Biodiversity Conservation in Agroecosystems: A Comparison of Surface-dwelling Beetle Diversity in Various Shade Coffee Production Systems in Costa Rica

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Abstract

Beetle diversity was determined in six coffee agroecosystems representing a spectrum of structural complexity including (in increasing order) a chemical free site without shade, Poró (*Erythrina poeppigiana*), Eucalyptus (*Eucalyptus deglupta*), Amarillón (*Terminalia amazonia*), Banana (*Musa* spp.), and a control site at Los Cusingos Neotropical Bird Sanctuary. At each site beetles were collected using pitfall traps while leaf litter quantities and soil properties were recorded.

Beetles were not related to structural complexity *per se* but were more strongly affected by soil and leaf litter characteristics. They showed relatively strong co-relations to increased leaf litter, increased soil fertility and decreased soil compaction.

Introduction

Within the complex mosaic of landscapes, protected areas occupy only five percent of land uses while agricultural activities cover at least one third of the world's total land area (FAO, 2001). Agricultural systems not only occupy a dominant position in terms of land use they have broad ranging affects to ecosystems and society. Agriculture is an important force in international economies and is the livelihood of a vast number of people worldwide.

During the past fifty years there has been great expansion and intensification of agricultural practices that has had major detrimental impacts to biodiversity via deforestation and land degradation. Most deforestation in Central America has occurred since the 1950's and estimates in the 1980's indicated that almost 60% of lowland forests had been felled for conversion to agriculture and pastoral use (Kricher 1997, 339). By the early 1980's approximately 83% of Costa Rican forests had been felled for agricultural purposes. This extensive deforestation reduced and isolated the remaining forests resulting in widespread fragmentation. Forest fragmentation increases the possibility of local extinction events as a result of decreased migration between fragments and reduced genetic variability. Small forest fragments are not only more susceptible to local extinction, but experience decreased core/perimeter ratios which reduces the percentage of undisturbed habitat. The process of agricultural expansion and forest fragmentation are clearly deleterious to biodiversity, as vast tracts of forest habitat are lost.

In response to agricultural expansion, protected area isolation, and forest fragmentation conservationists have begun to develop alternatives to protected areas that focus on strengthening the existing network. Some conservationists are now exploring the potential for biodiversity conservation in agroecosystems as a means to defeat the adverse effects of land conversion. An ideal agroecosystem to explore this potential is coffee production. Coffee is one of the leading sources of foreign exchange in Latin America, it occupies approximately

44% of permanent cropland and covers as area of 2.7 million hectares (Perfecto et al. 1996, 598). Although recent estimates indicate that coffee production in Costa Rica only occupies approximately 2% of agricultural lands, it is one of the major land use practices in the Quizarrá–Santa Elena region and thus ensuring that coffee production is ecologically sound is critical to biodiversity conservation in the region.

There has been a growing trend throughout Costa Rica and Latin America in general to convert to unshaded coffee systems in response to the desire for higher yields, increased productivity, and ultimately greater economic gains. Recent estimated suggest that 41% of coffee produced in Latin America have been converted to unshaded or reduced shade production systems (Gobbi 2000, 268). From an ecological perspective there is a need to develop positive incentives for farmers to adopt features of traditional coffee production systems which impose less negative impacts to the environment. Features such as including a wide variety of plant and animal species, few external inputs, and focused on the minimization of risk employing low levels of technology will make a strong contribution to maintaining environmental health (McNeely 1995, 21).

The benefits of growing coffee under shade are abundant and diverse. Shade trees can facilitate crop growth by suppressing weed growth, diversifying commercial products, manipulating environmental growth conditions, and improving the quality of the crop (Beer 1987, 5). Shade trees also are capable of improving soil fertility and soil protection by improving aeration and drainage via the growth of the shade tree root system, controlling the microclimatic conditions (including temperature and humidity), and reducing soil erosion. Shade trees can increase the carbon sequestering potential of the site, increase crop pollination, control pest outbreaks, and provide habitat for biodiversity.

Among these potential benefits of shade coffee lies the conservation of biodiversity. A number of studies have examined the potential of shade grown coffee to conserve biodiversity from a variety of perspectives. Studies in Mexico indicated that when the complexity of the coffee production system is reduced, there is a significant decrease in the species richness and diversity of medium-sized mammals (Gallina et al. 1996, 23). Studies in Guatemala and Costa Rica indicated that shade coffee was better able to support avian diversity than sun grown coffee (Greenberg et al. 1997, 456; and Gonzalez 1999, 76). Evidence such as this suggests that agroecosystems, specifically shade coffee systems, can be a refuge for the diversity of various groups of organisms.

Objectives of the Study

This research examines the ecological implications of shade coffee production and management decisions of coffee producers to biodiversity. These results contribute to an overall understanding of biodiversity conservation in agroecosystems and serve to compliment the findings of a comparative study of bird diversity in various shade coffee plantations in the Quizarrá-Santa Elena region (Znajda 2000, 87). This research ultimately explores the possibility that shade coffee production enhances the ability of protected areas to conserve biodiversity. The four main objectives for this study are:

(1) To gather information regarding coffee production, management, and the selection of shade trees to acquire an understanding of the factors influencing the decision-making process

(2) To determine surface-dwelling beetle diversity of the lowland forest of Los Cusingos Neotropical Bird Sanctuary to serve as a benchmark for surface-dwelling beetle diversity in undisturbed lowland forest habitats.

(3) To determine surface-dwelling beetle diversity within five different coffee production systems.

(4) To develop recommendations for agricultural practices that favor surface-dwelling beetle diversity and biodiversity in general.

