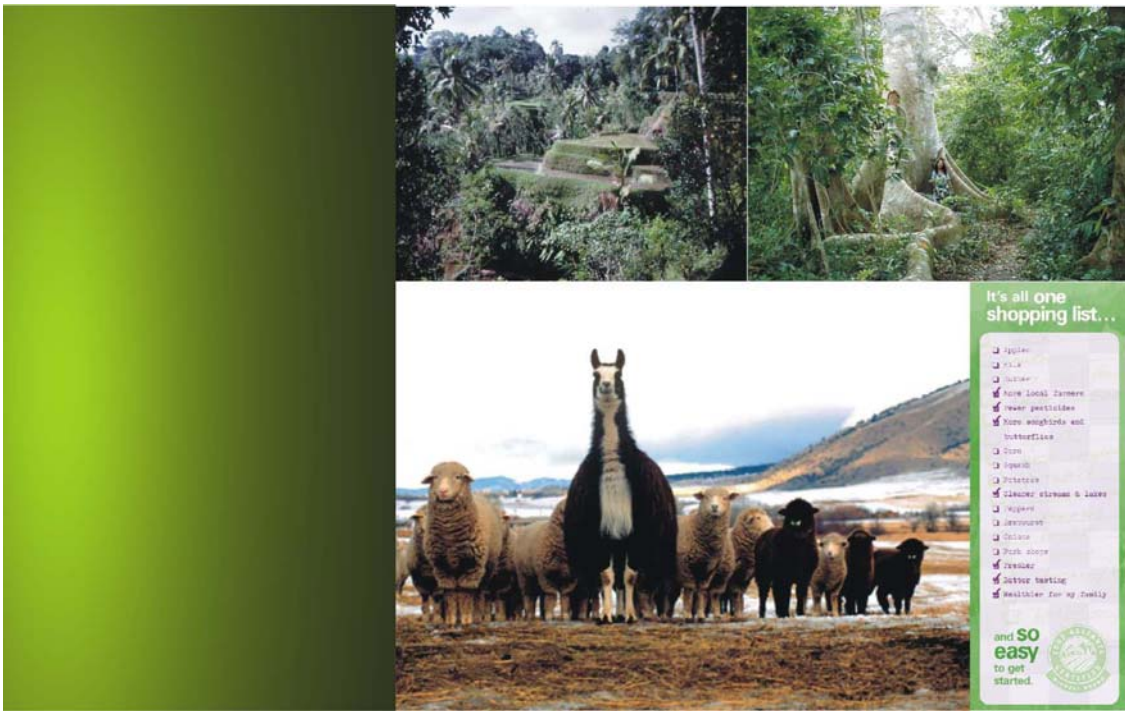

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UPDATE

Science, Policy & Emerging Issues

DOUBLE SPECIAL ISSUE: AGRICULTURE AND CONSERVATION

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A forum for information exchange on endangered species issues
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Cover Clockwise: rice terraces in Bali, Indonesia (J. Vandermeer); coffeee plantation in Chiapas, Mexico (J. Vandermeer); llama guarding over sheep in Montana (B. Weed and W. Campbell); part of a brochure advocating purchase of local, environmentally friendly, and socially responsible farms in the upper Midwest (produced by the Land Stewardship Project).

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John Vandermeer holds a Ph.D from the University of Michigan, where he has been faculty since 1971. His research interests include nonlinear dynamics, especially as applied to population models; dynamics of rain forest succession following catastrophic damage; ecology of multidimensional agroecological systems; and dynamics of rain forest destruction and conservation — socioeconomic and political analysis of neotropical conversion. He has done extensive fieldwork in Costa Rica, Nicaragua and Mexico.

From the Editor

Most scientists agree that we are facing a substantial loss of biodiversity comparable to the massive extinctions caused by natural disasters and climate change in the past. This time, however, the cause of the disappearance of species is human activities, in particular agriculture. Agricultural production in the last 200 years has become a more mechanized, input-dependent driven activity. For many policy makers, agronomists, agribussiness executives and conservationists, the food needs of an increasing population can only be met by increasing production of agricultural commodities, even if it means increasing the amount of inputs that are harmful to the environment and biodiversity such as chemical fertilizers, pesticides and genetically modified organisms. Advocates of agricultural intensification view agricultural landscapes as barren and insist that by increasing production in places already "devoid" of life, we can save the few "pristine" places left.

This special issue of the Endangered Species Update on agriculture and conservation challenges the belief that agricultural land is a sacrifice land with no importance for biodiversity and that crop yields must be increased to feed the world. First, as most of the contributors express, the most effective way species can be saved from extinction is if agricultural land is seen as recipient and source of biodiversity. Second, overproduction of most crops, not scarcity, has led to falling commodity prices, the bankruptcy of many small farmers, and the loss of biodiversity in many parts of the world. Agriculture *per se* is not the cause of biodiversity loss, but how some agricultural practices are carried out.

