but did not find enough amphibians and reptiles to quantify the potential benefits of certifying high-shade plantations for these groups. Seib (1986) reported that mixed shade plantations supported approximately 50% of snakes found in the original forest in Guatemala, and Rendón-Rojas (1994) reported only 16 species of reptiles (11) and amphibians (5) in coffee plantations in the state of Oaxaca, Mexico, compared to 77 and 94 species reported for undisturbed forests in Los Tuxtla (Pérez-Higereda et al., 1987) and the Lacandon forest (Lazcano-Barrero et al., 1992), respectively. Unfortunately, none of these studies involved extensive surveys comparable to those that have been undertaken in forest reserves, and therefore it is hard to draw conclusions about the role of agroforests in maintaining populations of reptiles, amphibians, and mammals.

Arthropods

In one of the earliest studies of arthropod diversity in coffee plantations, Morón and López-Méndez (1985) reported a total of 27,000 individuals of ground scavengers representing 78 families in a mixed shaded coffee plantation in Chiapas, Mexico. Ibarra-Núñez (1990) also reported a high abundance and diversity of arthropods on coffee bushes in the same plantation: almost 40,000 individuals representing 258 families and 609 morphospecies, with the Diptera (22%), Hymenoptera (21.8%), Coleoptera (13.3%), Homoptera (11.5%), and spiders (10.7%) being the most diverse taxa. A more detailed analysis of three families of web spiders yielded a total of 87 species, with 6 genera and 32 species representing new records for Chiapas and 3 genera and 11 species creating new records for Mexico (Ibarra-Núñez and Garcia Ballinas, 1998). Species richness in this plantation registered 31% of that reported for the entire state of Chiapas and 14% of that reported for all the country.

The potential of shaded coffee plantations to harbor high arthropod biodiversity was highlighted by the study of Perfecto et al. (1997) in Heredia, Costa Rica. Using the same methodology pioneered by Erwin and Scott (1980), Perfecto and colleagues fogged the canopy of shade trees in a traditional coffee plantation. In the canopy of a single *Erythrina poeppigeana*, they recorded 30 species of ants, 103 species of other Hymenoptera, and 126 species of beetles. In a second tree in the same plantation, they recorded 27 species of ants, 67 of other hymenopterans, and 110 species of beetles. Furthermore, the overlap of species between these two trees was only 14% for the beetles and 18% for the ants. This level of species richness is within the same order of magnitude as those reported for canopy arthropods in tropical forests (Erwin and Scott, 1980; Adis et al., 1984; Wilson 1987).

Other studies have also found the diversity of arthropods in coffee plantations to be similar to that of adjacent forests. For example, in Colombia, studies comparing soil arthropods (Sadeghian, 2000) in general and coprophagous beetles (Scarabinae) in particular (Molina, 2000) concluded that the two most diverse habitats were the forest and the shaded coffee plantation. Similarly, in a study with fruit-feeding butterflies in Chiapas, Mexico, Mas (1999) found no significant differences in species richness between a forest fragment and an adjacent rustic coffee plantation. Estrada et al. (1998) used rarefaction analysis and sampled different agricultural habitats and native forests to conclude that the forest had the highest diversity of dung beetles but that a cacao/coffee mixed shade plantation was the next most diverse habitat.

Although these studies underscore the importance of the shade coffee agroecosystem in the conservation of arthropod diversity, a few studies have reported significant differences in species composition and richness between native forest and coffee plantations. In a study in Las Cruces, Costa Rica, Ricketts et al. (2001) found a decline in species richness as well as in the number of unique species of moths between a forest reserve and both shade and sun coffee plantations. They concluded that distance from the forest rather than habitat type was the most important factor determining moth species richness. It is important to point out that the shaded coffee plantations that were sampled in this study were monospecific stands of shade trees of either *Erythrina* sp. or *Inga* sp. and therefore represent the less diverse side of the coffee management spectrum.

THE COFFEE TECHNIFICATION PROCESS

The loss of forest cover in Latin America, a genuine ecological crisis, is in part due to agrodeforestation in the coffee sector (Perfecto et al., 1996). Attempts to modernize coffee plantations in Latin America started in the 1950s (Rice, 1990), but it was not until the arrival in Brazil of the coffee leaf rust (*Hemeleia vastatrix*) in 1970 that the so-called technification programs really took hold. Countries in Central America and the Caribbean, encouraged by more than $81 million from USAID, began to implement programs aimed at converting coffee production from the low-input, low-intensity, and low-productivity shaded system to the highly technified unshaded system (Rice and Ward, 1996).

A recent study suggests that approximately 67% of all coffee production in northern Latin America has been affected by the technification trend in one way or another (Rice, 1999). Countries differ in the degree of coffee technification, ranging from less than 20% in El Salvador and Venezuela, to up to 69% in Colombia. But technification pressures persist in most countries, and unless better alternatives are offered to producers, this process may eventually eliminate most shaded plantations from the Latin American landscape, perhaps with dramatic social and environmental consequences for the region.*

The technification process includes a reduction or elimination of most planned biodiversity (i.e., the species that are intentionally incorporated into the agroecosystem). In the shaded coffee plantations, the planned biodiversity includes coffee plus all the shade, fruit, and timber trees. The most extreme technification results in the complete elimination of all trees except for the coffee bushes, essentially creating a monoculture (also called sun coffee or unshaded coffee) (Figure 6.3). However, this is only one component of the technification process, which frequently involves planting high-yielding varieties of coffee at a higher density, plus the application of agrochemicals such as fertilizers, herbicides, fungicides, and insecticides.

CONSEQUENCES OF TECHNIFICATION FOR BIODIVERSITY

The reduction or elimination of shade trees can have a devastating effect on biodiversity. Studies comparing sun coffee with shade coffee or with coffee with different levels of shade have shown that the technification of this agroecosystem results in a loss of biodiversity for most organisms.

Impact of Coffee Technification on Birds

The possibility that deforestation in the American tropics was responsible for the decline of several species of neotropical migratory birds (Askins, Lynch, and

* The most recent coffee crisis had surprising consequences. In the early 1990s when prices fell in the international market, large producers simply let their farms idle for awhile, awaiting better times (Perfecto, pers. obs. in Costa Rica). The small producers who had diverse farms with many fruit trees were able to gain some income from the noncoffee harvest from their farms. However, this recent crisis has resulted in coffee producers opting out of coffee altogether and transforming their plantations to other land uses such as cattle or corn milpas (Perfecto, pers. obs. in Mexico; Armbrecht, pers. obs. in Colombia).

Greenberg, 1990) focused attention on the coffee agroecosystem. Given that coffee agroforests had been recognized as important habitat and refugia for both migrant and resident birds (see previous section), the conversion of these diverse plantations to sun coffee could have detrimental effects on bird conservation. However, few studies have examined these effects on birds. In one of the earliest published studies, Borrero (1986) documented a dramatic decline in bird diversity in sun plantations in Colombia. In the Dominican Republic, Wunderle and Latta (1996) documented a shift from forest to shrubby second growth bird species when comparing monogeneric shade plantations with sun coffee. However, in Guatemala, Greenberg et al. (1997a) documented relatively low bird diversity in shaded coffee plantations dominated by either *Inga* or *Gliricidia* species, and both of these types of plantations had similar species richness as the sun plantation, although the *Inga* coffee plantation had slightly higher species richness than the others. Comparing bird species richness found in this study with a previous study in a traditional farm in Chiapas (Greenberg et al., 1997b), the authors estimated that sun coffee plantations support approximately half of the species diversity and density that traditional plantations do and suggested that coffee could only be important for bird conservation if a tall, taxonomically and structurally diverse canopy is maintained. Along those lines, Komar and Domínguez (2001) sampled 24 plantations with varying degrees of shade and structural diversity in El Salvador and found that 16 species of residents were negatively affected by intensification. Analyzing resident species in more detail, they reported that of 13 measured habitat variables, shade cover was the one that better predicted species richness and abundance of resident species. Based on these results, they developed a model that established 44% shade cover and 15 species of shade trees per 0.5 hectares as a threshold for the conservation of species that are sensible to perturbation. These results deviate somewhat from what is required by the Bird Friendly® and the Eco-OK™ coffee certification programs (discussed below) — 40% shade cover and 10 species of shade trees per hectare. With respect to the decline of bird diversity and abundance along the intensification gradient, the density of emergent trees (>5 m above the canopy) also appears to be important for resident species (Greenberg et al., 1997a; Komar and Domínguez, 2001).

