BIODIVERSITY OF FLORA AND FAUNA

IN SHADED COFFEE SYSTEMS

by

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EXECUTIVE SUMMARY

The research available on biodiversity in shaded coffee production systems is incomplete and fragmented, more so in some areas of biodiversity than in others. Below is a summary of the research documentation in each of six categories:

- Flora: Plant species diversity in shaded systems, particularly in traditional polyculture systems, is the category enjoying the best documentation. Research has been done on composition and structure of shade and companion species, including inventories of the different plant species in the shaded coffee systems.

- Birds: Studies have been performed to determine species richness and to analyze foraging behaviour of birds in shaded and unshaded systems, and some work has been done to compare shaded systems with richness in native forest. The research indicates that birds are found in greater abundance and diversity in shaded coffee systems than in unshaded systems. Traditional coffee systems that provide diverse mixes of natural and planted flora are associated with the greatest diversity of birds.

- Mammals: One detailed study was found that identified, classified, and categorised mammals by guilds or niches, and then compared these mammalian populations among coffee plantations, ranging from shaded to unshaded in character. Here again, mammals favored shaded systems; they also benefited from greater diversity of vegetation in coffee system environments.

- Reptiles and Amphibians: One study was found that reported reptile and amphibian species in shaded coffee systems in Mexico. The report showed species diversity to be less than in natural forests. More research needs to be done to compare species abundance in shaded versus unshaded environments.

- Arthropods: Studies carried out on arthropod populations in shaded and unshaded systems indicate that arthropod species richness is greater in shaded systems. Research also indicates that arthropods benefit from plant species richness within the coffee system. Research also shows that species that infest coffee plants are not significantly more of a problem in shaded systems than in unshaded ones.

- Other Macrofauna: The information here is sparse. One study found native earthworm species to be adversely affected by perturbation of the natural system. Introduced earthworm species flourished in these perturbed environments. More research needs to be done to determine the response of earthworms and other macrofauna to different coffee systems.

- Microbes: The research here is also scanty. One study discusses nitrogen-fixing bacteria. More research is needed on microbial diversity in coffee systems and how it relates to the fauna, as well as the possible commercial value of microbes to coffee farmers.

SPECIFIC FINDINGS OF IMPORTANCE

Although available evidence is not always extensive, some specific findings can be reported. Listed below are specific empirical findings that have been documented in the literature.

- The dichotomy between shaded and non-shaded Mexican coffee is important. However, there is a broad range of shaded coffee systems in Mexico, from shaded monocultures through to highly diverse rustic and traditional shaded polyculture systems. Shaded monoculture coffee production does not support high levels of biodiversity. Commercial polyculture coffee systems offer more economic returns than traditional ones with lower levels of biodiversity.

- In traditional (or rustic) systems and traditional polyculture systems, much of the original forest canopy and other forest flora remain *in situ* in fields, producing an agroecosystem that supports much more biodiversity than other less diverse shaded coffee systems.

- Flora biodiversity in traditional rustic systems and traditional polyculture systems is very high.

- The species richness that is found in coffee systems appears to be related to altitude and the natural forest type in the region.

- Management options are available to improve the attractiveness of coffee systems for fauna, while simultaneously maintaining coffee output at consistent and productive levels. Selection of canopy density, shade-tree varieties, and amount of shade-tree diversity are important factors in creating an agroecosystem that is attractive to fauna.

- Bird species richness in traditional shaded coffee systems in Mexico has been found to be higher than in some natural forests.

- Some authors encourage use of *Inga spp* as shade trees, because these species fix nitrogen in the soil (thereby improving coffee yield), provide multiple products to farmers, and provide a popular foraging platform for fauna (especially birds).

- Bird species' richness falls sharply in less shaded, less diverse coffee systems, because food sources like fruit, seeds and insects are less diverse and less abundant.

- A traditional coffee agroecosystem is one of the few productive agricultural systems that can sustain a diverse wild mammal population. Mammals provide an additional livelihood source for farm families.

PRODUCTIVITY OF SHADED VERSUS UNSHADED COFFEE SYSTEMS

A fair amount of material is available on productivity in shaded and unshaded systems. Research indicates that unshaded (also called 'modern' or 'technified') systems produce greater coffee yields, but they require greater inputs of materials and labor, as well as suffering diminishing returns as the coffee plants grow older. Coffee systems under 30 to 50% shade produce less coffee than the corresponding area of unshaded plants, but they require less investment in labor and materials and (arguably) produce higher quality coffee. Also, coffee plants in shaded systems enjoyed greater longevity. Certified "biodiverse-friendly" coffee systems can be financially viable.

OTHER BENEFITS OF SHADED SYSTEMS

Farmers derive other benefits from shaded polyculture systems as well. For example, their livelihood needs may be better met by the multitude of products and services provided by the more diverse agroecosystem of traditional (rustic) and shade polyculture coffee systems. Inventories of plant species in shaded coffee systems revealed a wealth of plants of commercial or domestic value to the farmer, above and beyond the value of the shade the canopy species provided.

SUMMARY

Promotion of shaded coffee systems has received an enormous amount of attention. A great number of opinion papers and web pages can be found on the Internet. Organisations concerned with the preservation of birds have launched campaigns promoting coffee production systems that address the needs of native and migratory species. Other organisations promote coffee systems that are less damaging to the environment than unshaded coffee systems, seeking to avoid the use of chemical fertiliser and pesticides that support high levels of output.

Ecological theory and empirical evidence suggest that shaded coffee systems do offer benefits in terms of higher biodiversity. However, the extent that biodiversity is actually higher is affected by the type of shaded coffee system. Traditional (rustic) and traditional shaded polyculture systems that incorporate coffee (and other planted crops) as added components into the natural ecosystem produce the greatest biodiversity benefits. In addition, small landowners primarily utilize these systems (five ha or less) so promotion of shade-grown coffee from these systems could help achieve other social objectives. In contrast, the biodiversity benefits from shaded monoculture and other less diverse coffee systems are less promising.

INTRODUCTION

The idea of shade-grown coffee has become fashionable, often defined with terms such as “sustainable coffee” and “environmentally friendly coffee.” Articles abound in newspapers, magazines and, especially, on the Internet promoting these concepts, as well as advertisements of companies offering shade-grown coffee for sale. Advertisers use the idea that consumers, by purchasing “sustainable” or “shade-grown” coffee, are helping to protect the natural environment and to conserve biodiversity of wildlife, particularly of birds, which enjoy a high recognition value. Furthermore, awareness and language are usually focused on comparisons of “shaded” versus “unshaded” systems, when in fact the observed range of coffee growing systems is more complex.

While these articles and advertisements serve to attract public interest, they do not offer much quantifiable information. A base of quantitative studies is available which establishes a limited foundation of data about plant and bird biodiversity, but the data are quite incomplete in other aspects of coffee system biodiversity, such as abundance of small vertebrates and macrofauna. Overall, the information base for biodiversity in coffee plantations, particularly with regards to the merits of shaded versus unshaded coffee, can be described as sketchy. However, in spite of the large gaps in the quantitative information, the available evidence (and ecological theory) suggest that biodiversity varies, perhaps significantly, across systems.

The aim of this study is to survey the available quantitative research and data about different aspects of biodiversity under alternative coffee management systems. The first part of the paper describes five basic categories of coffee management systems, with estimates of how much land under coffee cultivation can be found in these categories throughout Mexico. The next section presents the quantified research available on species diversity in the flora and fauna of these systems. The biodiversity among fauna is further divided into subcategories in order to give a more precise picture of what is known and what is lacking in each group.

COFFEE SYSTEMS IN MEXICO

Agriculture and other activities often displace or affect remaining natural forests. In Mexico, the growth and spread of coffee production has impacted natural forest, which in turn has effects on biodiversity. The table below (Table 1) shows the percentage of tropical and temperate forests displaced or affected by coffee fields in nine of the Mexican states that produce coffee.

