Shaded coffee and the stability of rainforest margins in northern Latin America

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Summary

Most native forests in Latin America are highly fragmented. In the mid elevation areas of Northern Latin America, the agricultural matrix is frequently composed of coffee. In this region, coffee has been traditionally cultivated under the diverse canopy of shade trees, representing a high quality matrix that can contribute to the social and ecological stability of the region. This agroforestry system has been proven to be important for biodiversity conservation. Studies over the last fifteen years have shown that shaded coffee plantations maintain a high diversity of vertebrates, invertebrates and plants. These organisms play an important role in the functioning of coffee agroecosystems. Shaded coffee plantations promote a high abundance and diversity of natural enemies that help to regulate herbivores, weeds and diseases. Shaded plantations also harbor a higher diversity of native pollinators which have been shown to contribute to higher coffee yields. Likewise, the diverse shade-tree component contributes to soil fertility and soil conservation and has been shown to contribute significantly to carbon sequestration. As a matrix, coffee agroforests also contribute to the conservation of biodiversity within

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forest fragments by promoting migration among fragments and facilitating a metapopulation structure. Three "sustainable" coffee certification programs have been developed to help farmers cope with the vagaries of the market: organic, fair-trade and biodiversity-friendly (or shade-grown). Although certified coffees still represent a small niche market, they have the potential to promote conservation and benefit the livelihoods of small producers. Especially under conditions of low international coffee prices, as those experienced in the first years of this century, these certification programs have contributed to the ecological and socio-economic stability of the coffee growing regions of northern Latin America.

Keywords: coffee agroecosystems, Latin America, certification programs, function of biodiversity, intensification

1 Introduction: Coffee agroecosystems and the stability of forest margins: a general framework

Most of the forest in the Neotropics is already highly fragmented. The predominant landscape in these regions consists of small to medium size forest fragments surrounded by a sea of managed systems, the agroecological matrix. The ecological and socio-economic stability of such landscapes depends on how this matrix is managed. A mosaic of diverse cropping and land use systems that are managed for both ecological and socio-economic goals of the local population would prevent the further erosion of the natural areas and would maintain biodiversity at the landscape level. In this chapter we review the role of the coffee agroecosystem in mid elevation regions of Northern Latin America in maintaining both the ecological and socio-economic stability of the region.

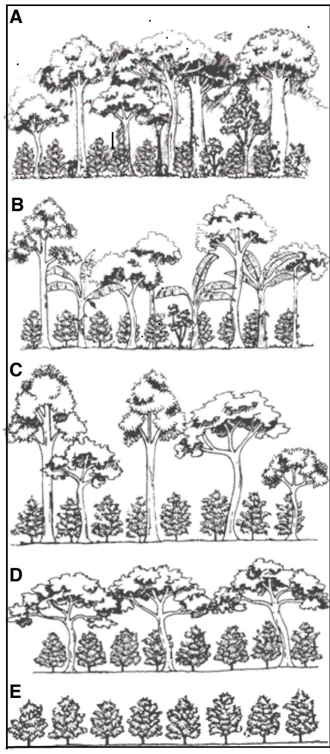
Before we examine the case of coffee in particular it is important to establish a more general framework for the need to integrate the agroecological matrix in conservation strategies. There are 5 reasons for doing so: 1) most tropical habitats in the region are already highly fragmented, 2) extinction rates are high even in large forest fragments, 3) the matrix itself is sometimes an important repository of biodiversity, 4) the matrix provides migration pathways from fragment to fragment, and 5) agriculture is not a permanent activity (Vandermeer et al. in press). With this framework we argue that conservation needs to be refocused, away from preservation areas and towards the matrix in which fragments of native habitat are situated. Vandermeer and colleagues (in press) argue that this is especially so in the light of what we now know about extinction patterns in fragments, metapopulation dynamics, biodiversity patterns in agroecosystems, movement patterns of various organisms, and postagricultural succession. Yet a focus on the matrix means taking part in the debates on the nature of development within the agricultural context, and, more specifically, modifying the paradigm that there is an intrinsic conflict between managed areas and conservation with one that distinguishes between different types of agricultural development and recognizes the critical role of the agricultural matrix in the conservation of biodiversity. The rest of this chapter analyzes these ideas within the context of the coffee landscapes in Northern Latin America. We first present a profile of the coffee agroecosystems in northern Latin America (section 2), then examine the ecological stability of coffee by reviewing the literature of biodiversity in coffee farms (section 3), the function of that biodiversity as it relates to coffee production and sustainability (section 4), and the role of shade coffee as a high quality matrix (section 5). Finally, we discuss how diverse coffee farms can contribute to the social stability of the region (section 6).

2 Coffee in northern Latin America

Coffee agroecosystems are particularly important both ecologically and economically in northern Latin America (Mexico, Central America, the Caribbean, and Colombia). Coffee does not cover as much land area as other agricultural activities – land in coffee production is roughly 3.6 million ha (FAO 2002). However, the ecological importance of coffee is a consequence of where it is produced, rather than how much land is under production. Coffee production greatly overlaps with the world's biodiversity hotspots (Hardner and Rice 2002) and may overlap with key forest habitats containing a large number of endemics (Moguel and Toledo 1999). Generally, coffee is grown on mid-elevation mountain ranges that in northern Latin America have been largely deforested. In El Salvador, for example, more than 90% of original forest cover has been lost, but shade grown coffee (representing 92% of production; Rice and Ward 1996) now accounts for roughly 80% of remaining forested area (Panayotou et al. 1997).

Economically, coffee is also exceedingly important for Latin America. Coffee makes up a large percentage of total agricultural export revenue in countries like Mexico and Peru (Nolasco 1985, Greenberg and Rice, 2000, Calo and Wise 2005). Throughout Latin America, there are large numbers of people producing coffee (Calo and Wise 2005) and several million depend on coffee income (Nolasco 1985). Approximately 95% of Mexican coffee producers (65.5% of total production area) are small producers, most of whom still manage coffee under traditional multi-species canopies and manage less than 5 ha each (Rice and Ward 1996).

Coffee was traditionally grown under a diverse, dense shade canopy, but recent intensification includes reducing shade tree density and diversity and agrochemical use (Figure 1; Moguel and Toledo 1999, Mas and Dietsch 2003). Much of the ecological importance of coffee directly relates to the role of traditional or shaded coffee in providing a high quality agricultural matrix and related ecosystem services not provided by intensive coffee systems. Many studies have measured biodiversity loss across the coffee intensification gra-



	MANAGEMENT SYSTEM	%SHADE* COVER	SHADE TREE* RICHNESS
A	RUSTIC	71-100	> 50
B	TRADITIONAL POLYCULTURE	41-70	21-50
C	COMMERCIAL POLYCULTURE	31-40	6-20
D	SHADED MONOCULTURE	10-30	1-5
E	UNSHADED (SUN) MONOCULTURE	0	0

Modiefied from: Moguel and Toledo 1999; Rain Forest Alliance.

* Figures for percent shade and tree species richness are approximates based on studies cited by Moguel and Toledo, 1999 and our own research (Perfecto et al. 2003).