The contributors to this special issue shed light on the connection between agriculture and conservation and the need of a paradigm shift. While habitat land preserved in areas such as national parks is vitally important, the persistence of biodiversity in the long run will be successful only if we stop seeing human landscapes as wasteland.

Saul Alarcon Farfan
Publication Editor

Habitat Changes in Colombian Coffee Farms Under Increasing Management Intensification

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Abstract

I analyzed a set of environmental and vegetation variables in order to characterize an intensification gradient for coffee production agroecosystems. I measured 14 habitat variables within 12 Colombian farms classified into four management systems at the Risaralda region of Colombia: Forests, Polygeneric Shaded coffee, Monogeneric Shaded coffee and Sun coffee plantations. The habitat variables were categorized into three vertical levels: arboreal, shrubs and soil. Univariate and multivariate analyses showed that the habitat effect is driven mainly by drastic changes (i.e. elimination) in the arboreal level along the intensification gradient, although variables at other levels showed gradual and sometimes unexpected changes. I then adapted the management index developed by Mas and Dietsch (2003) to the coffee plantations in this study. The quantitatively supported management index showed a close correspondence to the initial qualitatively classification of the farms. I conclude that intensification of coffee production has clear measurable effects on habitat characteristics and that the management index reflects the gradient of intensification in the studied farms. The approach of using the management index could be highly valuable for the programs of shade coffee certification and conservation goals.

Cambios en el Habitat en Plantaciones Colombianas de Café Bajo un Incremento en la Intensificación de Manejo

Resumen

Analizé una serie de variables ambientales y de vegetación para caracterizar un gradiente de intensificación para agroecosistemas de producción de café. Medí 14 variables relacionadas a habitat en 12 plantaciones colombianas clasificadas en cuatro sistemas de manejo en la región de Risaralda en Colombia: bosque, café de sombra poligenérico, café de sombra monogenérico y plantaciones de café sin sombra (de sol). Las variables relacionadas a habitat fueron categorizadas en tres niveles verticales: arbóreo, arbustivo y suelo. Los análisis de una sola variable y de variables múltiples mostraron que el efecto del habitat es influenciado principalmente por cambios drásticos (esto es, eliminación) en el nivel arbóreo a lo largo del gradiente de intensificación, aunque las variables a otros niveles mostraron cambios graduales y en algunos casos cambios inesperados. Posteriormente adapté el índice de manejo desarrollado por Mas y Dietsch (2003) para plantaciones de café. El análisis a nivel cualitativo obtenido con el índice de manejo mostró una correspondencia cercana a la clasificación cualitativa inicial de plantaciones. Concluí que la intensificación de la producción de café tiene claros efectos medibles en las características del habitat y que el índice de manejo refleja el gradiente de intensificación en las plantaciones estudiadas. La técnica de usar el índice de manejo pudiera ser altamente valiosa en los programas de certificación y conservación de café de sombra.

Changements des Habitats dans les Fermes Colombiennes sous une Intensification de Gestion

Résumé J'ai analysé un ensemble de variables environnementales et de végétation afin de caractériser un gradient d'intensification pour des agroécosystèmes de production de café. J'ai mesuré 14 variables d'habitat dans 12 fermes colombiennes classifiées dans quatre systèmes de gestion dans la région de Risaralda de la Colombie: Les forêts, des plantations café d'ombre polygenerique, des plantations café d'ombre monogenerique, et des plantations café du soleil. Les variables d'habitat ont été classées dans trois niveaux verticaux: arborescent, arbustes et sol. J'ai utilisé des analyses univariables et multivariables et ai constaté que l'effet d'habitat est conduit principalement par les changements énergiques (c.-à-d. élimination) de la végétation de niveau arborescent le long du gradient d'intensification, bien que les variables à d'autres niveaux aient montré les changements progressifs et parfois inattendus le long du gradient. Ensuite, j'ai adapté l'index de gestion développé par Mas et Dietsch (2003) aux plantations de café dans cet étude. L'index de gestion est quantitativement soutenu et a montré une bonne corrélation à la classification qualitatif originale des fermes. Je conclus que l'intensification de production de café a des effets clairement mesurables sur leur caractéristiques d'habitat et que l'index de gestion reflète le gradient de l'intensification dans les fermes étudiées. L'approche d'employer l'index de gestion peut être fortement valable pour les programmes avec les buts de certification et conservation de café d'ombre.