Table 1. Percentage of forests displaced or affected by coffee fields in Mexico.

	Tropical Forest		**Temperate Forest**	
State	**Rain %**	**Dry %**	**Cloud %**	**Pine-oak %**
Gulf of Mexico slopes				
San Luis Potosí	76.0	14.0	4.0	6.0
Puebla	51.5	1.0	7.0	40.5
Hidalgo	47.0	--	24.0	29.0
Veracruz	68.5	18.5	7.0	6.0
Pacific slopes				
Nayarit	-	82.5	-	17.5
Colima	-	83.0	-	17.0
Guerrero	-	45.0	5.0	50.0
Both slopes				
Oaxaca	76.0	14.0	4.0	6.0
Chiapas	54.5	12.0	15.3	18.0

Source: Moguel et al (1999).

Much of the land conversion occurred during the 1970s. According to Nestel (1995) the overall amount of land converted to coffee cultivation increased from 356,253 ha to 497,456 ha, an overall increase of 141,843 ha between 1970 and 1982. Between 1982 and 1996 there was an overall increase of 20,016 ha. A summary of changes by state is given in Table 2. The largest coffee-area increases in recent years have occurred in Puebla and Oaxaca.

Table 2. Agricultural land under coffee production

State	Amount of land in 1970 (ha)	Amount of land in 1982 (ha)	Amount of land in 1997 (ha)	Change in the amount of land 70-82 (ha)	Change in the amount of land 82-97 (ha)
Chiapas	131,449	163,268	155,729	+31,819	-7,539
Veracruz	94,897	98,196	104,055	+3,299	+5,859
Oaxaca	59,657	103,326	118,586	+43,669	+15,260
Puebla	23,133	33,593	41,814	+10,460	+8,221
Guerrero	18,740	40,939	35,434	+22,199	-5,505
Hidalgo	9,568	23,582	28,307	+14,014	+4,725
Others	18,169	34,552	33,547	+16,383	-1,005
Totals	**355,613**	**497,456**	**517,472**	**141,843**	**20,016**

Sources: Coffee Census, 1970 and 1982, Instituto Mexicano del Café (INMECAFE) Xalapa Veracruz, Mexico
Coffee Census, 1996-97, Consejo Mexicano del Café
+=incorporation of land in coffee
-=elimination of land in coffee

In Mexico there is a wide range of coffee production systems. Although a "shaded/non-shaded" dichotomy is an important distinction, it will be shown below that a finer set of distinctions in the form of coffee systems can be observed, and that these distinctions are important for assessing biodiversity. One aspect that is important is whether shade trees for shaded coffee are planted in monoculture or polyculture. Normally, shade polyculture creates an improved environment for biodiversity, relative to shade monoculture. Nestel (1995) has noted that 22% of the producers in Mexico use either shaded or unshaded monoculture, while 78% continued to use traditional management systems that are based upon shade-cover polyculture. It is in these highly diverse traditional systems that very high levels of biodiversity are found.

The important role of traditional coffee production practices in Mexico is a function of the land tenure patterns. In the Mexican coffee sector, small parcels of land devoted to coffee are commonplace. In other words, while Mexico has some large coffee estates (like those that are common in countries like Brazil), large plantations are not dominant in the coffee sector. Traditional production systems that are used almost exclusively by small landowners are virtually all-shaded (and/or mostly-shaded) polyculture, where coffee is intercropped with other trees, shrubs and food crops. Shown below (Table 3) are the land tenure patterns for the Mexican coffee sector. Overall, over 90% of landowners and over 60% of land devoted to coffee is with landholders with five or less hectares. This relative importance of small landowners is maintained across the three principal producing states of Chiapas, Oaxaca and Veracruz. Large estates (over 50 ha) account for about 8% of overall land in Mexico that is devoted to coffee production.

Table 3: Land tenure patterns in the coffee sector of Mexico (selected States and the national average)

Strata	**National**		**Chiapas**		**Oaxaca**		**Veracruz**	
(ha)	**% of owners**	**% of land**	**% of owners**	**% of land**	**% of owners**	**%of land**	**% of owners**	**% of land**
<2	73.1	37.6	73.2	38.2	65.9	34.1	73.5	36.7
2-5	18.6	26.0	17.8	21.0	23.6	29.6	19.9	31.5
5-10	6.2	16.2	6.6	14.4	8.1	19.3	5.0	15.5
10-20	1.7	9.0	1.6	7.5	2.1	9.6	1.1	7.0
20-50	0.3	3.6	0.5	4.4	0.2	2.4	0.3	3.4
>50	0.2	7.6	0.3	14.5	0.1	5.0	0.2	5.9

Source: Nestel (1996)

Small landholders tend to utilize rustic or traditional polyculture systems for several reasons. First, development of intensive monoculture involves substantial establishment costs, along with much higher annual operating costs (especially agricultural chemicals to combat weeds and insect pests). Second, the traditional systems better meet the varied livelihood objectives of small farmers for food and income security, family labor use and secondary forest product extraction. Many of the trees that form the shade canopy are planted, but relict forest trees can be (and usually are) found in the canopy. Meanwhile, the larger plantations are generally converted to intensive monocultures, which were once promoted by INMECAFE (the Mexican national coffee organization) as a more productive system. As a result of this conversion process, around 30% of the landscape vegetation devoted to coffee systems changed between 1970 and 1982 from highly diverse landscape to coffee monocultures with only a single species of shade tree (usually *Inga*), or no shade at all (Nestel 1995). Data (Figure 1) from the Consejo Mexicano del Café (2001) indicates that, between 1982 and 1997, the number of coffee producers increased substantially in all the regions (no data are available for 'others' in 1997). The overall production of coffee increased slightly from 273,578 to 305,981 tonnes, as shown in Figure 2 below. This suggests a reversing trend towards much smaller average coffee landholding size, much which is coffee mixed with other agricultural or forest products.