Study Region and Site Description

This study was conducted in the Quizarrá-Santa Elena region located in the county of Perez Zeledon in the El General Valley of southern Costa Rica. These communities are found within the Peñas Blancas watershed between the Las Nubes Biological Reserve to the northeast and the Los Cusingos Neotropical Bird Sanctuary to the south.

Sampling sites were selected to represent a gradient of structural complexity created by four of the most common shade grown coffee production systems in the region including Amarillón, Banana, Eucalyptus, and Poró. Los Cusingos Neotropical Bird Sanctuary served as a control site, and a small field that did not apply chemicals (entitled Organic) was included for comparison, resulting in a total of six sites. The six sites were each given a rank based on the level of structural complexity, where (Figure 1):

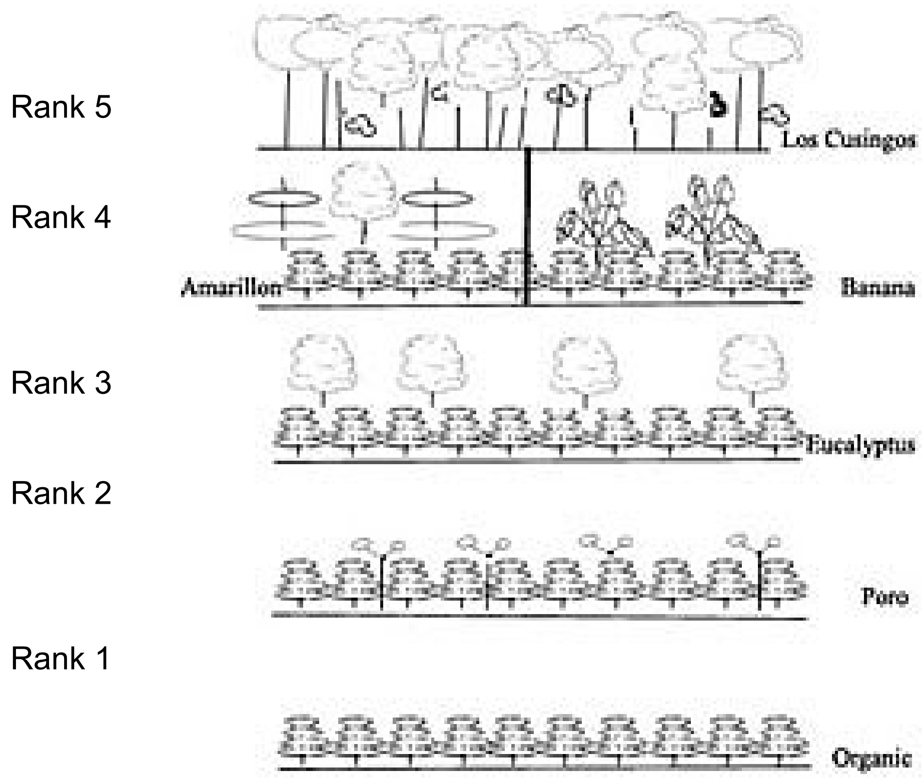
(a) Rank 1: *Coffee monoculture system* – with no shade tree species - Organic

(b) Rank 2: *Low agroforestry system* – with only one shade tree species subject to complete foliage removal three times annually – Poró (*Erythrina poeppigiana*)

(c) Rank 3: *Intermediate-low agroforestry system* – with only one shade tree species that provides significant cover due to abundant foliage and minimal pruning – Eucalyptus (*Eucalyptus deglupta*)

(d) Rank 4: *Intermediate agroforestry system* – with a low diversity of shade species (2 - 4 species) – Banana (*Musa* spp) and Amarillón (*Terminalia amazonia*)

(e) Rank 5: *Natural forest system* – with a higher diversity of shade tree species – Control (Los Cusingos)
(adapted from Perfecto and Snelling 1995, 1084)



Source: Adapted from Perfecto, I. and R. Snelling. (1995) Biodiversity and the transformation of an Agroecosystem: Ants in coffee plantations. *Ecological Applications* **5**(4), 1086.

Figure 1: Classification of shade coffee production systems in the Quizarrá – Santa Elena region.

The 1-hectare Organic site is located 3km south of Los Cusingos at an elevation of 600m. The field was planted the previous year and thus had no shade species present at the initial stages of the study, however, *E. poeppigiana* was planted during sampling period and will constitute the primary source of shade in the future.

The 9-hectare Poró site is located west of Los Cusingos at an elevation of 650m. Shade was generated by *E. poeppigiana*. Shade management practices were typical of Poró fields in that all branches were cut from the tops of the trees three times per year.

The 132-hectare Eucalyptus site is located 5km north of Los Cusingos and 5km south of Las Nubes at an elevation of 900m, but only a portion of the site (32-hectare) was used. Shade was generated by *E. deglupta* which experienced significant decrease in shade cover when owners reduced the quantity of Eucalyptus from 370 trees/hectare to 125 trees/hectare.

The 22-hectare Amarillón site is located to the south of Los Cusingos at an elevation of 700m. Shade is primarily generated by *T. amazonia* interspersed with Gallinazo (*Schizolobium parahybrum*). Other shade species are present but in much lower abundance including: Cedro (*Cedrela odorata*), Aguacate (*Persea americana*), Banana (*Musa* spp.), Mango (*Magifera indica*), María (*Callophyllum brasiliense*). Shade management practices were minimal as the shade species are characterized by diffuse foliage and heights of approximately 12m thus permitting sun to reach coffee layer.

The 8-hectare Banana site is located 5km northwest of Los Cusingos at an elevation of 700m. Shade is generated by a variety of *Musa* spp. including banana morado, banana criollo and platano. Other shade species are present but in much lower abundance including; Naranja dulce (*Citrus sinesis*), Limon acido (*Citrus auranifloia*), Guava (*Inga spectabilis*), and Poró (*E. poeppigiana*). Shade management practices included pruning of Poró and Guava twice annually. Banana was regularly cut after fruiting.