Neotropical migrants do not seem to be as affected by coffee intensification as residents. Since they are largely omnivores and have more generalized habitat requirements than most resident birds, vegetation changes associated with the intensification of coffee are less likely to affect them, especially when the transformation does not imply a complete removal of the canopy. Dietsch and Mas (2001) found that resident birds have a stronger forest association than migrants in Chiapas, Mexico, and that rustic coffee plantations provide the strongest conservation benefit for forest-associated birds. The most likely candidates to be affected by technification are the largely nectivorous Baltimore oriole, the Tennessee warbler, and the Cape May warbler, all three of which have experienced sharp population declines since 1980 when the technification process intensified (Perfecto et al., 1996).

Arthropods and Coffee Technification

Among arthropods, generalist ground-foraging ants have received considerable attention because they are easy to sample and occupy the same habitat in forests, shaded plantations, and sun plantations. Most studies with this group show a significant decrease in diversity along an intensification gradient. These studies are summarized in Table 6.1.

Perfecto and Vandermeer (1994) reported a 39% decline in ant species richness when comparing a traditional coffee plantation with a plantation with only *E. poeppigeana* as shade, and further 65% decline when comparing the monospecific shaded coffee plantation with a sun plantation. Perfecto and Snelling (1995) also

Table 6.1 Studies that Compare Ant Species Richness in Coffee Plantations with Different Levels of Intensification

Country	Group/Theme	Intensification Effect	Reference
Colombia	Leaf litter ants	Yes	Armbrecht and Perfecto, 2002
Colombia	Ground ants	Yes	Sadeghian, 2000
Colombia	Leaf litter ants	Yes	Sossa and Fernández, 2000[a]
Costa Rica	Ground ants (baits)	Yes	Benitez and Perfecto, 1990
Costa Rica	Ground ants	Yes	Perfecto and Snelling, 1995
	Ants foraging in coffee (baits)	No	
Costa Rica	Ground ants (baits)	Yes	Perfecto and Vandermeer, 1994
Costa Rica	Competitive relations	Yes	Perfecto and Vandermeer, 1996
Costa Rica	Arboreal ants (canopy fogging)	Yes	Perfecto et al., 1997
Mexico	Ground ants nesting in twigs	Yes	Armbrecht and Perfecto, in press
Mexico	Ants in coffee plants (D-vac)	Yes	Ibarra-Núñez et al., 1995[b]
Mexico	Foraging dynamics	Yes	Nestel and Dickschen, 1990[c]
Mexico	Ground ants (baits)	Yes	Perfecto and Vandermeer, 2002
Mexico	Ground ants (baits and pitfall traps)	No	Ramos, 2001
Panama	Army ants (*Eciton* and *Labidus*)	Yes	Roberts et al., 2000
Puerto Rico	Direct observations	Yes	Torres, 1984[d]

[a] Although the abundance of ants was lower in the shaded plantations, species richness is higher than in the unshaded plantations.
[b] This study found a higher species richness in an organic coffee plantation with higher shade than in a technified conventional farm dominated by *Inga*. However, the difference is not tested statistically.
[c] This study shows a much higher ant foraging activity in the sun coffee plantation as compared to the shaded plantations, mainly due to the dominance of *Solenopsis geminata* in plantations with higher sun exposure.
[d] Table 1 of this study shows similar ant richness in coffee plantations and forest plots.

reported that ground-foraging ants were positively and significantly correlated with the floristic and structural diversity of coffee farms along an intensification gradient. The only exception to this pattern was reported by Ramos (2001) for ground-dwelling ants in Mexico. In this study, no significant differences were found when comparing ant diversity in forests, multispecies shaded coffee, and coffee shaded with only *Inga*. However, the author points out that a qualitative analysis revealed that each habitat appears to have a different ant assemblage and suggests that forests and coffee plantations under different management contribute to ant diversity at the landscape level. In situations like these, it is important to examine the overlap of species within habitat and between habitats. In a similar study, Perfecto and Snelling (1995) reported much higher species similarity indices among coffee monocultures than among coffee agroforests, demonstrating that, at a landscape level, the agroforests contributed significantly more to species diversity than the coffee monocultures, even though the differences in species diversity locally were not very high.

The few studies that have sampled arboreal ants foraging in the coffee layer showed mixed results (see Table 6.1). While Perfecto and Snelling (1995) found no significant difference in ant diversity in the coffee layer between shaded and unshaded plantations, Ibarra-Núñez et al. (1995) and Perfecto et al. (1997) reported a higher ant species richness in coffee bushes in diverse plantations compared to more technified plantations. These conflicting results could be a consequence of the methods used for sampling the ant community. Perfecto and Snelling (1995) used tuna baiting, which tends to capture the generalist subcommunity of ants, while Ibarra-Núñez et al. (1995) and Perfecto et al. (1997) used D-vac sucking and insecticidal fogging of entire plants, respectively. It can thus be argued that, when a more complete sample of the ant assemblage is taken, a significant difference in ant species richness is detected between shaded and unshaded plantations. Canopy ants, those that nest and forage in the canopy of shade trees, have been less studied than ground-foraging ants or ants that forage in the coffee bushes, and the only study published to date that compares canopy ants along a coffee intensification gradient shows an even more accentuated reduction of species richness than that documented for ground or leaf litter ants (Perfecto et al., 1997).

Army ants also seem to be affected by the elimination of shade trees. A study in Panama reported that two species of army ants commonly found in forests were also present and abundant in shaded coffee plantations but not in unshaded plantations (Roberts et al., 2000). This study also found no difference in the number of swarms for these two species between forest and shade coffee plantations either near or far from the forest.

Several direct and indirect mechanisms have been proposed for the observed reduction of ant species richness along the technification gradient. Among the direct mechanisms are the loss of nesting sites for canopy and trunk nesting species (Perfecto and Vandermeer, 1994; Roberts et al., 2000) and changes in microclimatic conditions (Torres, 1984; Perfecto and Vandermeer, 1996). Indirect mechanisms include changes in the type of resources available for ants, which could alter the competitive interactions in the ant community (Perfecto, 1994; Perfecto and Snelling, 1995; Perfecto and Vandermeer, 1996).

Other arthropods also show declines in species richness with intensification (Table 6.2). Comparing shaded and unshaded plantations in Mexico, Nestel, Dickschen, and Altieri (1993) reported a reduction in species richness for soil macrocoleopterans. Similar results were reported by Estrada et al. (1998) for dung beetles. In both of these cases, the persistence of medium-sized diurnal mammals and the presence of decomposing fruits in the shaded plantations were given as possible reasons for the higher diversity in the shaded plantations.