Fig. 1. Diagram of the different coffee management systems with shade cover and shade tree richness.

dient. Rustic or traditional coffee farms with a high density and diversity of shade trees and high percentages of canopy cover conserve a large number and proportion of forest species (Perfecto et al. 1996, Greenberg et al. 1997, for example) and reduction of different aspects of shade negatively affect species richness (reviewed in Perfecto et al. 1996, Moguel and Toledo 1999, Perfecto and Armbrecht 2003, Donald 2004). Patterns of biodiversity loss strongly depend on the particular taxa studied (Daily et al. 2001, Perfecto et al. 2003), and matrix species composition may differ from native habitats (Rappole et al. 2003), yet most studies corroborate that a high density and diversity of shade trees in coffee plantations help preserve forest species. The conservation benefits of shade coffee are further enhanced by the proximity and connectedness of intact natural habitats (Ricketts 2001, Vandermeer and Carvajal 2001, Perfecto and Vandermeer 2002, Steffan-Dewenter 2002) and may allow for increased migration out of forest patches for resource use (Perfecto and Vandermeer 2002, Armbrecht and Perfecto 2003). Finally, shaded coffee farms are also prized for their contribution to various ecosystem services – functions that also can be negatively affected by intensification.

Coffee intensification, at microeconomic scales, is associated with increased yields and revenues, but also with increased costs for labor, fertilizers, and other on-farm products needed to carry out some of the functions that the missing biodiversity can no longer provide. In a process largely backed by INMECAFE (the National Coffee Federation of Mexico) coffee farmers throughout Mexico transformed their traditional coffee farms to shade monocultures, with drastic effects on biodiversity, and temporary increases in yields – ultimately drastically transforming the landscape (Nestel 1995, Rice 1997). More recently, in Vietnam and Indonesia, national initiatives and a drive for high profits have resulted in the development of large scale intensive coffee production (O'Brien and Kinnaird 2003). One study comparing the productivity and profitability in coffee farms in Costa Rica found that conventional farms produced on average 22% higher yields than did organically-managed farms, leading to overall higher profits (Lyngbæk et al. 2001). Yet, increased chemical inputs into coffee agroecosystems carry well documented costs for biodiversity and habitats bordering intensive agricultural systems (Perfecto et al. 1996). Furthermore, intensive techniques with high associated direct costs may make farmers more financially vulnerable to lower prices.

The economic importance of coffee to Latin Americans has been further demonstrated by recent international price crashes in coffee markets (Calo and Wise 2005). Between 1999 and 2002, coffee prices, determined by the commodities market of the NY stock exchange reached lows of $0.42 /lb (FAO 2002) – the lowest prices in 100 years based in real terms (Perfecto et al. 2005, Calo and Wise 2005). This recent crash, stemming largely from overproduction due to intensification efforts in Latin America and more production in Asia, has resulted in widespread environmental and social disasters (Gresser and Tickell 2002). Reportedly over 300,000 coffee growers in Mexico have abandoned their farms (LaFranchi 2001), and many other farmers have intensified their production further hoping to increase yields, or worse, have converted coffee farms to pastures or illegal crops (Perfecto and Armbrecht 2003). Although some argue that biodiverse farms may buffer against such price swings, those small farmers growing in a manner that protects biodiversity may not have sufficient capital to wait until prices swing back up. Low, but consistent fluctuations in coffee prices do affect smallholders (the majority of producers) more deeply. Thus finding techniques to provide economic and social stability in coffee growing regions will benefit ecological stability as well. If these techniques are not supported, it will enormously impact conservation efforts of any kind in the region.

3 Ecological stability: the coffee agroecosystem as a reservoir of biodiversity

3.1 Vertebrates

Bird use of coffee agroecosystems was an early focus of coffee biodiversity research. Perfecto and colleagues (1996) and others have summarized this early bird work that compared coffee management with high and low levels of shade (Dietsch 2005). Consistently high levels of bird diversity in heavily shaded coffee agroecosystems, comparable in many cases to tropical forests, were a primary motivation behind the movement to certify shade-grown coffee (R. Greenberg, personal communication). Based on their research, the Smithsonian Migratory Bird Center coined the term Bird-friendly^{TM} to name their shade-grown coffee certification program. Their criteria were shown to certify farms with significantly higher diversity of forest-associated birds and butterflies (Mas and Dietsch 2004). Recent work has focused on evaluating bird diversity across a fuller spectrum of management practices to identify the shape of biodiversity loss curves (Dietsch 2003).

While earlier research consistently showed a loss of diversity and abundance for all birds, these new studies are showing a more complex pattern of loss, with some components of the avifauna more sensitive to management intensity than others (Komar and Dominguez 2002, Dietsch 2003, Tejeda-Cruz and Sutherland 2004). In particular, forest-associated resident birds are sensitive to the introduction of even low-intensity coffee management (Dietsch 2003, Tejeda-Cruz and Sutherland 2004). However, a sizeable component of the bird diversity is coffee-associated and only begins to drop at higher levels of intensification (Dietsch 2003). There is also a seasonal component to bird diversity changes with the (northern winter) dry season presenting a significant bottleneck for forest-associated resident birds (Dietsch 2003). During this period, migratory birds are abundant and resource availability may be a serious constraint and may affect resident resource use (Jedlicka et al. 2006).

In farms with relatively low shade tree diversity, species of the genus *Inga* may act as a keystone resource to birds, but as the shade is diversified, other resources become more important. When *Inga* are in flower, they provide resources that help many bird species, especially migrants, persist through the dry winter months (Calvo and Blake 1998, Johnson 2000). The *Inga* flowers produce high quantities of nectar, attracting many insects as well as nectivorous and insectivorous birds (Johnson 2000). However, in a Chiapas farm augmented with native shade tree species, birds made disproportionately greater use of the additional resources provided by the increased tree diversity than in the farm dominated by *Inga* trees (Dietsch 2003). In El Salvador, Komar and Dominguez (2002) found that both structural and floristic habitat components contributed to resident bird diversity and abundance, with thresholds of 44% canopy cover and 15 tree species per 0.5 hectare important for the conservation of species sensitive to perturbation. In addition, shade-coffee farms with epiphytes maintained higher abundance and diversity of the inhabitant bird fauna than farms without epiphytes (Cruz-Angon and Greenberg 2005).

Small mammals including rodents and bats show similar diversity patterns as birds. For example, small mammal diversity was lowest in technified coffee when compared to forest and an organic shaded farm (Witt 2001). Gallinas and colleagues (1996) found that the diversity of medium-sized mammals was related to the vegetative structure of the coffee shade canopy. They recommended the maintenance of high tree diversity to provide food resources and protection for the mammal community. In Guatemala, bat diversity was higher in coffee with diverse shade and may be limited by roost site availability in more intensive coffee management systems (Valle and Calvo 2002). However, in Veracruz, Mexico, Estrada and Coates-Estrada (2001) attributed high bat diversity in both shaded and unshaded coffee systems to the high mobility of bats allowing these mammals to use habitats ephemerally even if roost sites are unavailable in technified areas. In Costa Rica, Daily and colleagues (2003) reported that small forest fragments contiguous with coffeee plantations did not differ from more extensive forests in species richness of non-flying mammals and where richer than other agricultural habitats, demonstrating that the quality of the coffee matrix affects diversity within the forest fragments. Though large mammals are probably limited by hunting pressure, particularly near rural communities, species without hunting pressure can persist and even maintain territories in shaded coffee farms. For example howler monkeys in Nicaragua successfully maintained territories in shade coffee making use of the tree diversity for leaf forage (McCann et al. 2003, Williams-Guillen 2003).