Introduction

Agricultural intensification has been defined as the patterns of land-use change with the common feature of increase resource use to augment agricultural production (Giller et al. 1997). It is generally associated with specialization, increasing mechanization and generalized use of agrochemicals and other external inputs (Giller et al. 1997; Decaens and Jimenez 2002). This intensification negatively impacts the agricultural land, which is usually the matrix among forest fragments and therefore valuable for conservation purposes (Vandermeer and Carvajal 2001, Perfecto and Vandermeer 2002). There is growing awareness in the literature that agroecosystems should be a priority in the biological conservation agenda (Paoletti et al. 1992; Pimentel et al. 1992; Vandermeer and Perfecto 1997; McNeely and Scherr 2003) due to growing evidence that some agroecosystems are repositories of high levels of biodiversity (Pimentel et al. 1992; Roth et al. 1994; Perfecto et al. 1996, 1997; Perfecto and Armbrecht 2003).

It has been well documented that agroecosystems with high planned biodiversity foster high levels of associated biodiversity and that the intensification of agriculture negatively affects associated biodiversity (Andow 1991; Pimentel et al. 1992; Decaens and Jimenez 2002; Perfecto and Armbrecht 2003). Swift et al. (1996) have hypothesized several predictions regarding alternative patterns in which associated biodiversity decreases with intensification of agriculture. However, testing mechanistic hypotheses first requires the quantification of intensification.

The coffee agroecosystem has received considerable attention over the last decade with regard to the effect of intensification on biodiversity (Nestel et al. 1993; Perfecto et al. 1996, 1997; Greenberg et al 1997a; Moguel and Toledo 1999; Dietsch 2003; Armbrecht and Perfecto 2003), but there is a need to quantify habitat changes for this particular case. There are two reasons that justify the need for a better quantification: first, coffee production occurs across a wide gradient of agricultural intensification, involving different levels and varieties of shade trees (Moguel and Toledo 1999; Perfecto et al. 1996, 1997; Johnson 2000); and second, this agroecosystem is now known to be important for conservation biology (Vandermeer and Perfecto 1997; Moguel and Toledo 1999; Rappole et al 2003; Perfecto and Armbrecht 2003).

Intensification of agriculture can be quantified through various indices, which consider the measurement of variables presumed to determine its degree at particular scales. Giller et al. (1997) proposed an index or "degree of intensification" which was further modified by Decaens and Jimenez (2002) and named "Agricultural Intensification Index" (AI). The Agricultural Intensification Index (AI) is the average of seven subindices, equally weighted, which range from 0-1: (1) LUI, the land use intensity, or the proportion of the year the system is cropped; (2) FF, the mean fire frequency or burnings/year;
(3) TF, the mean tillage frequency/year;
(4) MPF, the mean frequency of motorized practices/year; (5) SR, the mean annual stocking rate (International Animal Units/ha); (6) FR, the mean fertilization rate (kg of chemicals used per year); and (7) PCR, the mean pest control rate (kg of chemicals used per year).

The coffee agroforest poses additional challenges to researchers, since some of the intensification variables defined in the AI are not meaningful in this context (e.g., LUI, FF, TF) because coffee agroforests are not tilled, no fire is used (unless accidental), and coffee is a perennial crop (Beer 1998) standing for several decades (Willson 1999).

Despite the fact that new studies accounting for differences among shade regimes in coffee plantations have quantified independent variables related to the structure of vegetation and habitat changes (Babbar and Zak 1995; Perfecto and Vandermeer 1996; Greenberg et al. 1997a; Decaens and

Jimenez 2002; Klein et al. 2002; Armbrecht and Perfecto 2003; Mas and Dietsch 2003), many studies focusing on different coffee management systems have not reported such variables (e.g., Borrero 1986; Greenberg et al. 1997b; Beer, 1998; Wunderle and Latta 1996; Ibarra-Núñez and García-Ballinas1998; Molina 2000; Sossa and Fernandez 2001; Ricketts et al. 2001; Rojas et al. 2001; Perfecto and Vandermeer 2002). The potential problems associated with the failure to quantitatively assess intensification have been highlighted by Rappole et al. (2003), who argued that any plantation, regardless of the diversity and density of shade, could be considered a "shade coffee" plantation. The lack of a rigorous definition for shade coffee may have serious practical implications since shade coffee has emerged in recent years as an important component of biodiversity conservation programs among several environmental organizations such as Conservation International, The Rainforest Alliance and Eco-OK (Perfecto and Armbrecht 2003; Dietsch 2003).

Mas and Dietsch (2003) developed an index of management intensity (management index, MI) for coffee agroecosystems in order to evaluate whether qualitative differences between shade coffee agroecosystems correspond to quantitative differences in vegetation and farm management. Their index used seven equally weighted vegetation variables, which they considered directly related to flying insects such as butterflies. This management index was then related to the richness of fruit feeding butterflies in differentially shaded coffee plantations of Chiapas, Mexico (Mas and Dietsch 2003). The MI can be flexibly adapted to different targeted taxa in biodiversity studies. The present study is intended to test the extent to which a subjective categorical classification of farms along a gradient of intensification corresponds to a quantitatively supported classification by applying a modified version of Mas and Dietsch's management index. Additionally, this study aims to quantify habitat changes among Colombian coffee farms under a strong intensification process and compare them to other related studies.