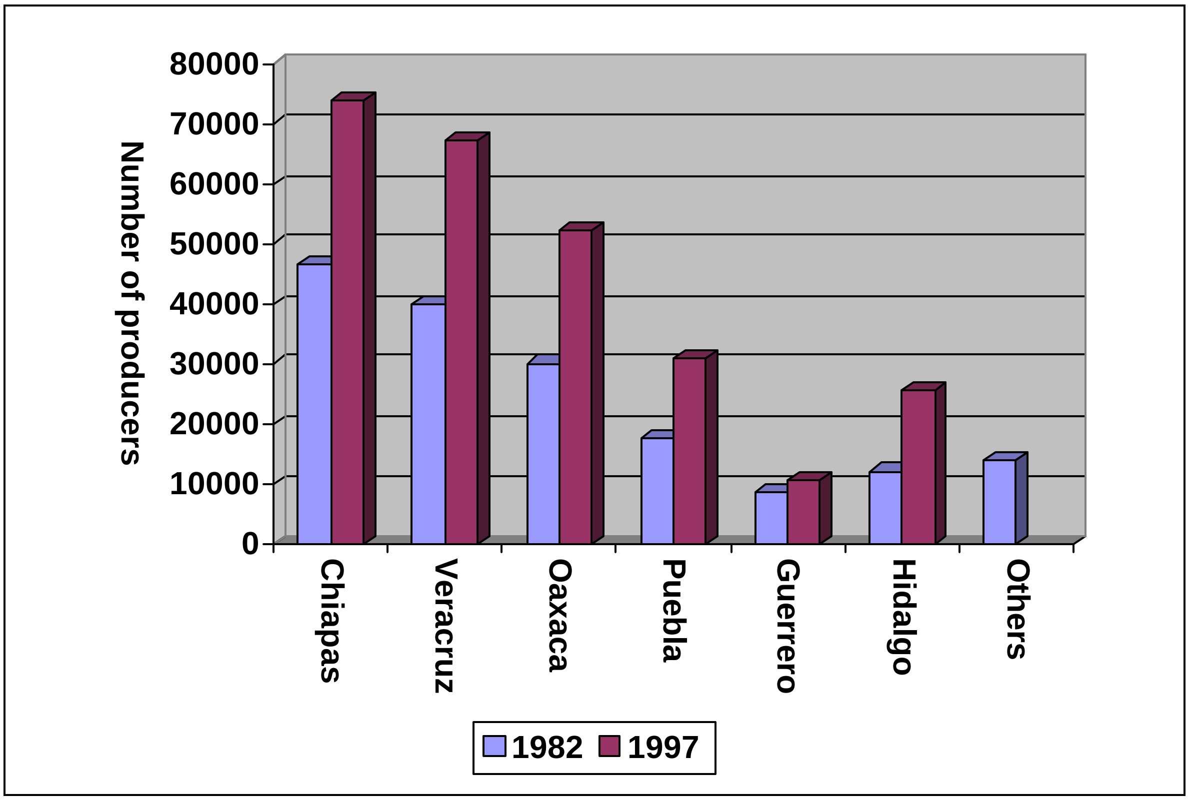

Figure 1: Number of Mexican Coffee Producers, 1982 and 1997.

Source: 1982 Figures adapted from Coffee census, Instituto Mexicano del Café (INMECAFE), Xalapa, Veracruz, Mexico. Figures for 1997 adapted from Consejo Mexicano del Café.

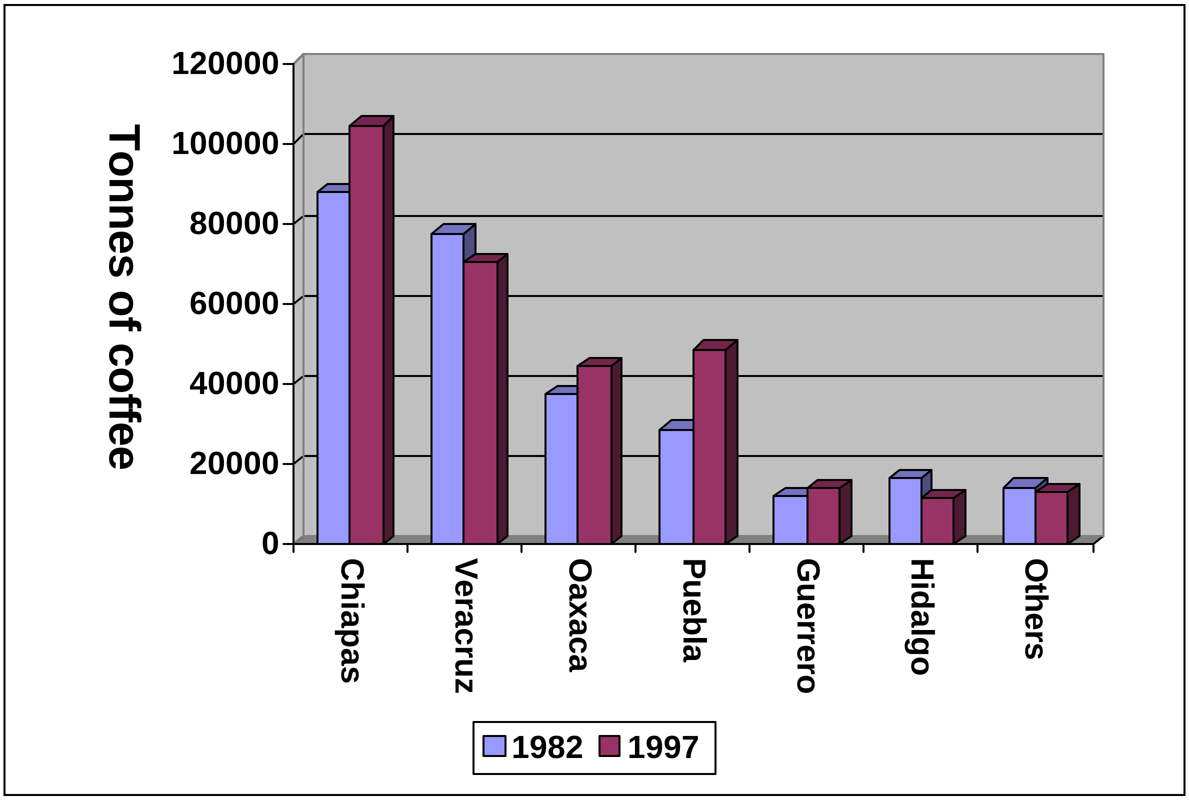

Figure 2: Coffee Production, 1982 and 1997 (tonnes)

Source: 1982 Figures adapted from Coffee census, Instituto Mexicano del Café (INMECAFE), Xalapa, Veracruz, Mexico. Figures for 1997 adapted from Consejo Mexicano del Café.

As will be discussed below, simple monoculture coffee/single shade tree systems offer reduced opportunities for maintenance of biodiversity in coffee plantations and can represent a catastrophic reduction in plant diversity, depending on how the coffee plantations are managed.

COFFEE MANAGEMENT SYSTEMS IN USE

Coffee plantations may be characterised into any one of five different management systems. However, it should be kept in mind that these systems are best thought of as a gradient from full-sun monoculture to highly shaded rustic polyculture.

- **Traditional or Rustic:** Farmers leave the original forest canopy intact; removing only such undergrowth as is necessary to plant the coffee shrubs underneath.

- **Traditional Polyculture or Coffee Garden:** Farmers make use of the original canopy, introducing useful plant species alongside the coffee shrubs.

- **Commercial Polyculture:** Farmers remove the original forest canopy and plant shade trees and legumes (less than 15 m tall), as well as other commercially useful species.

- **Shaded Monoculture:** Leguminous trees are used to provide shade and nitrogen to the coffee bushes.

- **Unshaded (or Full-sun) Monoculture:** Coffee bushes are exposed to direct sunlight and are not accompanied by other plants.

Table 4 shows the area in hectares of the different coffee growing systems summarized for the seven coffee producing regions in Mexico. As can be seen, rustic and traditional polyculture systems, which maintain the greatest level of managed biodiversity, account for almost 40% of the coffee area in Mexico. Thus, even though the number of small producers has increased substantially, the area devoted to shaded monoculture and full-sun monoculture is still a large share of production. Shaded monoculture (typically, but not always, with just one species of shade tree) accounts for 42% of total area.

Table 4: Area for each coffee system in 124 municipalities of seven coffee growing regions of Mexico.

Region (Number of municipalities)	***Total[a] area (ha)***	***Rustic***	***Traditional polyculture***	***Commercial polyculture***	***Shaded monoculture***	***Full-sun monoculture***
Total (124)	367,988	48,412	96,931	35,084	152,891	41,972
Percentage (%)	100	13	26	10	42	11

a. The total is from the original source and does not sum properly, possibly due to a typesetting error.
Source: Moguel & Toledo (1999).

Below (Table 5) is a summary of key distinguishing characteristics for "traditional" (Rustic and Traditional Polyculture) and "modern" (Shaded and Unshaded Monoculture) coffee production technologies. The table omits Commercial Polyculture because it straddles the two remaining categories and shares features with each of them.

Table 5: Distinguishing Characteristics for Coffee systems.