Coffee plantations have been found to be less effective in maintaining the diversity of reptiles and amphibians (Komar and Dominguez 2002, Pineda et al. 2005). It has been suggested that a more open canopy structure may create warmer, drier conditions that adversely affect some species within these taxa. In addition, amphibians are considered to be sensitive to pesticide and herbicide use. In particular, atrazine and glyphosate, regularly used herbicides in coffee, are toxic to amphibians (Hayes 2004, Relyea 2005). Another major hazard for reptiles, especially snakes, in agricultural landscapes is that workers usually kill them regardless of whether they are venomous or not (Dietsch, personal observation).

3.2 Invertebrates

Most studies show that traditional shaded coffee farms harbor a high diversity of invertebrates, and that species richness declines along the intensifiction gradient (for reviews see: Perfecto et al. 1996, Perfecto and Armbrecht 2003, Donald 2004, Somarriba et al. 2004). In Latin America, special attention has been devoted to ants. Of 21 studies covering soil, leaf-litter, arboreal and army ants, 18 show a significant decline in ant species richness with intensification (Table 1). Some studies show comparable values between adjacent forest remnants and coffee agroforests with respect to ant species richness (Perfecto and

Table 1. Studies examining the effect of coffee intensification on ant diversity and interactions

Country	Reference	group/theme	Effect
Colombia	Armbrecht et al. 2005	leaf litter	yes
Colombia	Armbrecht et al. 2004	leaf litter	yes
Colombia	Sadeghian 2000	soil	yes
Colombia	Sossa & Fernández 2000	leaf litter	yes
Colombia	Garcia & Botero 2005	Ponerinae	yes
Costa Rica	Benítez & Perfecto 1990	soil	yes
Costa Rica	Perfecto & Snelling 1995	soil	yes
		coffee plants	no
Costa Rica	Perfecto & Vandermeer 1994	soil	yes
Costa Rica	Barbera et al. 2004	soil	yes
Costa Rica	Perfecto & Vandermeer 1996	competition interactions	yes
Costa Rica	Perfecto et al. 1997	arboreal	yes
Mexico	Philpott et al. 2006	arboreal	yes
Mexico	Armbrecht & Perfecto 2003	soil and leaf litter	yes
Mexico	Perfecto et al. 2003	soil	yes
Mexico	Perfecto & Vandermeer 2002	soil	yes
Mexico	Lachaud & Garcia-Ballinas 1999	Ponerinae/Cerapachinae	yes
Mexico	Ibarra-Nuñez et al. 1995	coffee plants	yes
Mexico	Nestel & Dickschen 1990	foraging dynamics	yes
Mexico	Ramos-Suárez et al. 2002	soil	no
Panama	Roberts et al. 2000	army ants	yes
Puerto Rico	Torres 1984	soil	no

Vandermeer 2002, Ramos-Suárez et al. 2002, Perfecto et al. 2003). Identified mechanisms responsible for the reduction of ant species richness include loss of nesting sites (Philpott and Foster 2005), reduction in the leaf-litter complexity (Armbrecht et al. 2005), microclimatic changes (Perfecto and Vandermeer 1996), changes in ant competitive hierarchies (Perfecto 1994), and an enigmatic preference for diversity (Armbrecht et al. 2004).

Coffee agroforests have been found to maintain high diversity of other athropods such as beetles (Moron and López-Méndez 1985, Nestel et al. 1993, Perfecto et al. 1997, Estrada et al. 1998, Molina 2000, Pineda et al. 2005), butterflies (Botero and Baker 2002, Mas and Dietsch 2003, 2004, Valencia 2004, Krantz 2005), homopterans (Rojas et al. 2001, Franco et al. 2003), spiders (Ibarra-Núñez and García-Ballinas 1998), and non-formicid hymenopterans (Hanson 1991, Monro and Gauld 2002, Klein et al. 2002, Tylianakis et al. 2004). Although most studies do show a significant decline in arthropod species richness with the intensification of coffee, a few studies failed to show differences (for example, Ricketts et al. 2001, Klein et al 2002, Ramos-Suárez et al. 2002). The failure to detect a significant effect due to intensification could be due to landscape level features (Tscharntke et al. 2005), or could suggest that some organisms may even benefit from the more open habitats related to agricultural production (Klein et al. 2002). Several studies have found that closeness to the forest positively influenced arthropod richness within the coffee farms (Ricketts et al. 2001, Perfecto and Vandermeer 2002, Klein et al. 2003c, Armbrecht and Perfecto 2003, Horner-Devine et al. 2003, Ricketts 2004, DeMarco and Monteiro Coelho 2004, Krants 2005). Furthermore, different arthropod taxa or different guilds within a taxon show varying patterns of richness loss along the intensification gradient (Perfecto et al. 2003, Schulze et al. 2004, Pineda et al. 2005, Rivera and Armbrecht 2005, Armbrecht et al. in press) possibly due to different mechanisms such as spatial scale, landscape features, dispersion of the organism, or degree of diet specialization.

3.3 Plants

Ironically, although most of the biodiversity benefits of shade coffee are attributed to their high floristic diversity, which provides habitat to a variety of other organisms, very few studies have focused on plant diversity *per se*. Some researchers have compared woody-plant diversity among different types of coffee plantations and natural forest and have found similar species richness and structure (Reynoso 2004, Bandeira et al. 2005, Cruz-Lara et al. 2004). However, not all shaded coffee is the same. For example, rustic plantations are more like natural forest than traditional polycultures, which are dominated by one or two genera (Figure 1, Table 2). In Chiapas, Mexico, at least 40% of the species recorded in coffee plantations corresponded to the natural surrounding vegetation: tropical forest, pine-oak forest and cloud forest; the last of which is itself in a threatened status (Soto-Pinto et al. 2001). 224 plant species and 53 families, among trees, shrubs and palms were recorded from coffee shade in several studies in Chiapas. 97% of the total were native, most belonging to the Fabaceae (16.4%), Asteraceae (7.1%), Lauraceae (7.5%), Euphorbiaceae (4.5%), Tiliaceae (3.6%) and Moraceae (3.6%). Floristic composition and management intensity make a difference in terms of the potential for biodiversity conservation. The more complex the structure, given by tree height and diameter and canopy cover, the greater the potential for diversity conservation. Rustic coffee farms seem to present the best characteristics for conservation, followed by traditional polycultures (Figure 1, Table 2). Bandeira and colleagues (2005) studied 100 coffee stands in Oaxaca, Mexico. They stated that many of these coffee stands harbor as many as 34 species of wild trees. The floristic structure of rustic coffee farms was highly variable, given by a combination of factors such as human management, original stand cover and the asynchrony in development stage of different farms, promoting a large beta-diversity at the landscape level. Similar results have been reported by Méndez (in press), and Monro (2002) reported 200 tree species for coffee farms in El Salvador. Thus, although a single plantation may have a limited potential to preserve native tree species, it is the whole ensemble of floristically heterogeneous farms which renders this agroforestry system valuable

Table 2. Comparison of vegetation structure variables, woody-species richness and soil attributes between traditional polyculture coffee plantations, rustic coffee plantations and natural forest.