Study Site

The Andean mountains of Risaralda Department, Colombia (5º 08' N; 75º 56'W), where the Apía municipality is located, range between 1400-1900 m
a.s.l. Annual temperature and annual precipitation average 20°C and 2,320 mm respectively, the latter having a bimodal distribution with peaks in May and December (raw data from IDEAM Meteorological Stations, Colom

Farm's name	Management code	Area (ha)	Elevation (m a.s.l.)	Percentage slope (%)	Use of pesticides (appl./year)
MonteverdeF	For1	15	1845	59.6	None
Playabonita	For2	2	1444	61.3	None
El Porvenir	For3	1.5	1605	39.3	None
La Playita-1	PS1	15	1490	48.3	None (organic)
La Esperanza	PS2	4	1500	34.6	None (not organic)
La Clarita	PS3	7.5	1550	43.8	None (organic)
Monteverde	MS1	4	1720	43	Low
Buenos Aires	MS2	6	1440	40	Low
El Convenio	MS3	4	1465	64.4	Low
La Felisa	Sun1	6	1480	32.5	Moderate
La Estrella	Sun2	14	1470	17.5	Moderate
La Maria	Sun3	3	1405	2.5	High

bia, 2002). The Apía region has a rugged topography with scattered secondary forest fragments that become continuous at higher altitudes (~4000m elevation) at the "Tatamá Natural Reserve." The Apía was a typical, traditional shade coffee growing area for many decades. However, in the last 20 years, coffee crop cover has decreased by more than 700% (seven-fold) of the initial area covered (ANFCG, 2002), and 60-70% of the remaining tree cover is composed of plantains used as barriers (personal observation December 2002). During the last decade, many coffee plantations were converted into cattle pastures and other agricultural

Table 1. Names and general characteristics of the 12 farms involved in the study at the Apía Municipality of Risaralda Department, Colombia. Use of pesticides high: is at least two applica-tions/year (pesticides and herbicides), moderate: at least one ap-plication/year, low: less than one application/year.

uses, and the coffee plantations that still stand have suffered a dramatic intensification change. The changes involve variying degrees of elimination of shade trees including the complete elimination of any shade, which is concomitant with increasing application of agrochemicals for the control of the coffee berry borer and for weeds.

Twelve farms, grouped in four qualitatively classified management types were chosen haphazardly at the Apía municipality. Following Nestel

#	HABITAT VARIABLES	For1	For2	For3	PS1	PS2	PS3	MS1	MS2	MS3	Sun 1	Sun 2	Sun 3	P
1	Percentage canopy cover	96.1	96.7	90.5	69.0	80.9	86.9	36.9	74.3	77.4	25.3	24.2	36.9	<0.0001
2	Tree species richness	14	7.5	13.5	4.5	8	3.5	2	2	2	1.5	1	0.5	0.011
3	Tree density in 452 m^2 (#/circle)	24	14	30.5	12	23	6	9.5	5.5	5	1.5	1.5	1.5	0.012
4	% trees with epiphytes	10.7	18.8	28.2	41.7	27.1	72.9	5.6	10	40	25	25	0	NS
5	Total epiphytes	N/A	87	55	72	35	56	3	2	5	1	2	0	0.02
6	Average tree height (m)	8.5	7.3	9.0	6.2	7.7	7.9	10.4	8.0	9.5	7.3	4.0	3.7	0.032
7	%dominance of one shade tree	20.2	34.3	28.6	41.7	35.6	63.3	88.9	81.8	80.0	97.7	98.7	100	<0.0001
8	Average dbh, live trees	14.7	18.1	17.0	22.5	20.7	23.4	21.5	30.5	22.7	21.2	22.9	11.3	NS
9	Vertical Hetero-geneity (H')	1.5*	1.4*	1.5*	1.2	1.4	1.5	1.2	1.4	1.3	0.9	0.6	0.7	<0.001
10	Number of coffee bushes (78.5m^2)	43.5*	45.5*	73.5*	36.0	22.0	50.0	39.5	42.5	57.5	59.0	66.5	71.5	<0.0001
11	Average coffee height (m)	9.0*	8.9*	8.5*	2.0	2.5	2.5	2.2	2.6	2.2	1.8	1.7	1.4	0.024
12	Average number of logs in 4m2	4.8	5.1	4.5	3.4	4.3	5.2	2.3	2.3	1.2	0.9	1.4	0.2	<0.001
13	Log diameter (cm)	5.3	9.	6.0	7.1	8.9	7	5.7	4.8	8.7	11.1	13.6	7.4	NS
14	Avg # of logged trees in 4m^2	0.5	0.5	7.5	3.5	3	13.5	1.5	1.5	1	1.5	1.5	0.5	NS