Characteristic	**Traditional (Rustic & Traditional Polyculture)**	**Modern (Shaded and Unshaded Monoculture)**
Coffee variety	Tipica, Bourbon, Margogipe	Caturra, Catuai, Colombia, Guarnica Catimor
Coffee height	3-5m	2-3m
Shade cover	Moderate to heavy, 60-90%	None to moderate
Shade trees used	Tall (15-25m), mixed forest trees, legumes, fruit trees, bananas	Short (5-8m), legumes; often monocultures
Density of coffee plants	1000-2000/ha	3000-10,000/ha
Years to first harvest	4-6	3-4
Plantation life span	30+years	12-15 years
Agrochemical use	None to low	High, particularly fertilizer, herbicides, fungicides, nematocides
Pruning of coffee	Individualized pruning or no pruning	Standard stumping back after first or second year of full production
Labor requirements	Seasonal for harvest or pruning	Year-round maintenance with higher demands at harvest
Soil erosion	Low	High (particularly on slopes)

Source: Perfecto et al (1996)

The differences between the systems are vast. Traditional systems utilize different coffee varieties, which are managed less intensely. Pruning is minimized and labor use is greatly reduced for coffee, in order to free up family labor for other productive activities. Coffee plant density is one third to one fifth lower, planted under a wider range (and much different form) of shade trees. Shading is often very heavy (60% to 90%) under mixed forest trees, along with legumes, fruit trees, and bananas. Productivity is lower and agrochemical use is very low (often non-existent). In addition to the environmental benefits of greater on-farm biodiversity, soil erosion is much lower. The “modern” system of shaded or non-shaded coffee production is more intensive and productive, but requires significant use of agrochemicals (fertilizer, herbicides, fungicides and nematocides), all of which reduce biodiversity, and result in higher levels of soil erosion. Impacts of agrochemical use and soil erosion also occur off-farm, as soil and chemicals are washed downstream from intensive coffee plantations. Unfortunately, these off-farm impacts have not been systematically documented in the literature.

The structure for shade coffee plots also varies considerably. Table 6 shows data drawn from a sample of 35 plots in Chilón, Mexico. Producers in this region typically own between 0.5 and 3 ha of land, on which they grow coffee in traditional rustic or polyculture agroforestry. Coffee shrub density and shade cover, even within this relatively narrow range of systems, tend to vary because farmers maintain both highly shaded and relatively unshaded plots. The number of large trees (>10 cm d.b.h., or diameter at breast height) ranges from 100 to 1000 per ha, with basal area (affected by both number and diameter of shade trees) ranging from 20 to 516 m^2.

Table 6: Coffee system features from 36 study plots in Chilón, Mexico

Variable	***Mean of 36 plots***	***Minimum of 36 plots***	***Maximum of 36 plots***	***S.D.****
Coffee shrubs/ha	**1927**	**800**	**3500**	**548.6**
Shade cover (%)	**46.7**	**22.9**	**70.0**	**12.7**
<10 cm d.b.h. trees/ha	**177**	**0**	**500**	**41.6**
>10 cm d.b.h. tree/ha	**286**	**100**	**900**	**214.0**
Total shade trees/ha	**463**	**100**	**1000**	**221.9**
Basal area (m 2 /ha)	**171.3**	**20**	**516**	**143.8**
No. of species/plot	**3.5**	**1**	**8**	**1.9**

*S.D.=Standard Deviation

Source: Soto-Pinto et al (2000).

FLORA BIODIVERSITY

A number of studies have been performed on plant diversity in traditionally managed coffee systems. In traditional systems, farmers manage a wide range of biodiversity to extract products for a variety of uses. Coffee productivity is sacrificed in order to produce other products that are required in the livelihood systems of traditional farmers. The following summary is based on an extensive review of these studies carried out by Moguel and Toledo (1999):

- Rendón and Turribiarte (1985) reported 90 different plant species in coffee sites placed in oak and tropical dry forests.
- Molino (1986) reported 120 plant species in a coffee system derived from a tropical rain forest.
- Williams-Linera et al (1995) found 25 orchid species growing on shade trees in two coffee plantations.
- Márquez et al (1976) reported 90 epiphytic species growing in 10 coffee sites on coastal slopes, as well as 90 useful tree species.
- Alcorn (1983) found over 300 useful plant species in traditional polyculture sites managed by Huastec Indians.
- Moguel and Toledo (1999) compiled the table below (Table 7) of useful plant species from three different sources, which illustrates the variety of ways in which the plants can be used.

Table 7 reports data on the number of useful plants identified for shaded polyculture in three regions of Mexico. These data highlight the point made earlier about the multifaceted benefits that rustic and traditional polyculture systems provide for smallholders. A variety of foods (ranging from 17 to 51) medicinal plants (ranging from 5 to 25) and plants for construction materials (ranging from 7 to 28) are most commonly observed. Overall, the number of useful species ranges from 55 in Central Veracruz to 82 in Cosautlán.

Table 7: Number of Useful plant species in three multilayered shaded coffee sites in Mexico

Use	***Coatepec***	***Cosautlán***	***Central Veracruz***
Foods	17	51	24
Medicinal	25	10	5
Forage	4	3	-
Domestic use	14	-	-
Magic/religious	3	-	-
Ornamental	4	8	4
Construction	7	6	2
Other	-	6	28
Total	74	82	55

Sources: (from Coatepec) Pisanty & Carabias (1979),
(from Cosautlán) Molino (1986), (from Central Veracruz) Escamilla et al (1993)

Soto-Pinto et al, (2000) performed an even more detailed study in their investigation of the effect of shade on coffee production. First, they characterised five different strata of vegetation in the coffee system, as summarised in the table below (Table 8).

Table 8: Strata in Coffee Stands in Chiapas, Mexico

Strata Type	**Height**	**Composition &Characteristics**
Herbaceous	<1m	weeds, coffee seedlings, other tree seedlings
Shorter shrubs	1-3m	coffee shrubs, tall herbs, small fruit trees
Taller shrubs	3-6m	fruit trees, thin woody trees <10cm d.b.h.
Shorter shade	6-12m	large trees with canopies >10cm d.b.h.
Taller shade	12-20m	emergent trees, upper canopy >10cm d.b.h.

Source: Soto-Pinto et al (2000)

Then they described the shape of the different canopy trees to determine how they contributed to the overall shade structure (Table 9). Almost half of the trees formed a complete circle, providing a fairly uniform shade cover. However, "a systematic disposition of shade trees was not revealed" (p. 65)—indicating that the placement or location of the trees was not uniform. Trees provide 65% of the total shade vegetation, with non-coffee shrubs, woody herbs and palms providing the remainder.

Table 9: Treetop shapes of shade trees

Shape	**% of total**
Complete circle	49
Irregular circle	14
Half-circle	21
Less than Half-Circle, twigs, or sprouts	16

Source: Soto-Pinto et al (2000)

Table 10: Composition of shade vegetation:

Type	**% of total vegetation**
Trees	65.6
Non-coffee shrubs	24.6
Woody herbs	4.9
Palms	4.9

Source: Soto-Pinto et al (2000)

Soto-Pinto et al (2000) made an inventory of the non-coffee species on the plantations they studied in Chiapas. Then they interviewed the producers to determine the uses of the different species. They reported 61 useful species of shade trees and shrubs, 88.5% of which were indigenous species (Table 11).