Variables	Traditional Polyculture Coffee Plantation	Rustic Coffee Plantations	Natural Forest (Tropical forest)
Number of vegetation strata	2b (Jitotol, Sepultura)	3-4a (Jitotol, Sepultura)	More than 4 (Sepultura)
Vegetation cover (%)	49.7c (Sepultura)	80.7b (El Triunfo)	93.1a(El Triunfo)
		87.5 (Lacandona)	94.7 (Lacandona)
		68.4b(Sepultura)	91.2a (Sepultura)
	77a (Jitotol)	71b (pine/oak Jitotol)	
Tree height (m)	11a (Chilon & El Triunfo)	11a (Chilón)	12a (El Triunfo)
Tree diameter (cm)	27a (Jitotol)	24a (Jitotol)	
		18.7a (El Triunfo)	21.1a (El Triunfo)
Litter thickness (cm)	3.2a (Jitotol)	2.2b (Jitotol)	N.D.
Total aboveground biomass (ton/ha)	42b (Jitotol)	93.8a (Jitotol)	
Tree & shrub density	176 (Jitotol)	336b (El Trinfo)	887a (El Triunfo)
(individuals/ha)	282b (Jitotol)	316a (Jitotol)	
		463 (Chilón)	
		457 (Jitotol)	
Trees & shrub species	33/2700m^2 (Jitotol)	46/2700m^{2}b (Jitotol)	
richness (species/m^2)		21/1310m^2 (Lacandona)	39/1310m^2 (Lacandona)
		10/1000m^{2}b (El Triunfo)	30/1000m^{2}a (El Triunfo)
		18/1000m^2 (Chilón)	
		45/1000m^2 Oaxaca	35/1000m^2 Oaxaca
Organic matter	5.2a (Chilón)	5.3 a(Chilón)	6.06a (El Triunfo)
Phosphorous	5.5a (Chilón)	4b (Chilón)	3.2b (El Triunfo)
Ph	5.6 (Chilón)	5.7 (Chilón)	6 (El Triunfo)
Nitrogen	0.33a (Chilón)	0.33 a(Chilón)	0.21b (El Triunfo)
CIC	22.3a (Chilón)	35.4b (Chilón)	21.4a (El Triunfo)
Shannon diversity index	1.9307b (El Triunfo)	N.D.	3.0433b (El Triunfo)

A T-test was used to test for differences between two habitat types; a one-way ANOVA followed by Duncan's Multiple Range test was used to test for differences between three habitat types. Different letters between columns for the same locality mean significant difference at $p<0.05$.

Source: Soto-Pinto et al. 2000, Ramos-Suárez et al. 2002, Peeters et al. 2003, Cruz-Lara et al. 2004, Reynoso 2004, Bandeira et al. 2005.

for plant diversity conservation, particularly in a region where native forest vegetation has almost disappeared.

Studies on vascular epiphytes in coffee farms have reported a high species richness (Solís-Montero et al. 2005, Hietz 2005). Hietz (2005) reported 89 and 104 vascular epiphyte species in coffee and natural forest, respectively. This author stated that farms with small trees and sparse shade hosted fewer epiphytes than those with large trees, and pointed out the value of traditional polycultures for epiphyte diversity. However, Hietz (2005) also suggested that traditional polycultures may not be suitable for all epiphytes. In Veracruz, Mexico, Solís-Montero and colleagues (2005) reported high population densities (800 plants/ha) of three orchid species, pointing out that coffee farms may not replace the original conditions of a forest, but it is possible that orchids may survive and reproduce in farms that provide appropriate microclimate conditions for the orchids and their pollinators.

Finally, it is important to remember that agriculture is not a permanent activity (Kaimowitz 1996, Aide and Grau 2004) and that the regeneration of secondary and eventually mature forest is affected by the type of agriculture that is practice (Ferguson et al. 2003). In this respect, agroforestry systems and traditional shaded farms have been shown to play an important role in the regeneration of tropical forests in Nicaragua (Griffith 2000), El Salvador (Hecht et al. 2002) and Puerto Rico (Brasch 1987, Nir 1988).

4 Ecological stability: the function of biodiversity in the coffee agroecosystem

For more than a decade, studies addressing agricultural intensification in general (Tscharntke et al. 2005) and the intensification of coffee plantations in particular (Perfecto and Armbrecht 2003) have noted the loss of important ecosystem services and ecosystem functions as a consequence of reduced biodiversity. However, with a few exceptions, the role of biodiversity in maintaining ecosystem services and function have not been rigorously examined. Shaded coffee farms conserve plants, arthropods and vertebrates that have been shown to carry out important ecological functions such as nitrogen fixation, carbon sequestration, pest regulation, pollination and seed dispersal (Witt 2001, Klein et al. 2002, Callo-Concha et al. 2004, Perfecto et al. 2004, Ricketts et al. 2004). In the following section we summarize these studies and reflect on their influence with regard to the stability of tropical forest margins.

4.1 Pest regulation

Pest regulation depends both on bottom-up and top-down ecological forces (e.g. Dyer and Letourneau 1999). In the first case, agroforestry systems should rely mostly on a strategy of increased resilience - and other internal control mechanisms through enhancing diversity, but this does not automatically guarantee pest control (Rao et al. 2000). Top-down regulation in diverse traditional shaded coffee farms relies partly on the “natural enemies hypothesis” (Root 1973, Andow 1991) in which more resources provided by the complex vegetation structure leads to a higher abundance and richness of natural enemies of herbivores. Some ecological functions from natural enemies include parasitization, predation or deterrence of herbivores, all of which form part of complex food webs in traditional polyculture shaded coffee plantations (Philpott et al. 2004) and have proven to be an insurance preventing pest outbreaks (Perfecto et al. 2004). Langellotto and Denno’s meta-analysis (2004) showed that increasing habitat complexity leads to increases of invertebrate natural enemy abundances. This is consistent with studies in complex shaded coffee farms (Vandermeer et al. 2003), where trait mediated effects by parasitic influence, competitive interactions among arboreal ant predators (Philpott 2005), or predation by birds is affected by dominant ant species in trees (Philpott et al. 2005).

The most important coffee pest in LatinAmerica, the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolitidae), was found to be predated by ants at a significantly higher rate in shaded coffee than in sun coffee plantations of Colombia (Gallego and Armbrecht in press). Vélez and colleagues (2003) also found that *Gnamptogenys* pos. *sulcata*, an ant abundant in forests and shaded coffee but very rare or completely absent in sun coffee, is a very effective predator on adult berry borers. Other results from Costa Rica tested predation by three ant species (two of them abundant in open habitats) without any significant decrease in the berry borer in field trials (Varón 2002). Both, the intensification of coffee management and dry season negatively affected important ant forager predators in Mexico (Philpott et al. 2006a) and Colombia (Armbrecht 2003).

Another way to examine the potential effect of diversity on pest regulation is the insurance hypothesis (Yachi and Loreau 1999, Loreau et al. 2003), the idea that diversity protects functional properties of communities in the face of environmental perturbation. Perfecto and colleagues (2004) provided a test of the insurance hypothesis by examining insect predation by birds in coffee farms with different levels of floristic diversity. They simulated an outbreak of lepidopteran larvae on coffee plants and noted the larval disappearance rates inside and outside bird exclosures in two farms with distinct levels of shade. Significant differences were found associated with the exclosure treatment, indicating that birds can potentially prevent pest outbreaks. Interestingly, the effect was significant only for the farm with a high floristic diversity, providing partial evidence in support of the insurance hypothesis. Similarly, Soto-Pinto and colleagues (2002) found that the higher the number of vegetation strata, the lesser the incidence of coffee leaf rust (*Hemileia vastatrix*), suggesting that vegetation structure in coffee farms conditions the ecological relationships related to this important disease. These authors also noted that the higher the shade species richness the lesser the weed cover, suggesting that species richness promotes a larger number of habitats for herbivores and other weed-controlling organisms.