Species richness of phytophagous insects has also been shown to decline with intensification. Mas (1999) reported a significant decline in fruit-feeding butterflies along a coffee intensification gradient. In this study, only the more rustic plantation was able to maintain high species richness, which suggests that this group of butterflies is very sensitive to the disturbances caused by intensification (such as reduction in canopy cover). In a study comparing sun coffee with shade coffee plantations in Costa Rica, Rojas et al. (1999) report lower homopteran species richness in the sun coffee system.

Not all arthropods appear to respond in the same fashion. As mentioned above, in the study with moths in Costa Rica, Ricketts et al. (2001) found no significant differences in moth richness between monospecific shade and sun plantations. A study in Colombia reported no difference between shaded and unshaded plantations for hymenopterans other than ants (Sossa and Fernandez, 2000). A study comparing

Table 6.2 Studies that Compare Arthropod Species Richness in Coffee Plantations with Different Levels of Intensification

Country	Group/Theme	Intensification Effect	Reference
Colombia	Mesoarhtropods (ground)	Yes	Sadeghian, 2000
Colombia	Scarabaeinae (ground)	Yes	Molina, 2000
Costa Rica	Coleoptera and Hymenoptera (shade)	Yes	Perfecto et al., 1996
	Coleoptera and Hymenoptera (coffee)	Yes	
Costa Rica	Arthropods (coffee)	Mixed	Perfecto and Snelling, 1995
Costa Rica	Moths (light traps)	No	Ricketts et al., 2001
Jamaica	Arthropods (in general)	Yes	Johnson, 2000[a]
Mexico	Scarabaeinae (ground)	Yes	Estrada et al., 1998
Mexico	Homoptera (coffee, D-vac)	Yes	Ibarra-Núñez et al., 1995
Mexico	Butterflies (traps: coffee and canopy levels)	Yes	Mas, 1999
Mexico	Macrocoleopterans (ground)	Yes	Nestel et al., 1993
Mexico	Coffee leaf miner (coffee) (abundance)	No	Nestel et al., 1994
Mexico	Spiders (coffee)	Yes	Pinkus-Rendón, 2000[b]

[a] This study did not examine coffee plantations with different intensification levels, but rather areas that were dominated by different species of shade trees (*Inga vera* versus *Pseudoalbizia berteroana*).

[b] This study showed the reverse pattern: higher density and diversity of spiders in the more technified plantations.

spiders in two farms in the Soconusco region of Mexico suggests no differences in spider species richness between an organic farm with diverse shade and a technified conventional farm with shade dominated by *Inga* (Ibarra-Núñez et al., 1995), while another study in the same plantation found significantly higher spider diversity in the technified farm as compared to the organic and more shaded farm (Pinkus-Rendón, 2000). Yet unpublished data from a study in Costa Rica by one of the authors (Perfecto) suggest that spider diversity is higher in shade coffee than in sun coffee. Fogging and sampling ten coffee bushes each in a sun and a shade plantation, Perfecto et al. (1996) found a total of 29 and 44 spider morphospecies, respectively.

Researchers comparing arthropods in shaded and unshaded plantations often make the decision of focusing on one compound of the community. Because it is not practical to sample all components of the shaded plantation (ground, leaf litter, coffee bushes, canopy of shade trees), most studies focus on the components that are more accessible (i.e., leaf litter or coffee bushes). This makes the interpretations of results of biodiversity studies difficult. Particularly problematic are organisms that can inhabit different levels in trees and shrubs, such as spiders and arboreal ants. Without sampling the canopy of the shade trees along with the coffee bushes, it is difficult to make a generalization about diversity in coffee plantations with different levels of shade. Arboreal spiders could be using the coffee bushes in a plantation with few or no trees, while in a shaded plantation most of these species could be found on the canopy of trees and not on the coffee layer. The canopy of *Inga* can be particularly attractive for insect predators such as spiders because the canopy of shade trees has a much higher abundance of insects than the coffee bushes (Johnson, 2000). However, the high density of insects in the canopy can also attract birds, which can prey on the spiders (these types of trophic interactions will be discussed in the next section).

Although the majority of these studies show a reduction in arthropod biodiversity with coffee intensification (Tables 6.1 and 6.2), most of the studies consist of comparisons between two systems, usually shade and sun plantations. The few studies that have examined a gradient of shade suggest that the particular level of shade is important (Perfecto and Vandermeer, 1994; Perfecto and Snelling, 1995; Perfecto et al., 1997; Mas, 1999). As was discussed above, some species of shade trees, like *Inga*, support higher diversity and abundance of arthropods than others (Johnson, 2000). Furthermore, there is no reason to think that the trajectories of species decline should be the same for different taxa. Although comparative studies that include different taxa within the same sites are rare, our knowledge of the natural history of different groups suggests that some taxa are more susceptible to technification than others. This is evident within birds, where residents have been shown to be more susceptible to intensification than migrants (Greenberg et al., 1997*a*). Preliminary data from a study in Chiapas (Perfecto et al., in press) also suggest that ants and butterflies follow a very different pattern of richness decline along an intensification gradient (Figure 6.4). These differences make it difficult to establish criteria for the certification of shade coffee for conservation purposes. It is important to note that the approach taken here emphasizes species richness without concern for the identity of those species. For conservation purposes it will be important to identify forest species or species that are sensitive to perturbations.

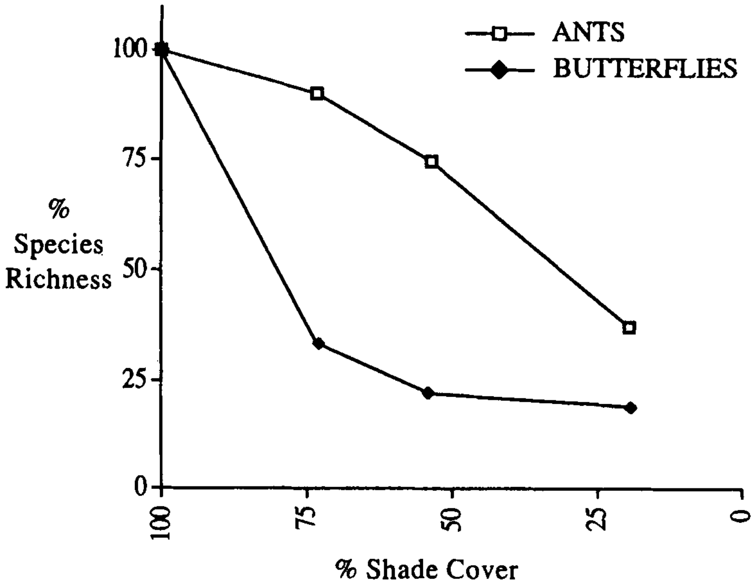

Figure 6.4 Percent of species richness (based on species richness in forest plots) of ants and butterflies in relationship to the percentage of shade cover in coffee plantations in the Soconusco region of Chiapas, Mexico. Data of species richness for 100% shade cover represents richness in forest plots. (Modified from Perfecto et al., in press.)

THE FUNCTION OF BIODIVERSITY IN THE REGULATION OF HERBIVORES

Based on ecological theory, we propose that the high diversity of organisms found in coffee plantations can play an important role in the functioning of that agroecosystem. Recent debate on the role of biodiversity in ecosystem function suggests that we should be cautious in making blanket statements about the subject (Huston, 1997; Huston et al., 2000; Loreau and Hector, 2001). One of the ecosystem functions that has been assumed to be enhanced by biodiversity is the regulation or control of insect pests (Altieri, 1993; Vandermeer and Perfecto, 1998). However, the relationship between pest control and biodiversity is a complicated one and should be examined more carefully on a system-by-system basis. In this section we will focus on the role of biodiversity in the regulation of insect herbivores in coffee because it is an area that is beginning to receive significant empirical attention. It also has obvious practical implications.