Table 11 Shade species in coffee stands from Chiapas, Mexico (Tallest species)

Local name	*Species*	***Use (s)***[a]	***Living form***	***Relative abundance***
Ashin'te	*Solanum aphyodendron* Knapp	1	Shrub	0.5
Atsam'te	*Myrica cerifera* L.	3, 5	Tree	0.5
Baas	*Desmoncus schippii* Burr.	1, 4	Tall Herb	0.5

Cacao	*Theobroma cacao* L.	1, 7	Shrub	1.4
Cacaté	*Oecopetalum mexicanum* Gr. & Th.	1	Tree	2.4
Cantelal tzi	*Senna papilosa* (B. & R.) I. & B.	5	Tree	0.5
Cedro	*Cedrela mexicana* Roe	3, 4, 7	Tree	0.9
Coquil'te b	*Inga pavoniana* Donn.	1, 5, 7	Tree	21.7
Chac'taj'mut	*Miconia* aff. *ibaguensis* (Bonpl.)Triana	3, 5	Tree	0.5
Chacaj or Luluy	*Bursera simaruba* (L.) S.	3	Tree	0.5
Chapay or act	*Astrocharium mexicanum* Liebm.	1	Palm	1.4
Chi'b	*Chamaedorea cataractarum* Liebm.	1	Tree	10.4
Chi'ch bat	*Croton draco* Schlecht.	7	Tree	0.9
Chii't b	*Chrysophyllum mexicanum* (Brand) Standl.	1, 5	Tree	2.4
Chinino	*Persea schiedeana* Nees	5	Tree	0.9
Guarón	*Cecropia obtusifolia* Bert	3	Tree	0.5
Guayaba	*Psidium guajava* L.	1, 5, 6	Tree	1.4
Hule	*Castilla elastica* Cerv.	1, 8	Tree	0.9
Ik'bat b	*Belotia mexicana* Shum.	7	Tree	2.4
Ichil'te	*Zanthoxilum* aff. *kellermanii* P. Wilson	3	Tree	0.5
Joma or Mojt´ o	*Chamaedorea tepejilote* Liebm.	1, 2	Palm	0.9
Jono 'ha	*Heliocarpus donnell-smithii* Rose	9	Tree	0.5
Juun	*Sapium* sp.	3, 4	Shrub	0.5
Jaal'te	*Clibadium arboreum* Donn. Sm.	5	Tree	0.5
Jitit'ul	Non identified	4, 5	Tree	0.5
Limón	*Citrus aurantifolia* Osb.	1	Shrub	1.9
Mandarina	*Citrus nobilis* Lour.	1	Shrub	0.5
Mango	*Mangifera indica* L.	1	Tree	0.5
Mistel	*Amphitecna macrophylla* (Seem.) Miers.	1	Tree	0.5
Momun	*Piper auritum* Kunth 1	1	Tall herb	1.4
Mot'e	*Erythrina* sp.	1,3	Tree	1.4
Naranja	*Citrus sinensis* Osb.	1, 6	Shrub	3.8
On'te	*Nectandra globosa* (Aublet) Mez.	1, 6	Tree	0.9
Pajul'te b	*Zanthoxilum* aff. *microcarpum* Griseb	5	Tree	1.4
Papaya	*Carica pennata* Heilb.	1	Tree	0.5
Pimil	*Calathea macrochlamys* Woodson & Standl.	1	Tall herb	1.9
Plátano roatan	*Musa sapientum* L.	1, 7	Tree	4.7
Pom'te	*Neurolaena lobata* (L.) R. Br.	5	Shrub	1.4
Pomarrosa	*Eugenia jambos* L.	1, 7	Tree	1.9
Sac juluchay	*Bernardia* aff. *interrupta* (Schel.) Muell-Arg.	5	Tree	0.5
Sac Mumus	*Lippia myriocephala* Schlech. & Cham.	3	Tree	1.9
Sajal Bat	*Heliocarpus mexicanus* (Turcz) Sprague	5,9	Tree	0.5
Saquil Bat	*Heliocarpus appendiculatus* Turcz.	5, 9	Tree	0.5
Shin'te b	*Lonchocarpus* sp.	5, 7	Shrub	1.5
Sitit	*Vernonia deppeana* Less.	5	Shrub	0.5
Sun	*Tithonia rotundifolia* (Miller) Blake	1	Shrub	0.5
Tanchit	*Casearia corymbosa* Kunth	3, 5	Tree	0.5
Toj'pos'te	*Cupania dentata* D.C.	5	Tree	0.5
Tumin'te	*Croton billbergianus* Mull Arg.	5	Tree	0.5
Tzajalobal	*Musa sapientum* L.	1,7,9	Shrub	0.5
Tzelel b	*Inga punctata* Willd.	5, 7	Tree	9.9
Tzost'e	*Liquidambar styraciflua* L.	3, 5	Tree	0.5

Ujchum	Non identified	7	Shrub	0.5
Ulusí	*Myriocarpum longipes* Liebm.	5	Tree	0.5
Weel	*Orthion subssesile* (Standl.) Steyerm. & Stadl.	5	Tree	0.5
Xacaxte	*Blepharidium mexicanum* Standl.	3, 5	Shrub	0.5
Xaxib'te	*Senna multijuga* (L.C. Rich.) I. & B. var *doylei*	3, 5, 7	Tree	0.9
Xoch'bat	*Heliocarpus reticulatus* Nash	5, 9	Tree	0.5
Ya can chamel	*Dendropanax arboreus* (L.) Dacne & Planchon	5	Shrub	0.5
Yash'ajal'te	*Eupatorium chiapensis* Rob.	5, 7	Shrub	0.9
Zapote	*Calocarpum zapota* Merr.	1, 7	Tree	0.9

a. Use Key: 1) Food, 2) Forage, 3) Construction, 4) Handicrafts, 5) Firewood, 6) Medicinal plant, 7) Shade, 8) Gum, 9) Other uses.

Source: Soto-Pinto et al (2000)

The six most frequently found species were

1. *Inga pavonia* (62% of total trees)
2. *Inga punctata* (28%)
3. *Musa sapientum* (18%)
4. *Calathea macrochlamys* (10%)
5. *Eugenia jambos* (10%)
6. *Citrus sinensis* (10%)

Inga spp. is a large family of species, one of the largest families of trees found in tropical and sub-tropical regions of the Americas. Some species have multiple uses, as can be seen in Table 11. For example, Inga is a good shade provider, fixes nitrogen in soil, provides excellent firewood, and some species produce large quantities of edible fruit. Food and fuel are by far the most common uses of the companion trees (Table 12), and they account for more than half of the overall use of the shade and shrub species in the coffee systems. These data on shade tree uses are similar to the data on shown above in Table 8.

Table 12: Uses of shade trees.

Use	**Percent (%)**
Food	26
Fuel	29
Construction	15
Forage, handicrafts, medicines, shade, gum, and other uses	30

Source: Soto-Pinto et al (2000)

Soto-Pinto et al found other species that had potential value not yet recognized, including fungi, ferns, orchids, epiphytic bromeliads, and plant species from the Araceae and Cycadacea families. Even dead trees and shrubs, which make up 3% of the shade cover, should be considered as useful because they provide habitat for birds and other macro and micro fauna.

Beer (1987) pointed out the possible disadvantages of shade trees to coffee and other perennial crops:

- Falling trees and branches from the shade cover can damage the understory crop.
- Sudden defoliation in the shade trees can cause severe shock to understory crops adapted to the shade.
- Additional manual labor may be necessary to keep the shade trees pruned.
- Mechanisation of the underlying crop is hampered.
- Terracing and other erosion control structures can be hampered by the shade trees.
- Modern crop varieties are often bred for monoculture conditions, and may not thrive in shade.
- Heavy shading can reduce the quality and quantity of the crop.
- Shade tree roots may compete with crop roots for resources.

- Allelopathic effects of the combination of Nogal *(Junglans spp.)* with coffee are potentially hazardous.
- Harvesting wood or fruit from the site may drain nutrients from the soil.

The farmer must weigh these possible disadvantages against the possible advantages to including shade trees in their coffee plots:

- More consistent yields make planning easier.
- Shade can improve the quality of the coffee crop
- Shade can increase the productive life of the coffee plants.
- Shade species can act as a buffer against rain, wind, and temperature extremes, which can harm the coffee crop.
- Shade trees help promote the activity of beneficial soil organisms, such as nitrogen fixers, and material decomposers.
- Shade trees can produce other commercially valuable products, such as fruit or wood, which serve as a hedge against coffee crop failure, or a drop in coffee prices.