Given these results, increasing diversity in agroecosystems has been proposed as a prophylactic strategy for pest control. Yet almost a third of reported studies in a recent review do not support the hypothesis that there is greater pest control in diversified agroforestry systems (Schroth et al. 2000). Some of the possible mechanisms mentioned include introducing plant species that harbor pests, changes in microclimate which benefit pest and diseases, and the physical protection of mammal and bird pests offered by trees (Schroth et al. 2000, Muriel and Vélez 2004). Therefore, this strategy should be promoted only in those cases where its effectiveness has been firmly established (Vandermeer and Perfecto 2000).

4.2 Pollination

Another ecosystem service affected by declines in arthropod diversity and abundance with intensification is coffee pollination. Although much discussion in the pollination biology literature debates the relative role of pollinator biomass versus diversity (Balvanera et al. 2001), several recent studies indicate that both are important for coffee pollination. Arabica coffee is a self-compatible species that does not require outcross pollination, but may nevertheless benefit from pollinator presence. High numbers of visits of honeybees (*Apis mellifera*) correlate to increased coffee fruit set and fruit weight (Raw and Free 1977, Manrique and Thimann 2002, Roubik 2002). This brings up an interesting conservation dilemma since *A. mellifera* is an introduced, and partly invasive, species in Latin America. There is an ongoing debate as to how dangerous this bee is for native (competitively inferior) bee species. So any advantages that can only be achieved at the cost of having this non-native species in the system are debatable. On the other hand, a study in coffee agroforests in Indonesia demostrated an increase in fruit set of *Coffea arabica* with the number of flower visiting bee species (Klein et al. 2003b). Furthermore, this and other studies have shown the importance of a diverse suite of pollinators, including both social and solitary bees, for pollination (Klein et al. 2003a) and pollen deposition (Ricketts 2004). Two recent studies in Brazil (DeMarco and Monteiro Coelho 2004) and Costa Rica (Ricketts et al. 2004) calculated that for coffee plants located near forest fragments, native bees increased yields by more than 14% and 20% respectively. Ricketts estimated that this represents a total dollar value of $62,000 for the farm studied in Costa Rica (Ricketts et al. 2004). This represents substantial benefits to farmers and highlights the importance of maintaining forest fragments within coffee landscapes, even if small. Finally, another study has documented that under high shade management, where activity of pollinators (including ants) is greater, the presence of ants, or some interaction between ants and flying pollinators affords higher fruit weights than under low shade conditions

(Philpott et al. 2006b). Although some researchers have found no effects of pollinators on coffee pollination (Nogueira-Neto et al. 1959), more recent evidence clearly indicates that in fact both diversity and abundance of bees, and potentially other pollinators, do increase yields, weights, and quality of coffee.

4.3 Vegetation structure, diversity and ecological functions

Some studies have emphasized the role of trees as "host" and food source for other organisms. Carlo and colleagues (2004) recorded bird species foraging on fruit trees in coffee plantations and natural forests. In their study, fruits comprised more than 50% of the diets for four focal bird species. They also reported differences in the number of foraging records for focal bird species between the commercial polyculture and forest habitats but few differences between rustic coffee and forests. In their study, the genera *Cecropia, Miconia, Schefflera, Phoradendron*, and *Guarea* were reported as the most important, providing birds with a fairly constant fruit supply. Other species such as *Brosimum alicastrum* have also been shown to be important food resources for frugivorous birds, deer and wild boar. As mentioned above *Inga* flowers offer an important resource for insectivorous and nectivorous birds in the winter months (Calvo and Blake 1998, Johnson 2000).

Other studies have shown the ecological function of the tree species most commonly planted with coffee. For instance *Ochroma pyramidale*, *Alchornea latifolia*, *Simarouba glauca* and *Theobroma cacao* are useful for soil conservation, erosion control and restoration of degraded soils (Vázquez-Yanez et al. 1999). Most legume species increase ecosystem–level nitrogen availability through nitrogen fixation, while other species, like *Trema micrantha* have been shown to have abundant mycorrhizal associations thus enhancing nutrient uptake (Dalla Rosa 1993).

Comparing coffee farms dominated by *Inga* species with rustic coffee Peeters and colleagues (2003) reported a significantly higher tree biomass in rustic coffee (Table 2). Similarly, Soto-Pinto (2001) and Soto-Pinto and colleagues (2000) found that soil cation exchange capacity, soil K and soil Ca were higher in rustic farms as compared to *Inga* dominated systems and that in rustic farms shade-species richness was positively correlated with soil Ca and soil cation exchange capacity. Overall, these studies suggest that maintaining diversity and managing shade cover (to around 45%) might be a good way of maintaining yields and balancing the relationships between soil nutrients, nutrient uptake, yields and floristic diversity.

4.4 Carbon sequestration

Recently the role of coffee agroforests in carbon sequestration has been recognized (De Jong et al. 1995, 1997). Coffee agroforests accumulate a high amount of aboveground biomass. Results from research in Chiapas (Peeters et al. 2003) showed 42 and 138 tonnes $ha^{-1}$of aboveground biomass contained in shade vegetation in polyculture coffee and rustic coffee systems respectively (coffee shrubs, soils, litter and roots not included). Callo-Concha and colleagues (2004) estimated 195.6 ton ha^{-1}for coffee with shade, similar to the amount found in homegardens. These data reveal that rustic coffee systems accumulate a significant amount of carbon, equivalent to 1/3 of the amount sequestered by primary forest (307 ton ha^{-1}, Rice and Greenberg 2000; 465.8 ton ha^{-1},Callo-Concha et al. 2004). Additionally, soils contain 6.8% of organic matter in these agroecosystems (Romero-Alvarado et al. 2002, Soto Pinto et al. 2001). Callo-Concha and colleagues (2004) reported that soil retained in coffee with shade, homegardens, silvopastoral systems and pastures represents more than 50% of total carbon. Agroforestry coffee systems may increase carbon sequestration by incorporating more trees, increasing density from 229 trees ha^{-1} to 393 trees ha^{-1}, which is the average density in rustic coffee plantations. According to Soto-Pinto and colleagues (2000) this increase in tree density does not affect yields as long as cover is managed at around 45%.

4.5 Floristic diversity and farmers perceptions of their function

An important source of knowledge about the effect of species diversity on ecosystem function comes from farmers who frequently manage floristic diversity for specific purposes related to the productivity, stability or sustainability of the agroecosystem (Méndez in press). In Chiapas, Mexico, farmers classified trees based primarily on tree morphology and functional attributes such as nurse characteristics, micro-climate modification, leaf litter production and decomposition rate and pest, disease and weed control. Pioneers, such as *Heliocarpus* aff. *popayensis*, *Callicarpa acuminata*, *Lippia myriocepahala, Liabum glabrum, Vernonia* spp. and *Croton* spp., were retained by farmers because of their nurse features (Soto-Pinto et al. in press). Farmers also mentioned that trees increase organic matter and therefore fertilise the soil, which is consistent with other research on farmer knowledge about tree-crop interactions (Thapa et al. 1995, Grossman 2003, Albertin and Nair 2004, Joshi et al. 2004). The role of trees in either encouraging or controlling pests, diseases and weeds was another feature perceived by farmers in Chiapas, as has also been reported from Nicaragua (Staver et al. 2001). According to farmer's knowledge in Chiapas, some trees "control weeds", while others "call for spiders and ants". In El Salvador and Nicaragua, coffee farmers that maintain tree diversity in their farms see themselves as contributing to environmental services, such as soil and water conservation, as well as providing habitat for birds and other animals (Méndez et al. 2002, Méndez and Bacon 2005).