Los Cusingos is 76 hectares in size and composed of primary and secondary forest, with sampling from this study occurring in the secondary forest portion. Again only a fraction of the secondary forest was used for sampling, which was completely surrounded by forest canopy cover. Shade was generated by the multiple layers of canopy cover ranging from 2 –25m in height, characteristic of natural forest vegetation.

Table 1: Characteristics of six sites compared for beetle diversity in the Quizarra - Santa Elena region of Costa Rica. (CV = coffee variety, CH = approximate coffee height). Quizarra- Santa Elena, Costa Rica. March - June 2000.

Site	Rank	Area (ha)	Elevation (MASL)	CV	CH (m)	Shade species	Other sources of shade	Surrounding land use
Los Cusingos	5	76	600-780	none	none	none predominate	natural forest cover	road sugar cane Rió Peñas Blancas Amarillón site coffee
Amarillón	4	22	700	Catuaí Caturra	1.0 - 2.5	*Terminalia amazonia*	Gallinazo Cedro Aguacate Banana Mango	Los Cusingos road homes & pig farm cultivated forest Rió Peñas Blancas
Banana	4	8	700	Catuaí Caturra, Catimor Bourbon CR 95,	1.5 - 2.0	*Musa* spp.	Naranja dulce Limón acido Guava Poró	road pasture sugar cane
Eucalyptus	3	132 (32)	900	Catuaí Catimor	1.0 - 2.5	*Eucalyptus deglupta*	none	coffee pasture Quebrada Caño
Poró	2	9	650	Catuaí Caturra	1.5 - 2.0	*Erythrina poeppigiana*	Yuca	forest strip road sugar cane Los Cusingos coffee
Organic	1	1	600	Catuaí Caturra CR 11-13	1.0	none predominate	Guava Banana Coco Yuca	pasture trail scrub-land forested strip

Methods

Surface-dwelling beetle sampling methods

As the size of the sites varied significantly and the primary purpose of the study was to have an understanding of effect of structural complexity on beetle diversity, I selected 10 sampling locations per site. Sampling was conducted using pitfall traps that were evenly distributed throughout each site.

Beetles were collected using pitfall traps designed according to Morrill (1975) which were cost efficient and easy to use. Traps consisted of 7oz and 14oz cups, the smaller of which was placed within the larger (Figure 2). The larger cup was punctured with small holes to provide drainage and was installed in the soil ensuring that the outer lip was level with the soil surface. The 7oz cup was filled with 70ml of 70% alcohol and placed inside the larger. As the mouths of the cups were different sizes, a paper funnel was inserted to seal the gap. During the wet season, small lean-to bamboo roofs covered traps to prevent them from overflowing. Trap samples were collected every third day, labeled and returned to the laboratory for identification. A total of 710 samples were collected during the sampling period, 329 during the dry season and 371 during the wet season.

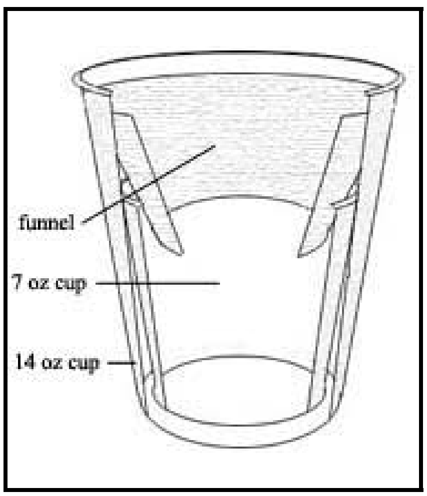


Figure 2: Plastic pitfall trap design. (Adopted from Morrill, 1975)

Beetles were removed from pitfall trap samples at the laboratory.Preliminary classification involved assigning an identification number to each species and creating a reference collection to be identified at the Instituto de Biodiversidad in San José. All species were identified to family, but most were not identified beyond this level and retained their original identification number for reference.

Soil Sampling and Leaf Litter Data Collection

Soil samples were extracted from each farm in May 2000. Samples were extracted from the topsoil from five points within each the site. The five extractions were thoroughly mixed and a smaller composite sample was sent to the Faculty of Agronomy at the University of Costa Rica for chemical and textural analysis. Soil extractions were analyzed to determine pH, the quantity of calcium, magnesium, potassium, aluminum, phosphorus, copper, iron, manganese, zinc and organic material. Textural analysis was conducted to determine the percentage of sand, loam and clay present. Soil compaction data was collected for each trap at each site. Again five points within a 1m radius of the trap were chosen and compaction was measured using a Lang penetrometer. The average compaction for each trap was used in the analysis.

Leaf litter depth was determined at each trap at each site using the average of five points within a 1m radius of the trap. Leaf litter data was collected at each visit to each trap to determine if leaf litter depths changed during the study period. Depth was measured using a ruler (mm).

Diversity measurement

Species richness, abundance and the number of samples were recorded for each measure of diversity at both the site and trap level. Diversity was measured at the trap level to determine if significant differences existed between the 10 traps at each site.

The Shannon index, its Evenness, and the Berger-Parker Index were calculated for each site for the west and dry seasons individually and the complete data set. The Shannon Index can be defined as: $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals in the *i*th species (Magurran 1988, 35). This index accounts for both the number of species and the relative abundance of that species. It is sensitive to rare species, and is simple and widely used, thereby facilitating comparisons. Evenness for the Shannon Index can be determined by:

$E = H'/H_{max} = H'/\ln S$ where: H' = observed species diversity, H_{max} = maximum species diversity and S = total number of species (Magurran 1988, 35).