Coffee in the Western Hemisphere does not have a high incidence of insect pests. However, up to 200 species of herbivores have been reported to feed on coffee (Le-Pelley, 1973). In a baseline study of the arthropod community in a shaded coffee plantation of the Soconusco region in southern Mexico, Ibarra-Núñez (1990) reported that 37.5% of the individuals and 25% of the species collected were phytophagous. However, despite the fact that more than a third of the individuals collected by Ibarra-Núñez (1990) were phytophagous, only a few species are considered pests in coffee throughout Latin America. Among these are *Hypothenemus hampei* (Ferrari), the coffee berry borer, *Leucoptera coffeella* (Guer-Men), the coffee leaf miner, several coccids and pseudococcids (*Planococcus citri*, Rissi, *Pseudococcus jongispinus* Torgioni-Tozzeti), several shoot borers (*Plagiohammus macuosos* Bates, *P. mexicanus, P. spinipensis*), and the red mite (*Oligonychus coffeae* Nietar). It has been suggested that the structurally complex and floristically diverse traditional coffee plantations support a high density and diversity of predators and parasitoids, which are ultimately responsible for the reduced number of insect pests in traditional plantations (Ibarra-Núñez, 1990; Perfecto and Castiñeiras, 1998). Ibarra-Núñez's study (1990) reported that 42% of the species and 25% of the individuals collected were predators or parasitoids. It has been suggested that generalist or polyphagous predators, like birds, ants, and spiders, are better at preventing pest outbreak than at suppressing outbreaks once they have occurred (Holmes, 1990; Riechert et al., 1999). We suspect that as diverse shaded coffee plantations, like those sampled by Ibarra-Núñez (1990), are transformed to less diverse or sun plantations, the diversity of generalist predators will decline, releasing herbivores from the predation pressures that presumably maintain them below pest threshold population densities.

Impact of Birds on Coffee Arthropods

As discussed above, shaded coffee plantations support among the highest densities and species richness of birds of any habitats, either natural or anthropogenic, in northern Latin America (Aguilar-Ortíz, 1982; Wunderle and Wide, 1993; Greenberg, Bichier, and Sterling, 1997*b*). Most species of birds are either insectivores or omnivores — with arthropods comprising the majority of their diet. Experimental exclosure studies over the past 20 years have demonstrated that birds often remove a large portion of the standing crop of arthropod populations — particularly large herbivorous arthropods (Holmes et al., 1979; Gradwohl and Greenberg, 1982; Moore and Yong, 1991; Bock et al., 1992; Marquis and Whelan, 1994). Other studies have further demonstrated a reduction in herbivore damage in the presence of insectivorous birds (Atlegrim, 1989; Marquis and Whelan, 1994), which resulted in an increased growth rate of study plants. However, very few studies have examined the impact of insectivorous birds on the arthropod community in coffee plantations. In a study in coffee plantations in Jamaica, Johnson (2000) reported that coffee with *Inga* as the primary shade trees had higher abundances of arthropods and birds than coffee dominated by another shade tree species, and suggested that bird communities in coffee respond to spatial variation in arthropod availability. The only bird exclosure study conducted in coffee plantations so far showed a 64 to 80% reduction in arthropods greater than 5 mm in length (Greenberg et al., 2000). These data suggest that the effect of birds is quite generalized across ecological and taxonomic groups of arthropods. Furthermore, there was a small but significant increase in herbivore damage within the exclosures. The sample size for this study was small and the time frame of the experiment short; yet interesting significant results were obtained. Because overall bird density and diversity decline with the intensification of coffee plantations, it is reasonable to suggest that their ability to regulate insect herbivores will also be reduced with intensification.

Unlike temperate systems, which have often been the focus of exclosure studies of bird insectivory, the tropical coffee agroecosystem experiences herbivory and insectivory throughout the year. During the north temperate winter (which encompasses both the dry season and the season of coffee harvest in Chiapas) insectivorous bird populations may double with the influx of migrants from the North. During the north temperate summer, coffee plants are engaged in their peak vegetative growth and insectivorous bird populations are smaller and engaged in breeding activities. Based on these differences it is reasonable to expect seasonal variation in the impact of avian insectivory on arthropod abundance and herbivore damage. During the winter months, a relatively high density of birds and low abundance of arthropods may result in large proportional reductions in arthropod abundance (as was demonstrated in the study of Greenberg, Bichier, and Cruz Angon, 2000). During the summer, birds are less common and arthropods are more abundant, so birds may have a lower impact. However, because breeding birds usually rely heavily upon large arthropods to raise young (Greenberg, 1995), and because this is the period of greatest leaf production, we would expect the greatest absolute reduction in herbivory to occur during this period.

Preliminary results of bird exclosure experiments in Chiapas, Mexico, show that birds significantly reduce the number of arthropods larger than 5 cm, but this difference does not appear to be stronger for the winter months (unpubl. data) (Figure 6.5). Birds also significantly reduce herbivory in coffee plants (unpubl. data). A recent study where lepidopteran larvae were used to simulate a pest outbreak inside and outside bird exclosures demonstrated that birds rapidly remove caterpillars from the coffee layer. But even more significant, the rate of removal was significantly faster in the diverse shaded plantations than in the more technified plantation (Perfecto et al., unpubl. data). These results suggest that diversely shaded coffee

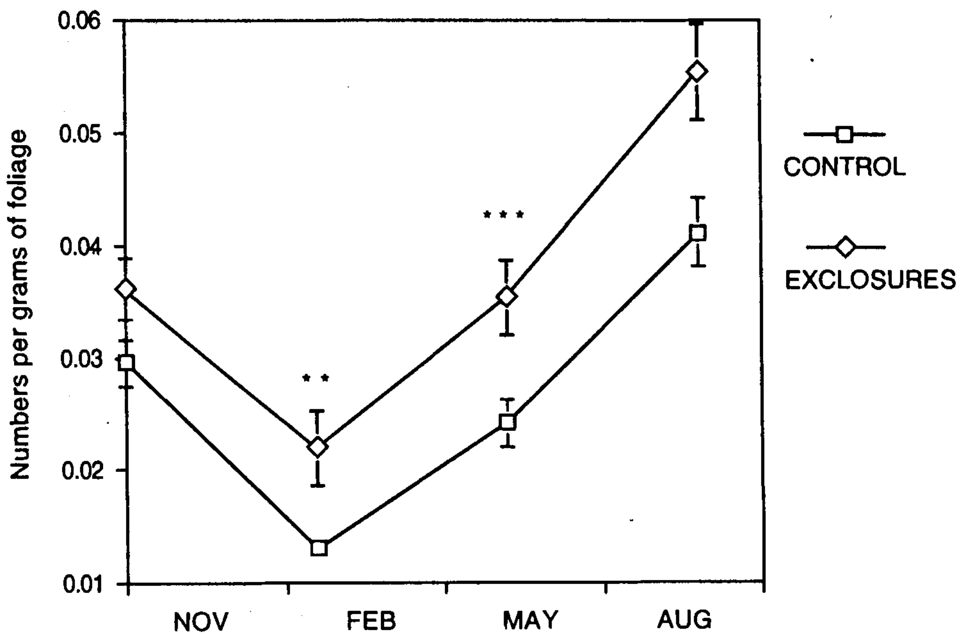

Figure 6.5 Numbers of arthropods >5 cm per gram of foliage of coffee in controls (n = 32) and bird exclosures (n = 32). ** = significance level of <0.01, *** = significance level of <0.001. Data from coffee farms in the Soconusco region of Chiapas.

plantations could also be more resistant to pest outbreaks than sun coffee because of the higher diversity and density of insectivorous birds that are present in these plantations. In a diverse coffee plantation, each herbivore species has to deal with a broader range of natural enemies than in the sun plantations, and therefore the probability that a particular herbivore would reach high population levels and become a pest is lower.