5 Ecological stability: shade coffee as a high quality matrix

As previously discussed, biodiversity conservation efforts benefit from the habitat provided by shade coffee management. However, habitat quality is only one variable in determining the biodiversity found at a particular location. Landscape context and configuration are also important (Perfecto and Vandermeer 2002, Armbrecht and Perfecto 2003, Tscharntke and Brandl 2004). The diversification of habitat structure seems to encourage use of agricultural habitats by a wide range of bird species (Mellink 1991). However, this habitat use is further enhanced by the proximity and connectedness of intact natural habitats. Estrada and colleagues (1997) studied anthropogenic landscapes in Los Tuxtlas, Mexico and found higher avian diversity in arboreal agricultural habitats (coffee, cacao, and other tree crops) than non-arboreal (corn, hot peppers, and bananas) with isolating distance and disturbance regime as important variables affecting species richness. Agricultural islands and live fencerows were important elements that reduce physical and biotic isolation among remaining forest fragments. Comparing Brazilian cacao agricultural landscapes with high and low forest cover, Faria and colleagues (2006) found that cacao agroforests (*cabrucas*) contained a bird diversity similar to that in nearby forests, but that in the heavily deforested landscape context the proportion of forest-associated bird species was lower. Similarly, Petit and colleagues (1999) suggest that proximity of extensive forest and presence of riparian vegetation may enhance plantation habitat value for many forest-associated bird species in Panama. While the landscape context determines which species may use an agricultural habitat, habitat features determine the permeability of agricultural landscapes to forest associated biodiversity.

Permeability refers to how “hard” or “soft” a habitat edge or boundary is for organisms moving from one habitat to another (Stamps et al. 1987). The change in habitat at a boundary affects the movement behavior of individual species differently depending on variables such as available foraging habitat and perceived predation risk. In general, there is an assumption that the more similar the vegetation in an adjacent habitat, the “softer” the edge – in other words, the more willing an individual will be to cross the boundary. In Mexico, Witt (2001) found that small mammals were more willing to forage for and to transport seeds across the boundary between a forest and coffee grown under diverse shade than the boundary between the same forest and coffee grown under a simplified and heavily managed shade monoculture. Different taxa can have differential permeability into the same habitat. For example, native and “Africanized” bees traveled different distances from forest fragments containing their hives into an intensive Costa Rican coffee plantation. There were high levels of native bee diversity visiting coffee flowers only near forest edges (~50 m) while “Africanized” honeybees were able to enhance pollination at intermediate distances up to 800 m (Ricketts 2004).

Willingness to move between patches and to use agriculture may vary depending on the type of agriculture at the edge (i.e., the sharpness or fuzziness of the edge) with greater use by forest-associated birds at lower contrast edges (Kirk et al. 1996). Certification efforts to raise the quality of the agricultural matrix (i.e., increased density and diversity of shade trees) may help in decreasing the sharpness of the edge. Furthermore, at the landscape level, as more farmers adopt certification methods, increases in matrix habitat quality may show threshold effects by improving overall connectivity and reducing fragmentation. Forest-associated species may then be less constrained by dispersal abilities and distance from source populations in reserves.

Another characteristic of boundaries affected by the sharpness of the habitat change across the boundary is referred to as edge effect. The environmental characteristics found at distinct habitat boundaries, for example increased ambient light, exposure to wind, and lower humidity at the interface between sun coffee and primary forest, can dramatically increase gap formation and alter the structure and diversity of vegetation found at the edge. In tropical forests, this edge effect can penetrate 200 m into tropical forests, effectively reducing the acreage of primary forest habitat (Laurance 1991, Kapos et al. 1997). The use of less intensive agricultural practices, such as shade coffee, along habitat boundaries and in buffer zones can ameliorate the environmental characteristics that produce this edge effect. Reducing edge effect effectively increases the size of the remaining forest habitat.

Shade coffee management may produce high quality habitat for buffer zones around tropical forest reserves and biological corridors between reserves (Dietsch 2005). This intervening habitat between intact forest patches is often referred to as the matrix and is part of the generalized landscape mosaic, composed of farms and other land-uses with varying degrees of habitat quality. This is particularly true in agricultural landscapes where each farmer makes management decisions more or less independently. Similar to the permeability of boundaries, the composition and configuration of this agricultural patchwork determines how readily and far forest-associated biodiversity will move into the mosaic.

Observed species loss with increased intensification raises questions about the mechanisms that underlie the loss of forest-associated biodiversity as coffee agriculture is intensified. Habitat selection theory suggests that abundance for many species is linked to factors associated with vegetative structure (i.e., appropriate nest-site, food, and other resource availability, Cody 1985). Nonetheless, caution should be used when using census data to demonstrate conservation benefits (Van Horne 1983). Source-sink dynamics, a special case of metapopulation theory, suggest that in lower quality habitat patches, populations can be maintained by the influx of individuals from source populations (Hanski 1999, Robinson et al. 1995). Though this may mask species loss near habitat fragments, proximity or connectedness to higher quality habitat can facilitate movement between suitable patches (Noss 1983, Noss and Harris 1986). Theoretically, this increased connectivity is the basis for focusing some conservation attention on the matrix. In metapopulation models, a higher quality matrix that facilitates movement between populations generally buffers against extinctions but in some circumstances the outcome is less predictable (Vandermeer and Carvajal 2001).

As a matrix between forest patches, coffee agroecosystems can also provide a range of habitat benefits for forest-associated biodiversity (from Dietsch 2005):

- *Improved Connectivity* – Forage and cover allow for movement of species through the matrix that would otherwise be isolated.
- *Temporary Resources* – Individuals leave their preferred habitat for short-term forays to make use of available resources (daily or seasonal migration).
- *Temporary Refuge* – Allows some reproduction (perhaps very low and the benefit is reproductive experience) for individuals which would prefer to breed in higher quality habitats but are excluded by members of their own species or prevented from reaching those areas (by dispersal barriers). When able, adults (or the next generation) move to higher quality territories and younger individuals replace them.
- *Permanent Residents* – Individuals breed successfully and may hold high quality territories. Adults remain on the territories; young disperse because the habitat is saturated (i.e., when there are no available territories).

In general, specific data are needed to assess whether coffee agroecosystems represent viable habitats for forest biodiversity or transitory habitats providing short-term resources or dispersal corridors.

It is important to note that not all taxa are constrained by the quality of the matrix, particularly groups with high mobility. In Costa Rica, Rickets and colleagues (2001) found that moth diversity formed "halos" of relatively high species richness and abundance extending over 1 km around forest patches irrespective of the land management. Yet other studies have shown distinct losses of moth diversity and species composition on far smaller spatial scales around natural tropical forest remnants (Beck et al. 2002, Fiedler et al. this volume). In open agricultural habitats of Costa Rica, Daily and colleagues (2001) found no correlation between distance from large fragments and bird species richness or abundance, though a significant portion of the avian diversity were restricted to forest fragments. This may be due to a significant proportion of the avifauna that seem to readily use and even prefer the dense shrub habitat produced by coffee management (Dietsch 2003, Lindell et al. 2004).