The Berger-Parker Index accounts for both richness and relative abundance, presents the proportional importance of the most dominant species, and is simple and easy to calculate. It is expressed as: $d = N_{max}/N$ where N_{max} = the number of individuals in the most abundant species and N = the number of all individuals (Magurran 1988, 41). The Berger-Parker index is expressed in the reciprocal form (1/d) so that increases in the index value follows an increase in species diversity or a decrease in dominance.

A similarity index compared sites in terms the similarity of surface-dwelling beetle species composition. Correlation coefficients were generated for species abundance, species richness, diversity, soil texture, soil compaction and soil chemical composition.

Results and Discussion

Coffee Management Practices in the Quizarrá-Santa Elena region

The majority of coffee production systems are small scale (less than 10 hectares) where farmers grow *Coffea arabica*. Most farmers elected to produce the sun tolerant cultivars (catuai, caturra and catimor) which are able to grow in complete sun but also produce well with shade cover. Coffee pruning was conducted once annually at all sites except Organic, and the plants were cut to a height of 30-40cm leaving only the trunk intact.

All coffee producers applied chemicals to their field in the form of fertilizers, herbicides and pesticides with the exception of the Organic site. In general fertilizers were applied three times annually in May, June and November to coincide with the flowering, fruiting and post-harvest periods. Fertilizers were ‘complete’ formulas sold as a mixture composed of nitrogen, phosphorus, potassium, magnesium, and boron in varying concentrations. Fertilizers were applied to increase the amount of nitrogen in the soil to promote increased growth rates and proper fruit development.

Herbicides were applied to fields two to three times annually depending on weed prevalence. Those sites that used little herbicide relied on shade and pruning trimmings as natural forms of weed control. The organic site relied on manual removal of weed species. Pesticides were used several times annually to combat a number of pests including ‘Ojo de gallo’ (*Myecena citricolor*), Roya del cafeto’ (*Hemileia vastatrix*) and ‘Mal de hilacha’ (*Pellicularia koleroga*).

The management of ground cover is an important element of the microhabitat conditions affecting surface-dwelling beetle diversity. The Amarillón and Poró sites maintained the areas between coffee rows essentially void of vegetation. Ground cover generated from coffee pruning was found in small piles while the area directly beneath coffee plants retained small amounts of vegetative cover. At the Poró site, leaf litter was generated from tree pruning activities. Cuttings were allowed to fall between rows and were not removed, leaving large areas covered in leaf litter. At the Banana site leaf litter had clumped distribution as banana plants were cut after fruiting and leaves. Leaf litter was also present from coffee pruning and small amounts of vegetation were also present directly beneath coffee plants. The Eucalyptus site had the greatest amount of vegetative cover as one-third of the trees were cut during the study period. Entire trees, trunks and branches were left on the ground creating large areas of complete soil coverage. Coffee pruning also added to leaf litter present. Ground cover at the Organic site was primarily composed of living vegetation permitted to grow amidst the coffee.

Evaluation of the sampling techniques

Pitfall traps were selected due to their ease of use, accessibility and low cost of materials; however, there are a number of criticisms of this sampling method. The most prominent is that catch varies from species to species depending on the level of activity, habitat and behavior (French et al. 1998, 1325). The catch differential among species is accentuated by the use of alcohol in the traps as it attracts organisms that feed on decaying/ fermenting vegetative material. Research has indicated that although pitfall traps may be subject to scrutiny, they provide a solid indication of species presence in an area and when used over a significant portion of the species assemblage's lifecycle, can provide an accurate indication of population size (French et al. 1998, 1325).

Species area curves were created for each site to determine if significant sampling was conducted to effectively represent the surface-dwelling beetle communities. Results indicated that significant sampling was conducted for all five coffee sites. More sampling at Los Cusingos was necessary to fully represent its diversity.

Beetle Community Composition for Five Coffee Sites

There were 5510 individual beetles found in 73 species of 30 families captured from all sites. Of those 30 families the majority of individuals were found in the Scolytidae family (53%) which contained only two species totaling 2924 individuals. Scolytidae consume decaying woody materials and the alcohol in traps potentially served as an attractant. The correlation coefficient revealed that a significant positive relationship exists between the Scolytidae species and all other beetle species which suggests that Scolytidae are both naturally occurring in the region and abundant. Therefore alcohol presence did not significantly alter the natural distribution and abundance of beetle species present. Other prevalent families included: Nitidulidae (17%), Elateridae (8.7%), Ptiliidae (7.4%), Curculionidae (3.8%), Mycetophagidae (3.7%), Chrysomelidae (2.6%) and Scarabaeidae (2.3%). The remaining 22 families occupied 1% or less of the total number of beetles captured (Appendix 1).

Beetle Community Composition at Los Cusingos Neotropical Bird Sanctuary

There were 1299 individual beetles found in 47 species of 22 families captured at Los Cusingos which indicates that the composition of beetle families captured in coffee sites closely resembled that of naturally occurring surface-dwelling coleopteran fauna. At Los Cusingos most of the individuals were found in Scolytidae (38%), Nitidulidae (23%), Ptiliidae (21%), Mycetophagidae (4%), Curculionidae (4%), Nosotendridae (4%) while the remaining 16 families occupied 1% or less of the total number of beetles captured. These results provide a preliminary indication of the diversity and abundance of surface-dwelling coleopteran fauna at Los Cusingos (Appendix 2).

Similarity of Species Composition between Coffee Sites

Jaccard's similarity index compared sites to determine the similarity of surface-dwelling beetle composition. Indices equal to 1 when the species composition is identical between sites and 0 when there are no species in common (Magurran 1988, 95). The null hypothesis is sites which exhibited similar structural complexity, reflected in rank status, have more species in common than those that have different structural complexity. Results indicated sites with the same ranking like Amarillón and Banana (rank 4) were highly similar in beetle species composition. Comparisons between other sites tended to result in similarity indices of 0.5, and had only moderately similar species composition. This potentially suggests that structural complexity is not a prominent factor determining surface-dwelling beetle species composition.