Impact of Ants on Other Coffee Arthropods

Ants are among the most important generalist predators in tropical ecosystems, both managed and natural. They are also numerically and ecologically dominant in these regions. For example, recent measurements suggest that ants and termites compose one third of the entire animal biomass of the Amazonian upland rainforest (Wilson, 1987). In Guianan cacao plantations, ants constitute 89% of the total insect numbers (Leston, 1973) and up to 70% of the arthropod biomass (Majer, 1976). In Ibarra-Núñez's study (1990), ants represented 12.2% of the total arthropods. Although not as diverse as other taxa, ants can have a high diversity in tropical agroecosystems and are almost always the most numerous of the arthropod taxa.

There are many instances of ants being used to limit pests, both in the tropics and in temperate ecosystems (see reviews in Way and Khoo, 1992; Perfecto and Castiñeiras, 1998). A study conducted in a shade coffee plantation in Chiapas, Mexico, demonstrated the potential of two Ponerinae species in controlling phytophagous insects (López Méndez, 1989). More recently, Ibarra-Núñez et al. (2001) conducted a prey analysis study for *Ectatomma ruidum* and *E. tuberculatum*, two common ant species in coffee plantations in Chiapas, and found that 17.8% and 11.3% of the prey items of these two species, respectively, were herbivores of coffee. Furthermore, in Colombia, leaf litter and soil ants were recently discovered preying on the coffee berry borer, the main coffee insect pest in all of Latin America (Vélez et al., 2000). In studies with artificial baits (fruit fly pupae or tuna fish), ants have been found to rapidly remove them, suggesting that they could potentially remove living herbivores (Armbrecht and Perfecto, in press; Philpott, unpubl. data).

With the reduction of ant diversity along the coffee intensification gradient (Nestel and Dickschen, 1990; Perfecto and Vandermeer, 1994; Perfecto and Snelling, 1995; Perfecto et al., 1997), a diverse community in shaded coffee plantations changes to one dominated by only a few species, mainly *Solenopsis geminata* and a few *Pheidole* species (Nestel and Dickschen, 1990; Perfecto and Vandermeer, 1994; Perfecto and Snelling, 1995). These few species are generalists, of approximately the same size, that nest in the ground and forage on the ground and lower vegetation. Both ant species have been reported to be effective predators and to cause reduction in herbivores in other agroecosystems (Risch and Carroll, 1982; Perfecto, 1990; Perfecto and Sediles, 1992). However, their effectiveness in controlling a variety of herbivores and potential pests in coffee is limited. For example, the coffee berry borer may be protected from *Solenopsis* germination once it is inside the seed, (*S. geminata* is too big to enter the holes, although this species could still have some impact on the adult coffee berry borer when they are outside the coffee berry.

It is also important to distinguish between two major groups of ants that forage in coffee bushes: the nondominant twig nesting ants, which have relatively small colonies, such as those in the genera *Pseudomyrmex*, some *Solenopsis*, and *Lepthotorax;* and the numerically dominant ants that make carton nests or nest in tree trunks and form large colonies, such as *Azteca*, *Camponotus*, and *Crematogaster* (Philpott, unpubl. data). These swarming ants usually are mutually exclusive, forming a mosaic of dominant ants with associated nondominant species in the canopy of shade trees (Leston, 1973; Majer, 1972, 1976). Recent studies in Mexico suggest that these swarming ants nest primarily in the shade trees and their foraging area includes several adjacent coffee bushes (Philpott, unpubl. data). A particularly interesting genus is *Azteca*, members of which form very large colonies and frequently dominate individual coffee bushes. A recent study suggests that even if these ants do not have a direct density-mediated effect on herbivores, they may have an indirect trait-mediated effect by harassing herbivores to the point that they have to move to another plant, reducing the feeding time of individual herbivores (Vandermeer et al., in press). Although the impact of ants on other arthropods has been well documented for other systems (Way and Khoo, 1992; Perfecto and Castiñeiras, 1998), their effect on potential insect pests in coffee is still unknown. Furthermore, some ant species are known to tend scales and other homopterans in coffee, and therefore their effect on coffee plants could be both negative and positive. More controlled experimental studies should be undertaken to evaluate these contradictory effects of ants on coffee herbivores.

Impact of Spiders on Other Coffee Arthropods

Ibarra-Núñez's (1990) baseline study reported 65 species of spiders belonging to 26 families, representing 14% of all the individual arthropods sampled in a coffee plantation in Chiapas, Mexico. In a more recent study of four spider families on three coffee farms in the same region, Ibarra-Núñez and Garcia-Ballinas (1998) reported 87 species belonging to 36 genera. In censuses of web-building spiders in coffee plantations of New Guinea, Robinson and Robinson (1974) estimated that there were 58,050 web-building spiders per hectare in coffee plantations and that these were responsible for the consumption of almost 40 million insects per year per hectare! Although these estimates are derived from extrapolations (from Robinson and Robinson, 1970) and not direct measurements of insect consumption by spiders, they give a general idea of the potential impact of spiders in controlling insect populations. In a recent study of prey analysis of seven common web-building spiders and two ant species, Ibarra-Núñez et al. (2001) found that the bulk of the prey of these nine predator species belonged to the insect orders Hymenoptera (primarily ants), Diptera, Homoptera, and Coleoptera. In general, the frequency of relative predation of any type of prey was proportional to their relative abundance. Herbivores and detritivorous and polyphagous arthropods (mainly ants) constituted the major part (84.7%) of the identified prey items (Ibarra-Núñez et al., 2001). This study also suggested that even though there was some overlap in prey species between different species of web-building spiders, their predation activity appears to be complementary. Essentially, different spider species occupy different microhabitats within an individual coffee bush. Recently, Riechert et al. (1999) experimentally demonstrated that prey abundance is reduced to lower levels by spider assemblages than by single populations. They suggested that species assemblages are better at sustaining levels of pest suppression because of temporal synchronies.

Relevant Trophic Interactions

Thus far we have discussed the separate effects of birds, ants, and spiders as natural enemies and potential regulators of herbivores in coffee plantations. However, it is important to note that these groups are for the most part generalist predators and will prey on each other. For example, in the bird exclosure study in Guatemala (Greenberg et al., 2000), birds caused a significant reduction of ants and spiders. Likewise, Ibarra-Núñez et al. (2001) reported ants as significant prey items of web spiders. Ants have been reported to eat spiders (Ibarra-Núñez et al., 2001) and each other (Hölldobler and Wilson, 1990), and some species, such as army ants and fire ants, can even kill bird nestlings (pers. obs.). Preliminary results from our study of the trophic structure in coffee plantations in Chiapas suggest that birds may be reducing spiders and spiders may be reducing parasitic wasps. In the first year of a large enclosure experiment, we found significantly higher numbers of spiders and significantly lower numbers of parasitic wasps inside bird exclosures than outside, where they were exposed to bird predation. The fact that we also found a significantly higher herbivory inside the exclosures suggests that other interactions are at play. Controlled exclosure experiments combining ants, spiders, wasps, and birds would be necessary to sort out the trophic web structure in coffee. Figure 6.6 shows a diagrammatic representation of the suspected main trophic interaction in the coffee agroecosystem, based on preliminary results from studies in Chiapas, Mexico. It is still too early to come to definite conclusions about the effects of diversity of the trophic structure of coffee and to accept the hypothesis that a high associated biodiversity functions as a buffer mechanism against pest outbreaks in coffee plantations. However, in spite of the high complexity inherent in this system, preliminary results point in that direction.