Nestel (1995) discusses how leguminous trees such as *Inga* spp. are able to fix nitrogen in their roots with the aid of nitrogen-fixing bacteria. Roskoski (1982) reported that the contribution of nitrogen to the coffee ecosystem through this process was approximately 35 kg/ha/year, representing 28% of the ecosystem's nitrogen intake. Nestel (1995) summarizes this and other features of shaded coffee systems as follows:

- Shade canopy intercepts solar radiation, wind, and rain, creating a more stable physical environment for the coffee crop.
- Problems with insect pests in shaded coffee may be less severe than in unshaded coffee due to the highly diverse and abundant, populations of beneficial insects found in shaded systems.

- This beneficial fauna may regulate the population levels of pestiferous insects below economic thresholds.
- Furthermore, shade trees also help to control the productivity of the herbaceous stratum, reducing the competition for nutrients between weeds and the coffee crop.
- Shade trees create more habitats for birds and soil insects, increasing the species and trophic diversity in the ecosystem.
- Shaded coffee systems possess intrinsic mechanisms for the recycling of nutrients, reducing the dependency of the system on and external supply of nutrients.
- The humus layer is also enhanced in shaded systems, resulting in greater diversity and abundance of the detritivorous fauna.
- The extensive root system of shade trees stabilizes soil particles, reducing soil erosion during torrential rains.

In addition, shade trees provide environmental services, such as promoting habitat for birds. Beer (1987) notes that the farmer can balance the positive factors against the negative ones, and suggests that farmers can manage the following characteristics in shade tree species:

- Trees that offer minimal competition for resources with the crop.
- Strong, deep roots, to offer stability and access to deep water.
- Ability to fix nitrogen.
- Non-brittle branches and stems to minimise breakage.
- Thornless stems and branches to facilitate management.
- Rapid apical growth, and quick regeneration of leaves in deciduous species, in order to provide optimal shade.
- Small leaves to minimise damage from falling on crop plants.
- Trees that have valuable wood, fruit or other products (such as rubber).
- Trees resistant to disease or pests, and not of a type that can harbour diseases or pests that can easily spread to the coffee crop.

- Trees should not have the capacity to become a weed.

Soto-Pinto et al estimated a correlation between shade species richness and altitude ($p<0.001$, $r^2 = 0.43$). For example, greater species richness was found in the higher altitudes corresponding to montane rainforest, while poor species richness was found at the lower altitudes corresponding to sub-perennial rainforest.

The variety of useful and economically valuable plants in traditional polyculture systems makes this system an attractive alternative for small landholders. These sites offer greater plant diversity, which provides habitat and food for fauna. Within specific coffee plots, management decisions can also influence the level and type of biodiversity, while maintaining coffee production. Thus, within specific forms of coffee production system, there are management activities that improve habitat for fauna. The Smithsonian Migratory Bird Centre (2001) has developed a list of specific recommendations to make coffee plantations more attractive to fauna. These recommendations directly address the needs of local and migratory birds for food and habitat:

- Provide a minimum canopy cover of 40 %.
- Don't trim epiphytic plants or hemi-epiphytic vines on shade trees.
- Farmers may remove unwanted plants or vines from coffee trees.
- Inspectors should verify that the forest converted to coffee production does not have legal protected status.
- That *Inga spp. m*ake up the backbone of the shade trees and that *Erythina spp., Gliricidia sepium, Greilllea robusta represent* less than 5% of the canopy.
- That no single species of *Inga* make up more than 50% of the *Inga* trees.
- Shade trees should reach a minimum o 12-15 meters in height.
- Farmers should plant trees that are shorter and taller than the backbone shade species in order to provide increased vertical structural diversity. These may be commercially valuable species. These lower and higher

strata trees should make up at least 20% each of the shade system, in addition to the (40%) backbone trees.

- Epiphytic and parasitic plants should be encouraged, and (ideally) should mimic remaining natural vegetation in a particular area.
- Farmers should leave dead limbs and snags wherever possible.
- Farmers should maintain living fences or border strips of trees along roadways and other borders to protect the understory.
- Likewise, farmers should maintain strips of natural second growth vegetation along small streams (5 m) and rivers (10 m).
- Inspectors should compare the Gestalt (overall) structures to the categories (e.g. rustic, traditional polyculture, commercial polyculture, and specialized shade)

Rustic and traditional polyculture management systems maintain the original canopy species and (in the case of traditional polyculture) can add further plant diversity to a coffee site. As a result, these systems largely comply with the Smithsonian Migratory Bird Centre recommendations.

FAUNA BIODIVERSITY

There are very few published research reports detailing fauna biodiversity in coffee plantations, relative to other forms of land cover. In addition, careful comparisons across the different forms of coffee systems have not been completed. It should be emphasised that it is very difficult to carry out comparative research studies on some forms of fauna, such as mammals, because other variables such as human population, hunting pressure, etc., will influence the findings. Below, we summarize the data that are available.

BIRDS

Birds (avian diversity) are a visible form of fauna and also capture substantial public interest. As a result, avian diversity has been the subject of more research attention (in addition to public awareness) regarding the impacts of coffee plantations on biodiversity than other forms of fauna. Bird populations and diversity are also interconnected with less widely appreciated (but important) forms of biodiversity such as insect populations (an important food source for birds). However, although there is evidence and ecological theory to suggest that bird numbers and biodiversity are higher in shaded coffee systems, especially so in rustic systems, the hard data are remarkably scant, which force caution in drawing conclusions.

The following is a summary of available studies.

- Greenberg et al. (1997) found 104 to 107 bird species in a commercial polyculture coffee system in Chiapas.
- Martínez and Peters (1996) found 136 to 184 bird species in traditional coffee plantations in Veracruz and Chiapas.
- Aguilar-Ortiz (1982) showed the bird species richness (136) of a traditional coffee parcel to be comparable to that of an adjacent remnant of cloud forest (138 species).
- Moguel and Toledo (1999) compiled findings from several sources and found that avian diversity in traditional shaded coffee systems was actually greater than in natural cloud forests, humid oak-pine forests, oak forests, and pine forests.

The available empirical literature suggests that shaded coffee, when produced in traditional coffee systems, supports a richness of bird species that is comparable to or possibly better than what is found in some natural forests.

The Smithsonian Institute Migratory Bird Centre (no date) has reported data on bird populations for coffee farms in Peru. They studied unshaded plantations, shaded coffee monoculture and diverse shaded (rustic) coffee systems. Only 70 species of birds (mostly small seed-eating species common on agricultural land) were observed in unshaded plantations. Diversity was higher in shaded monoculture, where 170 bird species were observed, including species commonly found in light woodlands and secondary forests. In diverse shaded plantations they observed nearly 240 species, including some species normally found in original forests.

Moguel and Toledo (1999) conducted species counts in a variety of native forest habitats, as well as in shaded coffee systems. They found that shaded coffee harboured fewer species than tropical rain forests or tropical dry forests, but more species than oak-pine forests or cloud forests. Figure 3 below shows the numbers of species found in each environment.