and Altieri (1992), the four management types were: Forest (F), Organic Polygeneric Shade coffee (PS), Monogeneric Shade coffee (MS), and Coffee Monoculture or Sun Coffee ("Sun"). For simplicity, each farm was assigned a code (Table 1). Two sets of criteria were used to decide the qualitative classification of the farm management type: a) a visual assessment of presence and diversity of trees; and b) information that farmers provided about farm management with regard to number of agrochemical applications per year and shade management. With regard to the forest fragments, I determined that the three forest fragments appeared to be secondary natural dense vegetation, disturbed and isolated. The forests were located relatively close to the coffee plantations (the primary forests that exist many kilometers from the municipality did not fit for comparison purposes of this study). The Monogeneric Shaded coffee plantations (MS) were subjectively perceived to be dominated by trees belonging to the genus *Inga* or *Cordia*. The Polygeneric Shaded coffee farms were organic and their shade trees were apparently more varied than those in the MSs. Sun coffee plantations had few or no shade trees, although it was not possible to find 100% open plantations because farmers still allow some isolated valuable trees and plantains within their plots. Therefore, measurements on the existing plantains (or any isolated tree) within these sun coffee plantations were done even though the habitat by definition should not have arboreal vegetation. As part of the study site description, percentage slope was calculated by measuring both the vertical and horizontal components of the slope at four haphazardly chosen sites at each farm.

Methods

The characterization of the habitat at the Apía region followed the protocol established by Mas and Dietsch (2003) for coffee farms under different management systems in Mexico. In this protocol, a "management index" quantifies the effects of the management intensification on the shade tree canopy. Seven variables, each varying from 0 (least intensive condition) to 1 (most intensive condition) were used in calculating this index. Although Mas and Dietsch's paper reports and statistically compares 13 vegetation variables among their seven farms, they actually used only seven of those variables to determine their management index. Not all of the variables used by Mas and Dietsch were measured in this study because they focused on fruit feeding butterflies (influenced by canopy structure) while I was seeking to develop a management index that would be applicable to the study of ground and leaf litter organisms such as ants. In the study, I obtained the following 14 habitat variables, which were grouped in three vertical strata: arboreal stratum, coffee bush stratum, and soil (low) stratum. The arboreal stratum included percentage canopy

Table 2. Average values for each of the variables measured (based on two circles per plot) to characterize the habitat of nine coffee plantations and three forest fragments at Apía. Variables are averages at either the "circle" level (#2,3,4,6,7,8,10, 15) or the "site" level (#1,9,11,12,13,14) or at the farm level (#5). Values marked M— are for understory plants. Last column, P, indicates alpha probability for mixed model analysis of variance. Degrees of freedom are 3, 8 except for variables 10 and 11 where forest values were taken out.

cover, tree species richness, tree density, percentage of trees with epiphytes, number of epiphytes, tree height, percentage dominance of one shade tree, and diameter at breast height (dbh) of live trees. The coffee bush stratum considered vertical heterogeneity (up to 5.4m), number of coffee bushes, and coffee height. The soil (low) stratum included the number of logs, log diameter, and number of logged trees.

All habitat variables were measured between November and December 2002 at the 12 farms. In each farm, two sampling sites (or "circles") separated by approximately 50-100m, were haphazardly selected. Each sampling site consisted of a circle of twelve-meter radius within which all trees greater than 8.13 cm diameter at breast height (dbh) were identified to species. Also a visual inventory of the tree species in each plot was made. Height, dbh, presence of epiphytes, fruit or flowers were recorded for each tree. All coffee bushes or understory plants in Forest sites between 2.5-8.1cm dbh were counted within a five-meter radius circle located at the center of the larger circle. These were the only trees recorded for the management index calculation, and additional visual search was done by a botanist at each of the plantation plots for an inventory of the trees. Canopy and soil sampling points were established at four-meter intervals along the north-south and east-west axis of the sampling location for a total of 13 sampling points. At each sampling point, a spherical densiometer (Forestry Suppliers, Biloxi, Mississippi) was used to obtain the percentage canopy cover; the diameter dead logs was measured and dead logs greater than 2.5cm were counted in a 2m x 2m area next to the sampling point. Vertical heterogeneity of the understory was measured using the Vertical Intercept Line technique (Mills et al. 1991). The technique uses a 5.4m aluminum tube labeled with tapes of two colors, one color defining nine vertical consecutive intervals of 60cm (A), and the other color defining 54 ten-centimeter intervals (B) in such a way that each of the large nine intervals contain six 10cm intervals. The tube was placed vertically between two coffee bushes. Any vegetation contact within an imaginary 1dm radius cylinder around each of the tube segment was registered. Shannon-Wiener index (Magurran 1988) was calculated by using large intervals as species and small intervals as abundances.