While matrix habitat is generally viewed as less desirable and only of temporary value for conservation, this is more the case for mobile organisms. For some less mobile taxonomic groups, less intensively managed coffee agroecosystems may be utilized as suitable habitat or may require several generations of residence time within the matrix before gene flow or population connectivity can occur between habitat fragments. For many ant taxa, dispersal only occurs during the winged reproductive period, after mating the queen removes her wings and builds a nest. Consequently successful dispersal across managed landscapes may require several colonies within intervening habitat of adequate quality to ensure success (Perfecto and Vandermeer 2002). Epiphytes and other plants face similar obstacles. Similarly, in more degraded landscapes, shade coffee farms can act as a refuge for biodiversity, providing forest-like habitat where none is available. For example, shade coffee may have provided refuge habitat for birds and orchids in Puerto Rico when much of the island was deforested (Brash 1987, Nir 1988).

In coffee landscapes, farm or patch size (i.e., grain or resolution) of the landscape mosaic is another important consideration affecting matrix quality (Forman 1995). Coffee farm size varies greatly by region. In Chiapas, Mexico, producers holding 5 ha or less account for 91% of the coffee growers in the state and control around 61% of the coffee land area (Rice 1997). Nonetheless, large farms are common and generally 300 ha in size with some family holdings over 1000 ha managed contiguously (Dietsch, personal observation). Though some large farms are managed to maintain high levels of diverse shade, the management is still relatively uniform across the entire farm. In contrast, small farmer landscapes form a patchwork of differing management systems with hedgerows or boundary vegetation to demarcate farms. In at least one study, heterogeneous small farmer landscapes have higher levels of bird diversity than homogenous large farmer landscapes (Dietsch, unpublished data). This may be due to the added habitat value from boundary vegetation or a greater accumulation of shade tree diversity as individual small farmers make different management choices for the shade canopy.

At the landscape level, there are many confounding effects that must be considered when comparing farms or management systems. More research is needed to identify and quantify conservation value from landscape features in coffee areas. In particular, care must be taken to distinguish conservation benefits that derive from vegetation management practices from those that result from the landscape context of the farm (Mas and Dietsch 2004). In addition, the role of habitat heterogeneity within agricultural landscapes needs more attention. Both the landscape context and quality of the matrix contribute to the conervation value of coffee agriculture. With most mid-altitude forests in northern Latin America already converted to coffee, understanding the role of small reserves and forest fragments in contributing to landscape diversity will be an important part of establishing a conservation baseline (Schelhas and Greenberg 1996). This baseline can be connected with studies aiming to understand how sensitive taxa and species select and use habitat. In particular, knowledge of survival and reproductive rates under different management practices will be necessary to understand the population ecology of species in managed landscapes. Apparently poor habitat may provide some population benefits (Foppen et al. 2000, Murphy 2001). Thus, metapopulation dynamics should be evaluated at the landscape level and combine fecundity and mortality estimates to predict patch persistence. Though shade-grown coffee may benefit species that prefer closed canopy forests, there may be conservation trade-offs with those that prefer more open habitats. More research is needed to identify how management activities affect each species and identify characteristics associated with those adversely affected. This will involve an assessment of species benefits (resources) and hazards (predators and disease) within management systems and the surrounding landscape.

6 Socio-economic stability

6.1 Coffee certification programs

One area that may contribute to ecological and socio-economic stability for coffee-growing regions is sustainable coffee certification. Generally, sustainable certification programs attempt to promote ecologically sustainable use of traditional coffee agroecosystems and promote social justice for coffee farmers. The established programs currently fall into three distinct categories: organic, fair-trade, and biodiversity friendly (shade-grown).

Organic certification generally addresses the adverse effects of agrochemical use with the broad goal to certify intercropping and alternative agrochemical-free practices that maintain soil fertility and control pests (Vandermeer 1995). All organic certification programs must comply with international standards maintained by the International Federation of Organic Agriculture Movements (IFOAM). The history of organic certification for coffee farms originated with Finca Irlanda in Chiapas, Mexico. Today, Mexico remains one of the largest suppliers of organic coffee worldwide. Higher prices and good international consumer recognition facilitate the spread of organically certified coffees, though certification costs are still a barrier for many farmers (Dudley et al. 1997, Gobbi 2000). National certification initiatives in producer countries (i.e. Certimex in Mexico) may, however, help to reduce costs at the producer level (Giovannucci 2003).

Fair-trade certification focuses on small coffee farmers. Under fair-trade programs, farmers belonging to smallholder cooperatives are guaranteed a minimum price (US$1.26/lb and US$1.41/lb for organic coffee or at least US$0.05/lb above market prices in 2004), receive financing aid from buyers, and are expected to use some added income towards social goals or improving cooperative infrastructure. Until 2004, farmers did not pay fees to be certified, but now cooperatives pay between roughly US$2500-3500 initially and US$650 per year to renew their fair-trade status. Additionally, they are charged about US$0.02/kg of fair-trade coffee exported (http://www.fairtrade.net). The fair-trade movement traces its history to the creation in 1988 of Max Havelaar in the Netherlands. Since then, fair-trade expanded into other European countries, the US and Canada. All fair-trade certification falls under the Fair Trade Labeling Organizations International (FLO) based in Germany. FLO coordinates certification and standards, but national initiatives are responsible for marketing fair-trade in country. Although fair-trade does not require organic certification, FLO encourages farmers to use integrated crop management techniques and a large proportion of cooperatives with fair-trade certification have organic certification. In some regions, such as Chiapas, Mexico, farmer organizations report that FLO inspectors require organic certification before allowing fair-trade certification (S. Philpott, personal observation, 2004).

Biodiversity friendly coffee certification (known also as eco-friendly, shade-grown, or Bird-friendly™) is the newest and least regulated of the three certifications. At the international level, shade-grown coffee is certified by two programs, the Smithsonian Migratory Bird Center Bird-Friendly™ and Rainforest Alliance Certified (formerly Eco-OK). Bird-Friendly™ criteria are generally acknowledged as more stringent, and more difficult for farmers to meet (Philpott and Dietsch 2003, Mas and Dietsch 2004). Biodiversity friendly certification is based on the concept that complex vegetative structure and diversity protect associated biodiversity and thus certification criteria relate to characteristics such as shade cover, tree diversity, density, and height, species composition and distribution, and maintenance of epiphytes. An important distinction between the two programs is that Bird-Friendly™ requires that farms also be organically certified. Rainforest Alliance Certified, although promoting soil conservation and integrated pest management techniques, does not require organic certification. Costs for biodiversity friendly certification are used to pay travel and per-diem expenses for inspectors. Both SMBC and Rainforest Alliance try to minimize costs by using local certification agencies.

When the international price of coffee is below susbsistance level, many small farmers are forced out of the market or decide to sell their land or plant other crops that may not be as environmentally friendly as shade coffee. During this last coffee crisis many coffee areas in Colombia were transformed into cattle pasture or were bought by large producers who intensified the coffee in order to increase their production. Given this, certification programs that offer a premium price may contribute to the ecological and social stability of coffee growing regions.