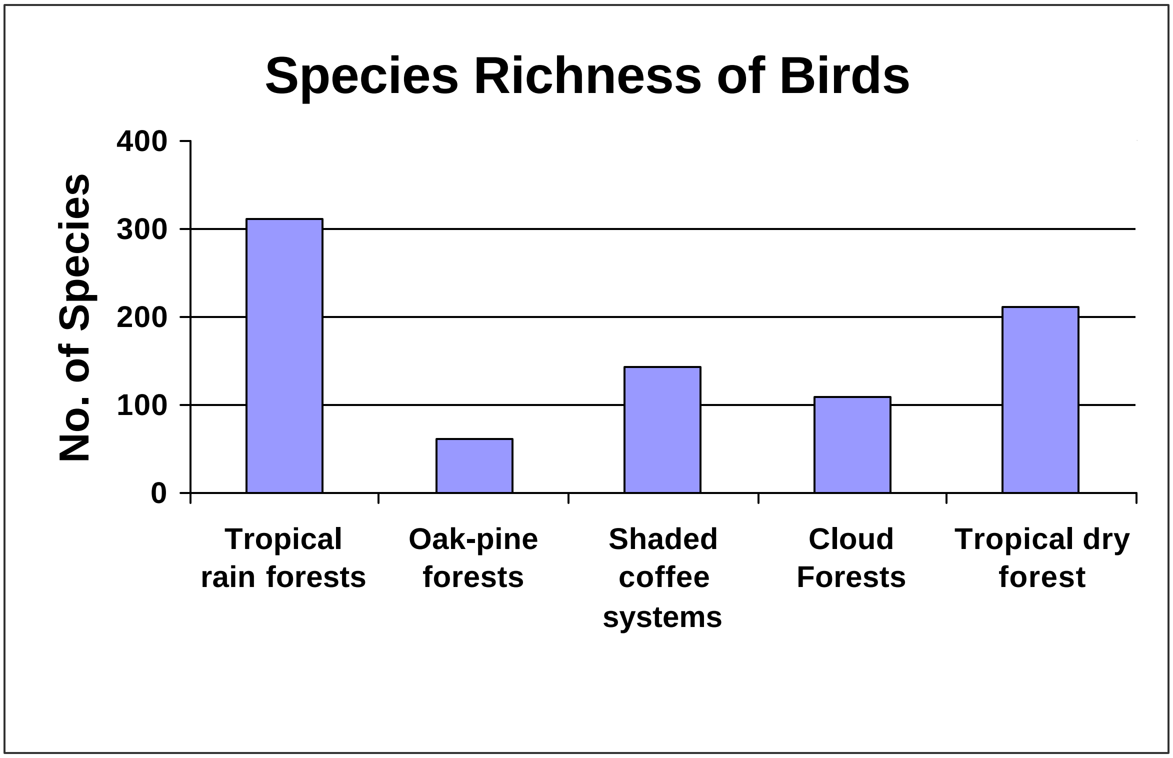

Figure 3: Comparative Species Richness of Shaded Coffee and Natural Forest

Note: Number of bird species drawn from 3 Mexican rain forest sites and 3 Mexican shaded coffee sites using traditional coffee systems. Tropical dry forest data were drawn from 2 sites, in oak-pine forests from 3 sites, and in cloud forests from one site. Mean values across sites are shown.
Source: Adapted from Moguel and Toledo (1999)

Other published data also suggest that species richness drops dramatically in less shaded, and less diverse environments. Martínez and Peters (1996) found 50 bird species in a shaded monoculture environment and only 6 to 12 species in unshaded monoculture environments.

Wunderle (1998), in a study evaluating the use birds make of different vegetative strata of 14 coffee plantations in the Dominican Republic, identified 24 species of birds, 19 of which he was able to observe enough to establish adequate sample sizes. Of these 19 species, 13 were permanent residents, five were Nearctic migrants, and one species was a Neotropical migrant. Wunderle observed 18 of the 19 species foraging at median heights that were significantly above the median maximum height of the coffee plants. The shade overstory was an important foraging site for a vast majority of the birds. Eight of the 19 species foraged exclusively in the overstory or the canopy, but not in the coffee bushes. The *Inga* trees were a very popular foraging platform, being used by 95% of the birds observed. The author notes that *Inga* leaves act as hosts for a variety of invertebrates , including grasshoppers, lepidopteran larvae, spiders, beetles, skipper larvae, microlepidoptera. These invertebrates are attracted away from coffee shrubs and other productive crops by the *Inga* leaves and themselves attract birds that prey on them. However, if chemical pesticides are utilised, insect numbers are lowered and the tree canopy will host lower numbers of birds.

Wunderle and Joseph (1996) also found a significant negative correlation between median avian foraging height and abundance in sun coffee point counts (Spearman r=-0.62, df=17,O=0.005). Thus, they concluded that birds that forage at a greater altitude are likely to be less abundant in unshaded coffee plantations. The coffee plants themselves were relatively unpopular foraging platforms, probably because of the low insect infestation rates of coffee plants. In a separate study, Wunderle and Latta (1996) found invertebrate abundance levels in coffee plants to be three times lower than on native, moist broadleaf forest.

Wunderle (1996) found that birds did not favor planted crops disproportionately in relation to their relative abundance in the plantations. For example, frugivores utilised citrus, avocado and guava trees, but only in direct proportion to their abundance on the plantation. This suggests that farmers can enhance a plantation’s attractiveness to birds by providing plant species that fruit and flower out of synchrony with each other, thus providing food resources for longer periods during the year.

Estrada et al (1997) showed that pastures, followed by non-arboreal crops (jalapeño, corn and bananas) were the poorest habitats for bird species, when sample size was accounted for. The habitats showing greatest species diversity were the forests, followed by cacao, *coffee*, live fence, mixed, citrus, and allspice (Table 13). In comparison with forest fragments, the mixed and cacao plantations and live fence were the most similar to natural habitats. Citrus, *coffee*, and allspice followed these habitats in terms of similarity to natural habitats. Thus, coffee compares in an intermediate manner to forest fragments in terms of providing diverse habitat for birds. These findings also offer evidence to support the argument that some agricultural habitats offer improved habitat and resource alternatives for birds, which could be promoted when faced with diminishing natural forest habitat.

Table 13: Census of Species and Birds in various agricultural habitats.

Habitat	Number of Sites	Number of Census Points	Species Registered	Species per Census point	*n*	Number of Birds per Census Point
Forest	50	459	178	4.9	4,932	15.5
Cacao	4	40	123	4.8	2,036	50.9
Coffee	4	40	98	4.2	1,678	41.9
Mixed	4	40	86	3.8	2,464	61.6
Citrus	4	40	82	3.8	2,029	50.7
Allspice	4	40	65	3.0	1,499	37.4
Live fence	4	40	97	4.6	3,722	93
Jalapeño	4	40	21	1.2	780	19.5
Corn	4	40	31	1.2	2,152	53.8
Bananas	4	40	9	0.5	160	4.2
Pasture	4	40	12	0.5	693	17.3
Total	90		226		22,145	

Source: Estrada et al (1997)

MAMMALS

Gallina et al. (1996) identified the following mammal species on 4 coffee plantations in Xalapa, Veracruz: 4 marsupials, 2 edentata, 1 rabbit, 4 large and midsize rodents, and 13 carnivores. Gallina et al also analysed the vegetation in four coffee plantations and determined that mammal diversity increases with the diversity or complexity of the vegetation. The table below describes salient characteristics of the vegetation on four samples, each of which represented a sample totalling 25000 m^2 from each of the four plantations. Samples one and four showed the most complexity, and sample three showed the least complexity.

Table 14: Description of Coffee Plots Studied

Characteristic	Sample 1	Sample 2	Sample 3	Sample 4
Overall density	moderate	low	high	high
Basal area	high	low	moderate	high
Cover	high	moderate	low	high
Tree diversity	high	low	moderate	high
Number of coffee plants	high	lower	high	high
Shrub cover	moderate	moderate	low	high
Herb Biomass	moderate	high	low	low
Herb Diversity	moderate	high	low	high

Source: Adapted from Gallina et al (1996)

Gallina et al. (1996) studied how changes in the arboreal strata affect different guilds of mammals. Guilds are groups of organisms that use similar resources, such as food, shelter, and foraging platforms. Table 15 below summarises response of the mammalian community to higher or lower levels of complexity in the coffee agrosystem.