COFFEE AGROFORESTS AS A HIGH-QUALITY AGRICULTURAL MATRIX

Up to this point we have focused attention on the biodiversity contained within coffee plantations themselves and the potential of coffee agroforests to serve as a refuge. However, coffee agroforests may be important for the conservation of biodiversity within forest fragments. Conservation biologists are increasingly aware that the matrix within which forest fragments exist may be as important for conservation as the forest fragments themselves (Laurance, 1991; Bierregaard et al., 1992; Franklin, 1993; Weins et al., 1993; Gustafson and Gardner, 1996; Jules, 1997; Vandermeer and Perfecto, 1997; Vandermeer and Carvajal, 2001). Theoretically, the matrix may affect the rate of migration of organisms among forest patches and thus influence extinction rates on a regional level, or the matrix may create conditions

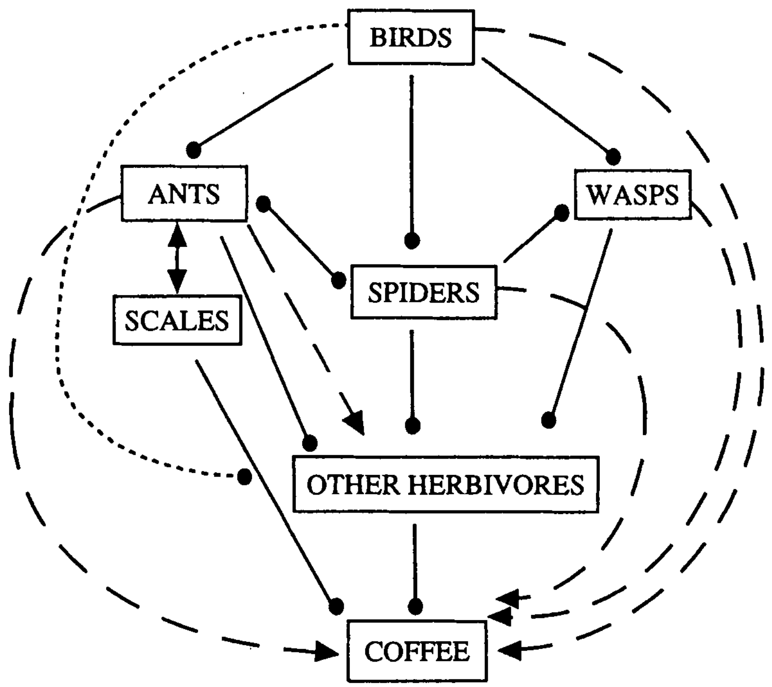

Figure 6.6 Diagram of the proposed main trophic interactions in a coffee plantation of the Soconusco region of Chiapas, Mexico. Arrowheads indicate positive effects and small closed circles indicate negative effects. Solid lines indicate direct effects, dashed lines indicate indirect effects acting through density or biomass modification, and the dotted line indicates the indirect effect acting through the modification of a direct effect.

that alter extinction rates within the forest fragments themselves (Gustafson and Gardner, 1996; Cantrell, Cosner, and Fagan, 1998). For example, the majority of frogs in the Manaus area of Brazil are maintained in forest fragments because they appear to use the surrounding matrix (Tocher et al., 1997).

Many of the mid-elevation regions in Latin America have lost large extensions of the original forest cover. However, many forest fragments remain scattered among the agricultural matrix. These small patches may not be suitable for megafauna, but they could be critical for the conservation of other organisms such as insects and other invertebrates, small- and medium-sized mammals, birds, and plants. Although it is desirable to develop programs to encourage the preservation of these many fragments, an additional problem is the management of the matrix in which they occur. In many tropical montane situations in northern Latin America, coffee plantations occupy most of the matrix. In the context of the matrix within which forest fragments are located, the coffee system thus represents what could be a variety of matrix qualities, from the rustic system to the sun system. It has been recently proposed that the different levels of coffee intensification (rustic coffee being the least intense, sun coffee being the most intense) represent different matrix qualities with respect to a selected bioindicator group (Perfecto and Vandermeer, 2002).

In this context, the quality of the matrix takes on a particular meaning. Focusing on the eventual need for interfragment migration, a high-quality matrix is one in which the barriers to migration are small. The matrix may not provide a source habitat for a particular species (i.e., the species may not be able to persist indefinitely there), but it may not be a perfect sink either (i.e., a propagule landing there may not perish immediately). The process of interfragment migration can be separated into two categories: direct and indirect migration (Perfecto and Vandermeer, 2002). For example, for ants, the principal migratory event is the time of nuptial flight. Flying ants may be carried long distances by the wind, but they mostly fly short distances to locate a nest site and establish a new colony (Hölldobler and Wilson, 1990). Direct migration occurs when a queen originating from a forest fragment is fertilized, flies, and lands on another forest fragment. The likelihood of this occurring depends on the size and spatial separation of forest fragments. Indirect migration occurs when a fertilized queen establishes a colony in the matrix and the colony survives in the matrix at least until it reaches maturity and produces new queens that will mate and disperse to find new nesting sites. Some of the fertilized queens will establish new colonies in the matrix to repeat the process. Eventually, one of the future generation offspring of the original queen establishes a colony in a new forest fragment. It is evident that the quality of the matrix is especially important for indirect migration, at least in this particular case. Even if the matrix is not a sufficiently high-quality habitat to maintain the population of a particular species in perpetuity (a source habitat), it may be sufficiently benign such that populations may be temporarily established, enabling indirect migration to occur.

Recent studies support the idea that shaded coffee represents a high-quality matrix for ants that live in forest fragments. Examining two farms, one an organic farm with considerable shade, the other a conventional farm with only spotty shade, Perfecto and Vandermeer (2002) found that species richness of ground-foraging ants attracted to tuna baits decreased with distance from the forest fragment in both matrix types. However, the rate of decrease in species richness was greater in the conventional farm (low-quality matrix) than in the organic farm (high-quality matrix). A similar study with leaf litter ants had even more dramatic results: a significant decline in species richness concomitant with distance from forest fragment in the technified coffee plantation but no significant distance relationship in the polycultural shaded plantation (Armbrecht and Perfecto, in press). On the other hand, a study with moths focusing on an agricultural matrix represented by a mosaic of systems that included coffee monocultures and shade coffee with one species of shade tree concluded that diversity was lower in all agricultural habitats, regardless of their composition, and that distance from the forest was the most important variable for species diversity (Ricketts et al., 2001). It is important to point out, however, that in this study the forest sampled was not a small fragment but actually a large reserve. Furthermore, the shaded coffee consisted of plantations with a single species of shade tree.