Species Richness and Abundance

Inspection of the data presented in Table 2, shows that overall species richness is highest for Los Cusingos and the Organic site (47 and 46 respectively), Amarillón and Poró sites (38 and 36 respectively) and Banana and Eucalyptus sites (33 and 31 respectively). The correlation coefficient indicates that abundance and species richness are strongly correlated. Results indicate that Los Cusingos (1299) and Organic (1063) are most abundant overall, followed by Amarillón (1016), Banana (777), Poró (659) and Eucalyptus (504). The correlation coefficient indicates a strong correlation between species richness, abundance and surface-dwelling beetle diversity.

Table 2: Measurements of beetle species richness, abundance, diversity and evenness for each of the five coffee sites and Los Cusingos. Results are presented for the entire study period then divided into dry and wet seasons. Quizarrá-Santa Elena region, Costa Rica, March-June 2000.

TOTAL						
	Los Cusingos	**Amarillón**	**Banana**	**Eucalyptus**	**Poró**	**Organic**
Species richness	47	38	33	31	36	46
No. samples	117	120	116	112	124	121
No. individuals	1299	1016	777	504	659	1063
Shannon	2.24	1.53	1.72	1.89	1.71	2.05
Evenness	0.52	0.42	0.49	0.55	0.48	0.54
Berger-Parker	2.65	1.51	1.6	1.8	2.17	2.17

DRY SEASON						
	Los Cusingos	**Amarillón**	**Banana**	**Eucalyptus**	**Poró**	**Organic**
Species richness	32	21	28	21	28	36
No. samples	58	50	57	46	59	59
No. individuals	690	344	381	238	242	363
Shannon	2.14	1.5	1.75	1.53	1.82	2.55
Evenness	0.62	0.49	0.53	0.5	0.55	0.71

Berger-Parker	2.82	1.56	1.69	1.56	1.69	2.98

WET SEASON						
	Los Cusingos	**Amarillón**	**Banana**	**Eucalyptus**	**Poró**	**Organic**
Species richness	37	34	24	25	28	34
No. samples	59	70	59	56	65	62
No. individuals	612	681	401	272	431	754
Shannon	1.97	1.52	1.58	2.09	1.59	1.72
Evenness	0.55	0.42	0.5	0.65	0.48	0.49
Berger-Parker	2.5	1.51	1.55	2.14	1.58	2.05

Diversity Indices

Diversity was measured using the Shannon Index and the Berger-Parker Index. The Shannon index was selected because it has good discriminatory ability between similar sites, only moderately influenced by sample size, sensitive to changes in species richness rather than dominance, simple to calculate, and is widely used (Magurran 1988, 79). Even though not widely used, the Berger-Parker index was selected because it is sensitive to dominant species (in this case Scolytidae species) and has low sensitivity to sample size. Results from both indices (Table 2) show that Los Cusingos has the highest overall surface-dwelling beetle diversity followed by the Organic site which is consistent with species richness and abundance patterns. According to Table 2, this trend is observed for both wet and dry seasons. What changes considerably between wet and dry seasons, however, is the position of the Eucalyptus site showing relatively high diversity in the wet season and low in the dry season. The Poró and Banana sites exhibited moderate levels of diversity and remained similar for both seasons. The Amarillón site showed the lowest diversity for both seasons.

Analysis conducted for the total diversity showed that Los Cusingos, with the highest overall diversity, was significantly different from all other sites. The Organic site was significantly different from all sites except Eucalyptus. Eucalyptus, Poró and Banana were not significantly different from one another and Amarillón, with the lowest diversity, was significantly different from all other sites.

It was hypothesized that higher levels of structural complexity (rank) would have greater surface-dwelling beetle diversity. It was expected that diversity would be classed from highest to lowest: Los Cusingos (rank 5), Amarillón and Banana (rank 4), Eucalyptus (rank 3), Poró (rank 2) and Organic (rank 1). The observed results suggest that the degree of structural complexity does not affect surface-dwelling beetle diversity as Banana (rank 4), Eucalyptus (rank 3) and Poró (rank 2) were not significantly different. Evidence here suggests that surface-dwelling beetle diversity is not correlated to structural complexity generated by shade species and the possibility that other factors have a higher degree of influence over beetle diversity is explored below.

Leaf Litter Results

The accumulation of dead leave and twigs, commonly referred to as the litter layer presents important habitat for surface-dwelling beetles as it provides decaying material and fungi for consumption and houses a variety of springtails (Collembola) and mites (Acarina) for predacious species. It is hypothesized there is a positive relationship between the quantity of litter (depth) present and beetle diversity.

Prior to examining this hypothesis, the relationship of average litter depth to structural complexity (rank) is explored. The correlation coefficient suggests there is a positive correlation between average litter depth and structural complexity. Los Cusingos (rank 5) showed the greatest average litter depth and was significantly different from all other sites. The Eucalyptus (rank 3), Amarillón and Banana (rank 4), Poró (rank 2) sites followed and were not significantly different from one another. The Organic site (rank 1) showed significantly lower litter depths than others. This pattern was expected as increasing structural complexity generated by deciduous shade species increases the amount of leaf litter deposits. The Eucalyptus site exhibited greater litter depths than predicted because the producer had recently cut one-third of the trees, which increased the quantity of litter at the site.