Table 15: Mammalian response to complexity of coffee plot habitat

Mammalian Community	Coffee Agrosystem Higher complexity	Less complexity	Decrease (%)
Number of guilds occupied	11	6	45
Ecological richness	23	13	43
Ecological diversity*	0.95	0.54	43
Ecological equitability	0.92	0.69	24

*Ecological diversity was determined based on the Shannon-Weiner Index

Equitablity= the property of population distribution that refers to the numerical equality of various species populations in a community; Maximum equitability (1.00) is attained when all species maintain approximately equal populations.
Source Gallina et al (1996)

Gallina et al (1996) stress the conviction that biodiversity is not necessarily incompatible with a productive coffee system. They add that a diverse coffee agrosystem is an important habitat alternative for mammals (1996, pp. 25-26):

> The coffee agrosystem is one of the few productive systems capable of sustaining a highly diverse mammalian community, in spite of the transformation of the original vegetation, by maintaining arboreal strata for the coffee shade, thus providing good sources of food, shelter, nests, and protection for the mammals. The more susceptible mammals would be the species that depend on the trees, mainly anteaters, kinkajous, porcupine, margay, racoon, and coati. Most of these species are in danger.

They note further that, not only is the vegetation structure important, but also the “patchiness of the habitat,” that is to say the variations in vegetation and topography of the environment. Thus, the more variety the habitat offers, the greater animal species diversity it can support.

REPTILES AND AMPHIBIANS

Rendón-Rojas (1994) carried out a 64-hour daytime collection of reptiles and amphibians on a shaded coffee system, growing under an assembly of native trees in Oaxaca. The author found 16 species (5 of amphibians and 11 of reptiles). This number is somewhat lower than that reported in inventories of tropical rainforests, as reported by Pérez-Heredia et al.(1987), who encountered 94 species in Los Tuxtlas, by Lazcano-Barranco et al. (1992), who found 77 species in Chiapas. Moguel et al (1999) recommend more detailed inventories of herpetofauna be carried out in both daytime and nighttime collections under different coffee system conditions in order to follow up on the preliminary findings by Rendón-Rojas (1994). None of the available studies compare shaded to unshaded coffee systems.

ARTHROPODS

Ibarra-Nuñez (1990) carried out a study of the arthropods residing in the zone between ground level and 2 meters in a coffee garden near Tapachula, Chiapas, and collected individuals belonging to 609 (morpho) species and 258 families. Moguel and Toledo (1999) comment that these findings, in terms of relative numbers, are similar to those found by Janzen (1973) in tropical rainforest.

Perfecto et al (1996) collected arthropods in different coffee systems in Costa Rica and constructed the following table.

Table 16: Number of species of beetles, ants, wasps, and spiders in the canopy shade trees and coffee plants in different types of coffee farms, based on fogging with Pyrethin-based insecticides.

Species	**Type of farm**	**Number of species**			
		Beetles	**Ants**	**Non-ant hymenoptera**	**Spiders**
Shade trees					
Erythina poeppigiana	Traditional	126	30	103	NA
Erythina fusca	Traditional	110	27	61	NA
Annona sp.		NA	10	63	NA
E. poeppigiana	Technified with shade	48	5	46	NA
Coffee plants					
Coffea arabica[a]	Traditional	39	14	34	44
"	Technified with shade	29	9	31	NA
"	Technified no shade	29	8	30	29

NA: Data not available at time of printing

a. Coffee based on ten plants per treatment

Source: Perfecto et al. (1996)

Within plot diversity of insects is very large, so care is required in interpreting counts of species numbers. Within the same field and same shade tree species, located in close proximity, there is significant variation in insect species that are found. For example, Perfecto et al (p. 602) report the following data when collecting samples for their study:

> In the canopy of a single *Erythina poeppigiana* they recorded 30 species ants, 103 species of other hymenopterans, and 126 species of beetles. A second tree yielded 27 species of ants, 61 species of hymenopterans, and 110 species of beetles. Although the two sampled trees were less than 200 m apart, the overlap was only 14% for beetles and 18% for ants. These preliminary results suggest that shaded plantations can have local species diversity within the same order of magnitude as undisturbed forest.

Recall, also, the symbiotic relationship between insect population/variety and bird population/variety. Higher insect variety in diverse coffee systems provides a food platform to support additional avian diversity. Coffee plants, perhaps because they are introduced species, and perhaps because their leaves contain high concentrations of alkaloids, have relatively few insect pests of economic importance. Perfecto et al (1996) also reported 34% more spiders in coffee bushes in a traditional coffee system than in a monoculture. In a study by Konnarova(1985) under different management systems in Cuba, the author found that coffee leaf miners (*L. coffeella)* was present in relatively equal numbers in shaded and unshaded conditions. However, *Hymenoptera parasitica, Zagrammosoma* sp, and *Chrysonotomia* sp., which prey on coffee leaf miners, were favored by shaded conditions.

OTHER MACROFAUNA

Fragoso et al. (1993) found 97 species (71 native and 26 exotic) of earthworm in different environments of south-eastern Mexico. Of these, only 11 species were widely distributed. They also found that native species were adversely affected by disruption of the natural system. Exotic species, on the other hand, tended to thrive in disrupted ecosystems, particularly in tree plantations and pastures. This seems to indicate that native earthworm species would survive better in rustic coffee systems, while exotic species would benefit from other coffee systems. Further studies need to be done to determine the richness of native and exotic earthworm species in different coffee systems.

MICROBIAL DIVERSITY

Little research appears to be available on microbial diversity in coffee systems. However, as Russell (1997) points out that there are “few, if any microbiologically sterile sites in the environment.” It is possible that, if traditionally managed coffee sites enjoy other forms of biodiversity, such as mammals, arthropods and birds that these sites would also have more microbial diversity. However, the data are not available.

ECONOMIC FACTORS

The Smithsonian Migratory Bird Centre (2001) advocates a minimum shade cover in coffee plantations of 40% at solar noon (even after pruning). However, it should be noted that a maximum shade cover should also be maintained. Soto-Pinto et al (2000) reported highest coffee yields under a shade cover of between 30 and 45%. This is in keeping with findings in Costa Rica by Muschler (1997), which indicated optimal yields at 40% shade cover. Nevertheless, Soto-Pinto et al (2000) found that coffee farmers can obtain robust yields even under 50% shade; furthermore, they advocate this approach in coffee systems utilizing montane rain forest and sub-perennial rain forest in order to preserve as much natural forest as possible.

Gobbi (2000) studied the financial viability of investing in biodiversity-friendly certification in farms under five different production systems in western El Salvador:

- Traditional polyculture
- Commercial polyculture
- Technified shade (shaded monoculture) at an elevation of less than 1200 m.
- Technified shade (shaded monoculture) at an elevation of more than 1200 m.
- Unshaded monoculture.

The criteria established in 1997 by the El Salvador Ministry of Environment and Natural Resources for certification of coffee plantations as biodiversity-friendly are:

- Shade over coffee plants must cover a minimum of 40% of the land, with even distribution.
- Shade must be composed of a minimum of 10 native tree species, with a minimum density of 1.4 individuals of each species per hectare
- Prescribed conservationist practices for managing forest, soil, and bodies of water must be adopted.
- Hunting and removal of flora and fauna for commercial purposes are prohibited.
- Only authorized low-toxicity pesticides must be used, following international standards for the application of agrochemicals.
- Workers must be trained in the use, storage, and application of agrochemicals.

Using simulation analysis, Gobbi (2000) found that investments to meet the certification criteria were financially viable for farms that utilize the different coffee production systems in El Salvador. Because financially feasibility is directly linked to coffee yield, he found that the unshaded monoculture system had the highest potential profits. However, simulated returns for the traditional polyculture system, while lower than the returns for unshaded monoculture production also were considerably less risky. Furthermore, traditional polyculture systems require the smallest initial investment.

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