Based on these results, Perfecto and Vandermeer (2002) propose placing the focus on the quality of the agricultural matrix as an alternative strategy for dealing with habitat fragmentation. Rather than attempting to promote corridors of high-quality habitat (usually tacitly assumed to be necessarily the same as the fragment habitat itself), the question should be framed in terms of matrix quality. Although a matrix may be formally a sink for most populations of concern, if it provides for sufficient survivorship to ensure travel from fragment to fragment, that is all that is required for some organisms. Although a high-quality matrix is frequently difficult to construct, in the case of coffee, many of the plantations are already what might be considered a high-quality matrix, and the challenge would be to preserve them in the face of significant pressures pushing for their technification.

SHADE, BIODIVERSITY, YIELD, AND CERTIFICATION PROGRAMS

In the past 5 years, several biodiversity-friendly coffee certification programs have emerged as market-based strategies to promote either the conservation of diverse agroforests or the restoration of sun plantations to shade plantations. The appearance in the international market of organic and fair trade coffee led the way to the marketing of shade coffee as a green product. Several coffee labels, such as Bird Friendly and Eco-OK (Figure 6.7) began to appear in the market in the late 1990s and generated interest among consumers and producers alike (McLean, 1997; Koelle, 1998; Kotchen et al., in press). The following section reviews the earlier certification programs that set the stage for shade coffee certification and then discusses the shade certification programs themselves.

Organic Coffee

Organic coffee is coffee that has been grown using organic, chemical-free methods. Organic coffee occupies a sector of the gourmet or specialty coffee market that now represents 30% of the total coffee market and continues to grow (McLean, 1997). While standards for organic production have been set by larger governmental bodies, such as the European Economic Community and the U.S. Organic Food Production Act, it has been third-party certifiers like the Organic Crop Improvement Association, Quality Assurance International, and Naturland whose seals have become synonymous with chemical-free production. As a result, coffee grown on certified organic farms throughout Latin America and the world can earn premium prices, as much as 50% higher than conventional production, although it is more common for the premium to be in the range of 10 to 15% (Rice and Ward, 1996).

A. B. C.

Figure 6.7 Certification coffee labels. (From (A) Smithsonian's Bird Friendly, (B) Rainforest Alliance's Eco-OK, and (C) the brand logo for Equal Exchange. With permission.)

The primary goal of organic certification programs has been to protect the health of the consumers, not the environment or the producers' well-being. Although this is changing somewhat, the emphasis is still on consumer health. More recently, however, the International Federation of Organic Agricultural Movements (IFOAM), which accredits affiliated organizations that certify farms, in addition to their basic standards (IFOAM, 1996) has developed special criteria for coffee. These criteria include the planting of shade trees and the composting of the coffee pulp, as well as guidelines on social rights and fair trade (McLean, 1997). The way in which these will be implemented remains to be seen.

Fair Trade

Fair trade certification is newer and less established than organic certification, particularly in the U.S. It is based on the principle that the international trading system is unfair and that structures should be set up to provide small producers in the Third World with fair prices for their produce. Organizations like Max Havelaar and the Fair Trade Foundation in Europe have created reputable programs that certify that producers receive a fair price for their produce by cutting out the middle person and by guaranteeing prices in advance, thus benefiting cooperatives. The accompanying focus on development assistance for building schools and health-care centers has created enough added value to the product that consumers are willing to pay more, though not quite the premiums earned by organic coffees. While there are at present only a few fledgling fair trade certifiers in North America, at least one company, Equal Exchange (Figure 6.7), has been working for over 10 years to develop this market in the U.S. and make the model work. In Europe, fair trade certified coffee represents only about 3% of the total coffee market (McLean, 1997); in the U.S., this percentage is much lower.

Shade Coffee

The new developments in IFOAM aside, most organic certification programs do not guarantee environmental conservation or elements of social justice. A farmer can have a completely shadeless plantation that employs hundreds of migrant workers housed under inhumane conditions, paying miserable wages, and still be certified organic. Likewise, fair trade certification has no guidelines to ensure environmental conservation, although most small producers in Latin America have shaded coffee farms. Furthermore, notably missing from both of the certification systems is the attention to other pressing ecological issues, like the loss of biodiversity that accompanies the removal of shade trees. To address this issue, and to spread information on the ecological value of shaded coffee farms, the First Sustainable Coffee Congress was organized by the Smithsonian Migratory Bird Center in 1996. This meeting inspired the formation of two new certification programs for sustainable or shade coffee.

Smithsonian's Bird Friendly Label

In its efforts to conserve bird habitats for neotropical migratory birds in Latin America, the Smithsonian Migratory Bird Center (SMBC) developed an innovative program to certify coffee as bird-friendly. Initially, the SMBC developed a series of guidelines mostly related to the shade, and teamed up with Cafe Audubon, an ecoorganic coffee company. The rationale was that by adding the SMBC guidelines to already certified organic farms, the ecological integrity of the farms would be ensured. The main problem with this model is that social justice issues are omitted and left to the fair trade labels, resulting in a certification program that is more for birds than for people. The logo and name of Smithsonian bird-friendly coffee make the focus on bird conservation clear (Figure 6.7). Although the association with the Audubon Society was terminated after a few years, the focus is still on bird conservation, and the certification criteria are designed to maintain habitats for birds (http://www.natzoo.si.edu/smbc/Research/Coffee/Thoughtpaper/thoughtpaper.htm).

Rainforest Alliance's Eco-OK Label

The certification program developed by the Rainforest Alliance has broader goals that stretch beyond just coffee. As stated on their web page (http://www.rainforest-alliance.org/index.html), their idea is to integrate all of the criteria mentioned so far — regulating chemical use, shade canopy, overall ecological integrity of the farm and its surroundings, and social justice. The Rainforest Alliance, a nonprofit organization dedicated to the conservation of tropical forests, is not new to the certification business. It developed the first international program for inspecting and certifying tropical woods that come from ecologically managed forests, the Smart Wood® label. It is also responsible for the Eco-OK coffee, bananas, cacao, citrus, and other export crops. Its Better Banana Program best illustrates the Alliance's philosophy about green labels. In this program the Alliance has worked very closely with Chiquita Brands, a large multinational corporation with operations in Latin America. The argument is that in order to save habitat on a large scale, it is necessary to form alliances with large, influential producers as well as small farmers. This philosophy has guided the Eco-OK program in coffee, and the Alliance begun to certify large producers in Central America. The Eco-OK program has certified 3500 ha of coffee in Mesoamerica (27% in El Salvador) and 4355 ha more are waiting to be certified (Belloso, 2001). A major criticism of the Eco-OK label is that in its efforts to expand and work with large producers, the Alliance's standards have become too lenient and only echo already existing practices and laws (McLean, 1997).

There is another major problem with the Rain Forest Alliance's approach that has received little attention. By certifying large coffee producers, who, because of their size, produce large quantities of coffee, they may be saturating an already small niche market for shade coffee. This could have a negative impact on the initiatives that focus on small producers and that have a higher potential for addressing issues of social justice. It also illustrates the danger of banking on the environmental concerns of consumers in the industrialized nations to address social justice issues for small farmers in developing countries. Furthermore, large producers are more prone to respond to economic incentives (i.e., profits) than small producers, who may have many reasons for producing coffee in diverse agroforestry systems, including risk avoidance, tradition, and reliance on other noncoffee products from their plantations. By working with large coffee producers whose primary motivation is profit maximization, the Rainforest Alliance is taking the risk that under conditions of high coffee prices in the international market, the producers will abandon the Eco-OK certification to increase production as fast a possible and take advantage of the favorable prices. It is important to point out that the premium price for Eco-OK certified coffee is not much, and, as with many other certification programs, the percentage of the premium declines with higher prices of the noncertified commodity. The higher the coffee prices in the international market, the less advantageous it will be for a producer to have an Eco-OK or any other green certification.