Data analyses: Means of the variables for the four management types were statistically compared by mixed model nested analyses of variance with

#	MGMT INDICES	For1	For2	For3	PS1	PS2	PS3	MS1	MS2	MS3	Sun1	Sun2	Sun3
1	% canopy cover (0.0=100%, 1.0=0%)	0.04	0.03	0.09	0.31	0.19	0.13	0.63	0.26	0.23	0.75	0.76	0.63
2	Tree species richness (0.0=16 spp., 1.0=0species)	0.13	0.53	0.16	0.72	0.5	0.78	0.88	0.88	0.88	0.91	0.94	0.97
3	Tree density (0.0=48 trees, 1.0=0 trees)	0.27	0.58	0.08	0.64	0.303	0.818	0.71	0.83	0.85	0.97	0.97	0.97
7	Percentage dominance (0.0=20.2%; 1.0=100%)	0	0.18	0.11	0.27	0.19	0.54	0.86	0.77	0.75	0.97	0.98	1
9	Vertical Heterogeneity (H')(0.0=1.59; 1.0=0.6)	0.11	0.19	0.09	0.37	0.23	0.09	0.38	0.24	0.3	0.73	0.98	0.9
10	Number of coffee bushes (0.0=0 bushes, 1.0=77 bushes	N/A	N/A	N/A	0.47	0.29	0.65	0.51	0.55	0.75	0.77	0.86	0.93
11	Average coffee height (m) (0.0=2.7m, 1.35=1.0)	N/A	N/A	N/A	0.51	0.15	0.15	0.4	0.08	0.4	0.71	0.71	0.99
12	Average number of logs (0.0=6 logs, 1.0=0 logs)	0.21	0.15	0.25	0.44	0.29	0.14	0.62	0.62	0.81	0.86	0.78	0.97

circles nested within farms and farms nested within managements. Tests for assumptions of normality (Kolmorogov-Smirnov tests) and homogeneity of variances (Levene's tests) (Zar 1999) were carried out. Data not normally distributed were transformed (inverse of the square root) in order to meet this assumption (Zar 1999). Tukey post-hoc tests were performed whenever the statistical differences were detected. Multiple comparison post-hoc tests were Bonferroni corrected. All univariate analyses were performed using SPSS-10 for Windows (SPSS Inc©). Multivariate analyses involved cluster analyses (Ward linkage method and Euclidian distances) and principal component analyses as implemented by Statistica-5 for Windows, multivariate exploratory techniques (Statistica Inc. 2002, ©Copyright StatSoft, Inc.).

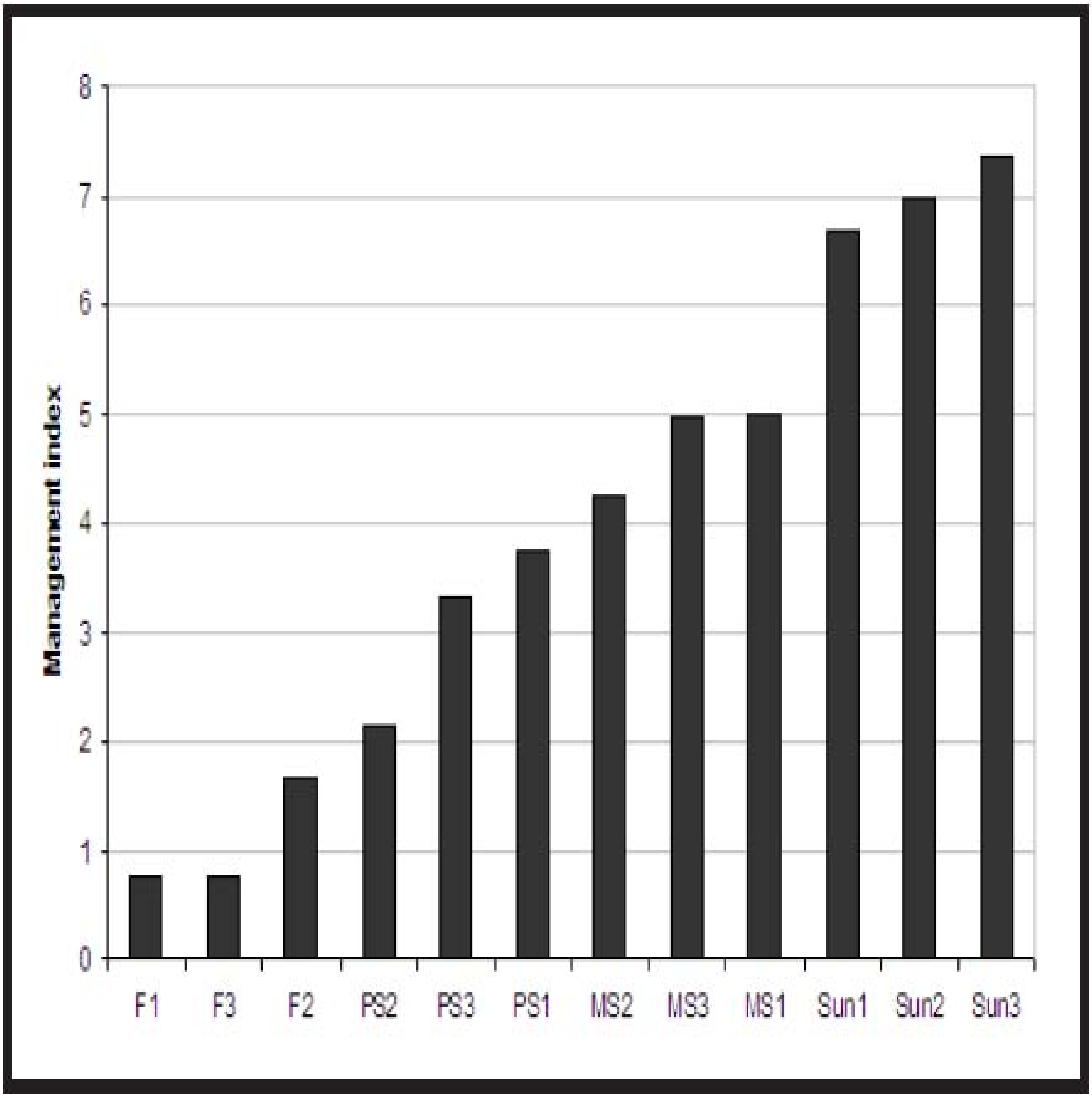
Management index: Mas and Dietch's management index (MI) weighs each of the variables equally along a scale from