Of the 29 beetle families found, 14 are characteristic of litter layer fauna including Scolytidae, Nitidulidae, Ptiliidae, Curculionidae, Scarabaeidae, Histeridae, Elateridae, Scydmaenidae, Tenebrionidae, Carabidae, Staphylinidae, Hydrophilidae, Colytiidae and Erotylidae. These families cumulatively represent over 90% of all beetles (Crowson 1981, 581). Average litter depth was positively correlated to beetle abundance and species diversity. This correlation can be accredited to increased leaf litter depths that increased the quantity of habitats for surface-dwelling beetles. As previously indicated leaf litter provides decaying material, fungi and prey species that form significant food sources for beetles. The litter layer is shown to be an important element to the ecology of surface-dwelling beetles and therefore retaining pruning trimmings as ground cover is pivotal to conserving beetle diversity in coffee agroecosystems.

Soil Results

This study focuses on three soil properties, namely, texture, compaction and cation exchange capacity (CEC) as an indication of fertility and their relationship to beetle diversity. The vast majority of soil arthropods live in the uppermost layers of the soil composed of the organic upper layer of plant debris and the topsoil layer composed of the upper, fine mineral soil that is interspersed with organic materials (Eisenbeis and Wichard 1987, 2). Since the relationship of leaf litter has already been discussed, this section focuses on the topsoil and the relationship of its properties to beetle diversity.

Soil plays an important role in ecology of most beetle families in a variety of lifecycle stages but most predominantly as immature stages. The majority of beetles deposit eggs into soil chambers that develop into larval forms, which rely solely on the soil environment for food acquisition. Other species use soil environments as adults searching for food items such as small animals, plants, roots, fungi and humic materials. Beetles rely on the soil system for both food acquisition and development thus soils are considered one of, if not the most, important habitats for beetles.

Soil texture plays an important role in the filtration of water, aeration and penetration capacity of plant roots. Texture also alters the workability of the soil and impacts the suitability of soils as habitat for a number of arthropod and vertebrate species. Soil texture is characterizes by the quantities on sand, loam and clay present. It was hypothesized that sites with loose soils (i.e. sandy) would have greater beetle abundance and diversity than more compact soils (i.e. clay) since sandy soils facilitate movement and prey presence. Soil texture analysis indicated that Amarillón and Los Cusingos sites were predominantly sandy soils. The Banana site also contained high quantities of sand mixed with loam (sandy loam), the Eucalyptus site was sandy, clay, loam, while the Organic and Poró sites were predominantly clay soils.

Results indicate that there is a strong positive correlation between the amount of sand in soils and rank, meaning those sites with high structural complexity had greater quantities of sand. Correlation coefficient results indicate that the percentage of sand in soils has a higher correlation to beetle abundance, richness and diversity than the percentage of clay or loam. The percentage of sand present in soils affects the movement of burrowing beetle species and dictates the availability of micro-faunal prey for predacious species. The weakness of this correlation may relate to the observation that the eight dominant families of beetles found in coffee fields were not burrowing as adults nor were they predacious. These families are characterized by species that are primarily phytopagous, saprophagous, fungivorous, and caprophagous. Therefore, it appears that soil texture is not a determinant of surface-dwelling beetle diversity as demonstrated by the weakness of the correlation.

Soil fertility is based on the sum of calcium, aluminum, potassium, and magnesium that is referred to as the cation exchange capacity (CEC) of the soil. Generally soils are considered highly fertile in tropical systems when the CEC is greater than 25 cmol/L, moderately fertile between 5 and 25 cmol/L and infertile below 5 cmol/L. In this study the CEC for all sites was in the moderate to low range (less than 25 cmol/L). The Organic and Eucalyptus sites showed moderate soil fertility (7.15 and 6.45 cmol/L respectively), the Amarillón, Banana and Los Cusingos sites showed low fertility (3.79, 3.76, and 3.06 cmol/L) while the Poró site was infertile (1.37 cmol/L).

The CEC of soils was negatively correlated to the structural complexity (rank) and leaf litter meaning that those sites with high structural complexity and greater litter depth showed lower fertility than sites that were less structurally complex or had less litter. It was expected that Los Cusingos would have the lowest soil fertility since the leaf litter was highest at that site. CEC tends to increase with increases in organic content (increased loam content) as it exhibits strong bonding capacity (Gerrard 2000, 42). Therefore, it was expected that the Organic site, which is a clay loam soil showed the highest CEC fertility as it retains binding capacity in the loam.

The CEC was moderately correlated to beetle diversity, whereby increased fertility showed higher levels of beetle diversity. I hypothesize that this correlation stems from adults and larval beetles occupying similar habitats, whereby increased soil fertility increases larval beetle populations and subsequently adult ones. This hypothesis is based on results from an investigation of the possibility of higher taxa to predict overall arthropod diversity (Weaver 1995, 940). Weaver examined correlations between several different taxonomic groups and found that species richness of the Coleoptera adults was correlated to richness of larval forms. This hypothesis is yet to be tested and thus no conclusions are drawn at this time.

Soil compaction can cause deterioration of soil structure by influencing the proper functioning of most physical, chemical and biological properties, which in turn can adversely affect soil fertility and productivity (Heisler and Kaiser 1995, 159). Alteration of soil structure as a result of compaction, leads to decreased porosity, decreased water permeability, aeration, gas exchange, denitrification rates, and negatively impacts soil mesofauna (including beetles) by restricting the creation of burrows for adult and larval forms.

Soils composed of large amounts of sand have low compaction, while those composed of clay or loam have higher compaction levels. Los Cusingos has highly sandy soils and the lowest degree of compaction. The Amarillón and Banana sites showed low compaction as well being composed of sandy loam clay, and loam soils. The Poró site, which was primarily clay, showed high compaction. The Eucalyptus site, a sandy loam clay soil, showed the highest degree of compaction. The Organic site showed very low compaction possibly because soils were protected by vegetation, who's root systems served to loosen soils and increase aeration.