Striking a Balance between Conservation and Economic Goals

Data currently available do not allow us to say with confidence what levels of shade or what qualitative vegetative structure are the best for maintaining biodiversity in coffee plantations. As shown in Figure 6.4, different organisms may exhibit different patterns of diversity loss along an intensification gradient. Therefore, it is very difficult to propose all-encompassing criteria that would enhance the conservation of all biodiversity. A possible solution to this problem is to certify only the so-called rustic plantations, which have been shown to maintain a high diversity of most taxa studied so far. While this approach may preserve the most biodiversity, plantations with very dense shade canopies may also have very low coffee yield.

There are very few studies that examine the relationship between shade management and coffee yield (Escalante, 1995; Hernández et al., 1997; Muschler, 1997a,b; Soto-Pinto et al., 2000), yet producers' perception is that dense shade significantly reduces yield. Therefore, many producers will not be inclined to seek shade coffee certification unless the price premium is sufficiently high to overcome yield losses, which could discourage consumption in consumer countries. A recent economic analysis of the financial feasibility of investing in the certification criteria for a biodiversity-friendly coffee in El Salvador indicates that investment was financially viable for all types of plantations investigated (including sun or unshaded plantations) (Gobbi, 2000). However, this study also highlights the importance of yield for the financial viability of the investment. Of all types of farms, only the traditional shaded plantation was risk-free, primarily due to no change in yield associated with the certification criteria. The higher risk was obtained for the sun coffee, because the investment for complying with biodiversity-friendly criteria was higher and yields were assumed to be reduced due to an increase in shade cover (Gobbi, 2000), even though the shade cover that is required under the current certification programs is below 50%.

Shade coffee certification programs have emerged primarily from conservation concerns, and this bias is reflected in the certification criteria that have been developed for the different programs (Mas, 1999). However, for these programs to be widely accepted by farmers, they have to incorporate the economic goals of the producers in addition to the broader environmental goals. The success of shade coffee certification programs will depend on the adoption of these programs by coffee producers in Latin America and the willingness of consumers in the North to pay premium prices for environmental services. Certification criteria should thus be based on scientific knowledge regarding the response of biodiversity to vegetative structure as well as realistic assessments of the willingness of farmers to satisfy those criteria. Therefore, it is important for those establishing the criteria to have some information about the interactions between shade, biodiversity, and yield. In Figure 6.8 we illustrate an example of the relationship between percent yield and percent of species richness based on the percent canopy openness and its relationship to yield and species richness. This example is based on the relationship between percentage of shade and species richness illustrated in Figure 6.4 for ants and butterflies in the Soconusco region of Chiapas, and on data from Soto-Pinto et al. (2000) of the relationship between percent shade and yield for coffee farms in the Chilon region of Chiapas. Based on this example, maintaining 80% of the yield (based on the highest yield that can be achieved within a range of canopy openness) results in the maintenance of 33% and 82% of the species richness of butterflies and ants, respectively.

With this approach it would be possible to examine how yield and species richness are related in a particular region. This type of information can guide farmers' management decisions in terms of how much shade to have in their plantations. It could also help certification organizations in setting more realistic criteria for shaded coffee certification.

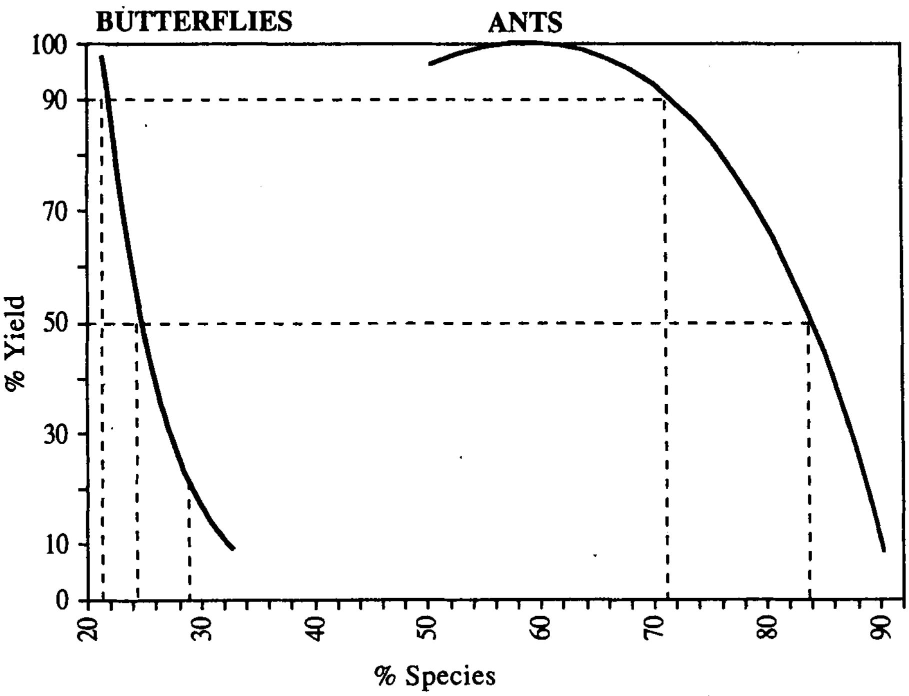

Figure 6.8 Relationship between percent of species of ants and butterflies and percent coffee yield. (Based on data from Figure 6.4 and yield data from Soto-Pinto et al., 2000.)

CONCLUSION

This chapter discussed the economic and ecological importance of the coffee agroecosystem in northern Latin America. As one of the most traded commodities in the world, coffee affects the economic life of hundreds of thousands of farmers and farm workers in northern Latin America. Coffee is grown in countries that have been identified as megadiverse and in regions with high levels of endemism. Furthermore, in countries that have been devastated by deforestation, shade coffee represents one of the few forested habitats left for wildlife. As was shown above, the extensive literature on biodiversity in coffee plantations provides ample evidence that the coffee agroforests are important habitats for biodiversity and that they are particularly critical in midelevation areas where natural forests are highly fragmented. By providing a high-quality matrix, coffee agroforests serve as either permanent or temporary habitat to forest species, or at least as safe passage for species that require closed-canopy forests. Furthermore, some evidence suggests that the high diversity of the coffee agroforests has important ecological functions, especially with regard to pest regulation. The trend toward coffee technification has encouraged a deforestation process, which has resulted in a dramatic loss of biodiversity in the montane landscapes of northern Latin America. Ironically, it has also contributed to an overproduction of coffee, which has depressed prices internationally and inflicted much misery on small producers and workers alike. In 2001, the International Coffee Council (2001) predicted that the coffee crisis will continue and that in the medium term there could be a dismanteling or weakening of the coffee sector in countries that depend heavily on this commodity. Among the many possible devastating consequences of the continuation of this crisis are social and political instability, increased external debt, and increased violence. Ecologically, the consequences of the crisis could be even more devastating than the technification process as producers leave coffee production altogether and establish cattle ranches or annual crops. At this crossroad, a sensible long-term solution to the coffee crisis may be to promote shade-grown coffee with the goal of reducing worldwide overproduction of coffee while simultaneously promoting biodiversity conservation in sensitive tropical and subtropical areas where coffee is produced. Furthermore, linking shade-grown coffee certification programs with the already-established organic and fair trade systems may offer the best solution for sustainable development in the coffee sector. Producers would not only receive the benefits of higher prices for their coffee, but would contribute to lowering global coffee production to better match consumer demand while conserving biodiversity and promoting a truly sustainable export crop in tropical nations.

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