6.2 Biodiversity, shade, and yield

The basic complaint that farmers state regarding biodiversity friendly certification is based on the conventional wisdom that as vegetation cover and complexity increases, yield and thus profits will decline. A growing number of studies have investigated the relationships between shade and yield finding either that 1) yields increase with shade removal, 2) yields do not differ in moderately shaded and sun plantations, or 3) maximum yields are found from approximately 35-65% shade cover, and are lower with either lower or higher cover (Soto-Pinto et al. 2000, Staver et al. 2001). Yet more indirect tests of this relationship show that high levels of shade is associated with increased bee diversity and increased fruit set (i.e. yield) (Klein et al. 2003a,b) and that increased shade levels reduce leaf rust infection and weed growth (Soto-Pinto et al. 2002). These increases in ecosystem services in turn directly relate to increased yields and/or profits. Thus some scientific and economic evidence indicates that biodiverse farms may be financially preferable due to 1) alternative products harvested, 2) price premiums for organic and / or biodiversity friendly certified coffee, and 3) complex (and not necessarily negative) relationships between shade, yield, and net incomes.

Shaded coffee farms offer additional income to farmers from timber and non-timber products made available from the shade trees (Somarriba et al. 2004). In Peru, shade tree products may account for about 30% of revenues – especially fruits and firewood rather than timber (R. Rice, unpublished data 2002). Escalante and colleagues (1987) found that fruits from the shade canopy accounted for 55-60% of income, and timber for 3%. In Costa Rica, fruits sales accounted for 5-11% of income from coffee growing areas (Lagemann and Heuveldop 1983). Having available products from the shade tree canopy reduces vulnerability to market fluctuations and household dependence on outside products while increasing local commerce. Especially when coffee prices are low, the alternative income can protect farmers from financial ruin.

The coffee certification programs mentioned above are currently providing some compensation to farmers for the trade-off between protecting biodiversity and yield. Gobbi (2000) found that making the transition from intensive monocultures or traditional polycultures to biodiversity friendly production and certification is economically viable because of price premiums made for certified coffee. Another perspective regarding price premiums for biodiversity friendly production is presented by Perfecto and colleagues (2005). By superimposing data from studies investigating both the relationship between shade cover and biodiversity and shade cover and yield, they investigated theoretically how changes in species richness of two taxa (ants and butterflies) related to coffee yields, and in turn to premiums needed to compensate for potential yield losses with increased biodiversity. For those taxa relatively less sensitive to shade (and thus yield) reduction (such as ants), only moderate price premiums are needed to compensate for yield losses. In contrast, for forest specialists or those taxa highly sensitive to habitat changes (such as butterflies), increasing shade levels needed to protect a critical number of species may result in lowers yields making larger price premiums necessary to compensate farmers.

But how high a premium are consumers willing to pay? According to Giovannuci (2003), in 2002, premiums paid to farmers were: organic \$0.15 - \$0.30/lb, fair-trade \$0.66/lb, and shade-grown \$0.10-\$0-.60/lb. The majority of coffee industry participants support price premiums, and consumers are somewhat willing to pay higher prices for sustainable coffees. This willingness is reflected in the high growth rates for this sector of the coffee market (26.5% annually in 2001-2002). Although consumption may be relatively low (1-2% of total market), sustainable coffees affect many coffee farm households and these price premiums offer substantial economic incentives for participants (Giovannucci 2003, Calo and Wise 2005).

6.3 The dilemma of a stable price for an internationally traded commodity

Price fluctuations in the coffee market may have widespread ecological effects. Low coffee prices in the early 1990's, following the disintegration of the International Coffee Agreement, led to landscape transformations (Nestel 1995). Many smallholders became more indebted and lost their lands (Renard 1992). Many other farmers transformed their coffee crops to more environmentally destructive crops as a result of low prices (Nestel 1995). The recent and more drastic price crashes in the late 1990's are having similar effects. Blackman and colleagues (2003) in a land-use survey of coffee-growing areas of Oaxaca, Mexico found that proximity to urban centers and receiving higher coffee prices (via membership in coffee cooperatives) reduced the probability of land clearing. They suggest that the collapse of coffee prices has increased deforestation but non-timber agroforestry crops, when offering price advantages, may help in forest conservation. Persistent low prices, below production costs have motivated farmers to abandon their crops. This may lead to short-term conservation benefits as forests regenerate in abandoned coffee areas. But in the long-term, farmers are more likely to convert to more intensive land uses. Furthermore, workers on large farms will be laid off or smallholders will necessarily turn to other crops thus contributing to more forest clearing (Vandermeer and Perfecto 2005).

Whatever the motive, fluctuating prices of coffee lead to widespread economic and ecological instability in regions where coffee is grown. At the global level, failure to address fluctuating coffee prices will incur additional conservation costs. With the selling price below production costs, farmers can no longer afford to harvest coffee, and are forced to seek other options to feed their families leading to greater deforestation. While shade-grown coffee premiums paid to farmers may encourage shade coffee in forests (Rappole et al. 2003, O'Brien and Kinnard 2003), encouraging less intensive agricultural practices and re-educating agricultural extension agents in biodiversity techniques may instead stabilize local economies reducing pressure on primary forests. Although farmers may hesitate to adopt shade-grown coffee on an individual basis, creating price incentives for shade, organic and fair trade coffee may help break this cycle and is precisely why making sure premiums are sufficient is an important consideration. A recent study has shown that organic and fair trade coffee reduce small farmers' livelihood vulnerability (Bacon 2005). While some farmers and researchers might be doubtful about potential benefits of biodiversity friendly certification (Rappole et al. 2003, O'Brien and Kinnard 2003), with proper price premiums and income alternatives, gains for individual farmers due to biodiversity friendly certification can have similar effects as organic and fair trade certification (Philpott and Dietsch 2003, Dietsch et al. 2004).

7 Conclusions

Shaded coffee as a reservoir of biodiversity and as a high quality matrix can provide ecological and socioeconomic stability to rainforest areas. At least a decade of research on the potential of coffee agroforests to conserve biodiversity has demonstrated that this management system has a high conservation value for biodiversity. More recent research, though, highlights the complexities of refocusing conservation in the matrix. While shade coffee has been shown to maintain high species richness for most taxa examined, not all taxa respond equally to varying levels of disturbance associated with coffee management. Furthermore, different components of a taxon can exhibit different levels of susceptibility to disturbance. Some forest specialists birds, for example, are eliminated even in highly shaded coffee plantations.

This reality highlights the need to have a landscape approach to biodiversity conservation, where the forest fragments and the mosaic of agroecosystems are seen as interdependent. At the landscape level shaded coffee farms can contribute to overall biodiversity in two ways. First, the coffee agroforests themselves serve as a habitat for many organisms and can maintain high levels of biodiversity. Second, the coffee agroforests represent a high quality matrix that facilitates migration between forest fragments allowing for the maintenance of diversity within a metapopulation structure. Therefore, even if the most rustic coffee plantations do not provide a permanent high quality habitat for certain forest specialists, it can serve as a permeable matrix that facilitates interfragment movement and allows the maintenance of a metapopulation structure.

The diversity contained both within the coffee agroforests as well as in the forest fragments adjacent to coffee farms have been shown to provide ecological services and maintain ecosystem functions of importance for the productivity and sustainability of the coffee agroecosystem, as well as more general environmental services. Functions and services such as pest control, pollination, enhanced soil fertility and carbon sequestration have been shown to be be diminished with the intensification of the agroecosytem. Small farmers in Latin America rely on these ecosystem services provided by biodiversity more than large resource-rich farmers who may substitute some biological functions with agrochemicals. Therefore, the maintenance of biodiversity and its associated functions is important for the ecological stability of the coffee growing regions of Latin America where most of the farmers own/manage less than 5 hectares. Likewise, coffee certification programs that encourage environmental protection and biodiversity conservation and provide a premium price can improve farmer's livelihoods increasing socioeconomic stability within the coffee growing regions of Latin America.

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