0.0 to 1.0 (0.0 represents the least man-aged/most "natural" system). The standardized index values for the variables

Table 3. Standardized values for the variables included in the Management Index for each of the coffee farms and forests patches, according to Mas and Dietsch protocol (2003). The real values for most intensive condition (1) and least intensive condition (0.0) are shown in parenthesis in the first column, numbers in the first column refer to the variable numbers in Table 2. N/A: not applicable and treated as zero in the management index.

are then added together such that the number of variables included in the study constitute the maximum value possible reached by the MI. Thus, Mas and Dietsch's (2003) index ranges from 0.0 to a possible high of seven, since theyused seven variables for their index.

Different variables were treated somewhat differently in the management index following Mas and Dietsch's (2003) protocol. For example, with vari



ables such as tree species richness, which is assumed to decrease as intensification increases, the 0.0 value was based on the tree species richness for the richest circle in the richest forest. The assumption is that the expected tree species richness could vary depending on the native forest type present in the region. Therefore in this study, for each farm, the proportion of the average tree species richness with respect to the richest forest (Table 2) was calculated and then subtracted from

1.0, so that a higher value would reflect a higher intensification (e.g., the number of tree species in the second circle of F1 forest was 16 species). This procedure was used to obtain the following standardized values: tree species richness; tree abundance; number of logs; percentage canopy cover (assuming 100% is 0.0 value); and percentage trees with epiphytes.

Proportion of the relative difference was used to calculate the standardized values (Mas and Dietsch 2003) for six additional variables: percentage dominance of one tree species in the plantation, average tree height, average diameter of logs on soil, average coffee bush height, vertical heterogeneity, and live trees dbh. For example, for the average tree height, 1.0 was based on the circle with the lowest average tree height on the assumption that more intensive management includes regular pruning that produces a lower average tree height. The 0.0 value for average tree height (ATH) was based on the point with the overall highest value which was assumed to be the least intensive condition. The ATH value for each point was calculated as the proportion of overall lowest value, then subtracted from 1.0 (Index Value = 1-[point ATH – low ATH]/ [high ATH – low ATH]). For this study, the lowest ATH was three and the highest was 10.65m. This quantification procedure amplifies the range of variation of the index since a lower limit (above zero) is defined, so the standardized values for each variable determined in this way are relative to the Apía region. The standardized value management index for variables such as logged tree bases and number of coffee bushes was calculated as the proportion relative to the highest value found in any of the 26 circles. These two variables are assumed to increase with management intensification.

Summarizing, 14 variables were measured in all of the farms at Apía (Table 2), but only eight (Table 3, for reasons presented in the discussion section) were actually used to calculate the management index for each farm. Standardized values for all of the variables were calculated at the farm level, and not at the circle level.