Soil compaction was negatively correlated to site rank, meaning that higher structural complexity occurred at sites with low soil compaction levels. Structurally complex systems, composed of several species, have more extensive root systems that promote aeration of soils and reduce compaction. Surface-dwelling beetle abundance and diversity was strongly negatively correlated to soil compaction. As indicated above, many beetle families present in this study use soils for movement, feeding on fungi, and larval development. Therefore, increased beetle abundance in soils that are not compacted is reflective of the higher potential for mobility, presence of habitat for prey and area for fungal growth.

Conclusions and Recommendations

Strengthening the effectiveness of protected areas by conserving biodiversity in agroecosystems is a complex process but one that is achievable. This study explored the potential to maintain biodiversity in coffee production systems by examining surface-dwelling beetle communities. The results have not only contributed to understanding the relationship of surface-dwelling beetles to ecological features (structural complexity and soil properties) and management decisions (i.e., impacts of soil management practices and chemical applications) but have indicated that coffee agroecosystems are capable of maintaining moderately diverse populations of surface-dwelling beetles.

These conclusions pertain specifically to surface-dwelling beetle diversity but provide insight towards the total biodiversity of the five coffee production systems. The decision to use Coleoptera, a very coarse taxonomic, was made because species names were not known. Research by Lawton et al. (1998) suggested that in cases where taxonomic groups share the same habitat or had food web linkages, one taxon could indicate changes in species richness of other taxonomic groups. Applying that observation to this study suggests that surface-dwelling beetle diversity may provide a good preliminary indication of surface-dwelling insect diversity because they share similar habitat requirements. Lawton et al. (1998); however, caution that some researchers advise that conclusions about total species richness based on observations from one taxonomic group maybe misleading and suggest that monitoring changes in biodiversity require a wide range of taxa including species with very different life histories and ecologies. For this reason I believe the strongest conclusions regarding the capacity of these coffee production systems to conserve biodiversity is by examining the results of this study with those from Znajda (2000).

Znajda's avian diversity study (2000) did not include measurements at Los Cusingos nor at the Organic site but focused on the four other coffee production systems. Since avian diversity at Los Cusingos is known to be high and results indicate this to be true for surface-dwelling beetles I conclude that it is capable of retaining high levels of biodiversity despite encroachment and fragmentation. Bird diversity and surface-dwelling beetle diversity in Eucalyptus, Poró and Banana sites were not significantly different from one another and were able to retain moderate levels of biodiversity. Results for the Amarillón site differed greatly for birds and beetles and thus no conclusions can be drawn concerning its abilities to conserve total biodiversity until further research is conducted.

The overall management objective for ecologically sound coffee production in the region is the maintenance of moderate production of high quality coffee while maximizing biodiversity to the greatest extent possible. Naturally reverting to traditional coffee production practices is unfeasible and uneconomical. However, elements from traditional systems can be applied to coffee production practices in the region without reducing economic benefits. The three elements include an increase in shade cover, decrease in chemical inputs and emphasis on the health of the entire system including soils. Firstly, to promote high levels of total biodiversity it is recommended that the amount of shade cover be increased using Eucalyptus, Banana or Poró since these sites were able to support moderate diversity levels of birds and beetles. It is recommended that the Poró trees not be cut so drastically and allowed to retain foliage to support birds and other species. Secondly, to further support total biodiversity it is recommended that chemical applications be reduced or preferably eliminated based on the evidence provided by the Organic site which supported higher levels of surface-dwelling beetle diversity than all other coffee production systems examined. Thirdly, the final element to improve coffee production practices is an emphasis on ground cover, soils and their properties. Results indicate that beetles prefer sites with high cation exchange capacity, low compaction and high leaf litter content. It is recommended that coffee producers increase leaf litter content by increasing shade cover and allowing litter to decompose naturally rather than piling, thus distributing the nutrients from leaf litter more evenly throughout the fields. These alterations to existing coffee production systems in the Quizarrá-Santa Elena region should strengthen the ability of coffee fields to conserve biodiversity and contribute to strengthening the protected areas network.

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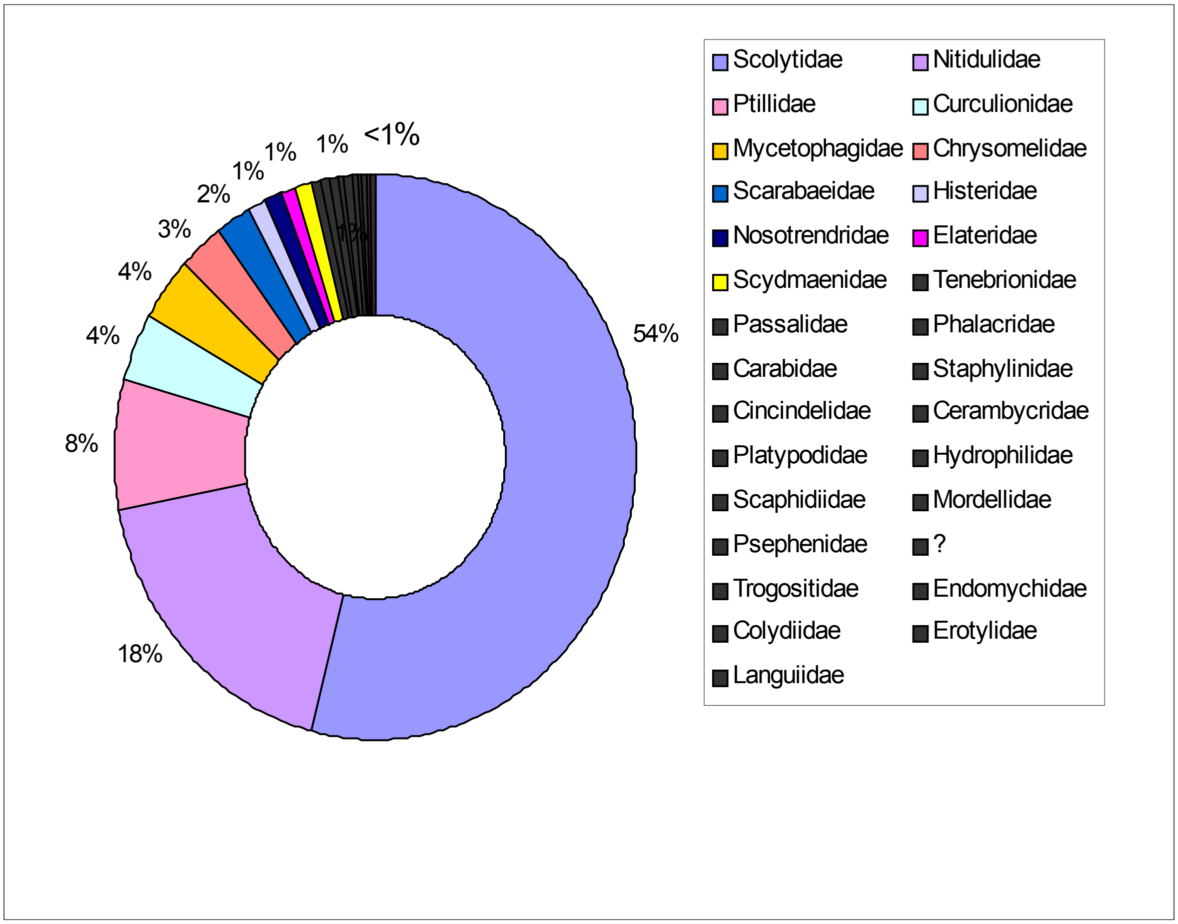
Appendix 1:

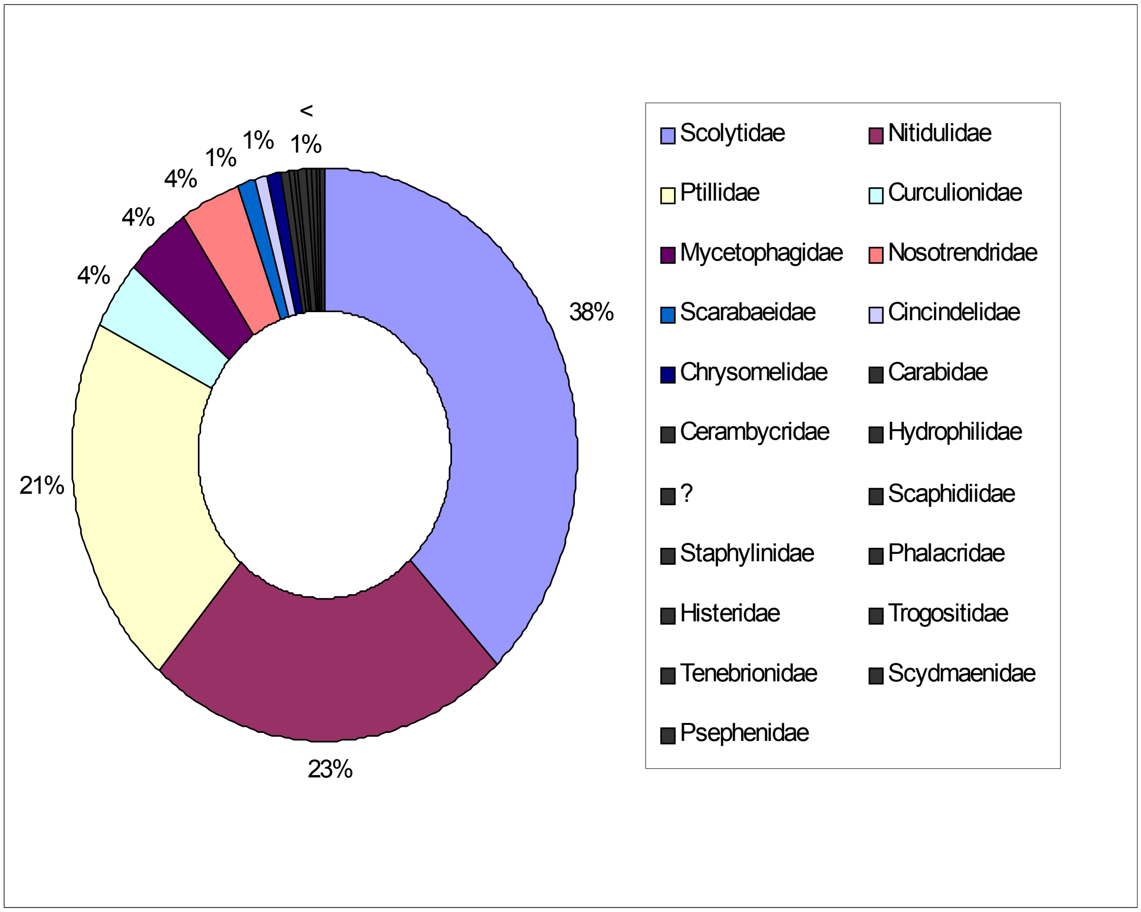
Percentage of individuals from each family present in total captures from pitfall



traps in the Quizarrá-Santa Elena region, Costa Rica, March-June 2000.

Appendix 2:

Percentage of beetles from each family captured in pitfall traps at Los Cusingos



Neotropical Bird Sanctuary, Quizarrá-Santa Elena region, Costa Rica, March-June 2000.