Results

Most of the 14 habitat or vegetation variables exhibited increasing or decreasing trends throughout the intensification gradient of coffee agriculture (Tables 2, 3; Figures 1, 4), with the exception of five: percentage of trees with epiphytes, tree height, dbh of live trees,

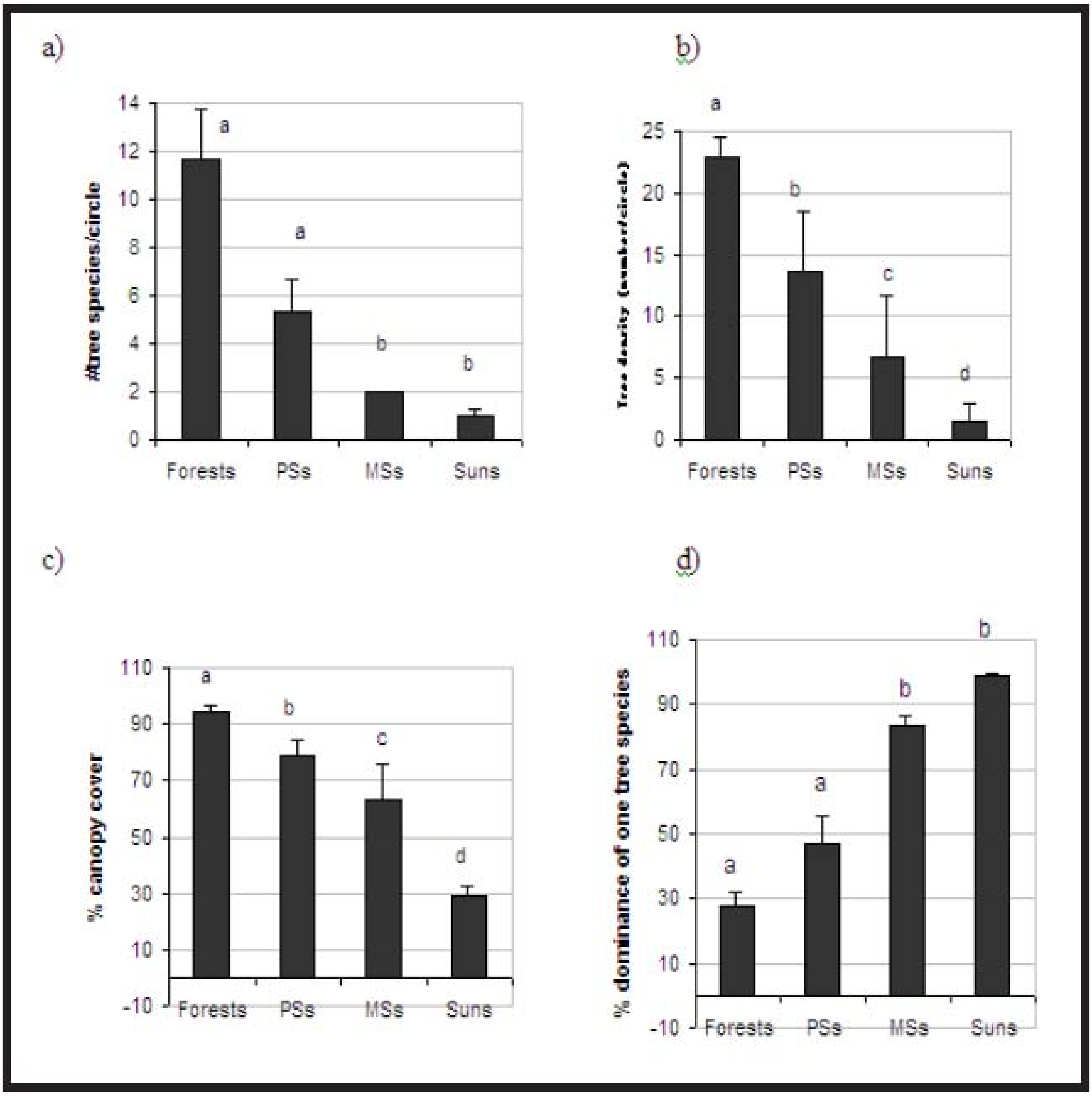
Figure 1. Total management index in each of the 12 farms, considering all of the habitat variables measured. The index may vary from 0.0 (least intense) to eight (most intense management). Since the Management Index value applies for the farm, and not for each circle, no error bars are presented.

diameter of fallen logs, and number of logged trees. The five variables that did not show a clear trend were withdrawn from the total management index values (Table 3).

For further clarity, the variables were grouped into three strata or vertical levels: arboreal (variables #1-8); coffee bushes (variables #9-11); and soil (variables #12-14) (numbers in parenthesis refer to those variables numbers in Table 2). For the arboreal level, those habitat variables that visually impact an observer showed a gradual change along the gradient of agricultural intensification (Figure 2). For the coffee and soil levels, changes were frequently more obvious in the Sun coffee plantations than in the shaded ones (Figures 3 and 4). The "coffee bush" level variables showed that the density of coffee plants significantly increased in the Sun coffee plantations, while the vertical heterogeneity and coffee bush height decreased (Figure 3). The apparent contradiction between the trend of these last two variables is explained because bushes are smaller in Sun coffee, and thus have less altitudinal categories accounting for an increasing vertical heterogeneity. The average number of logs, the only soil-level variable that showed significant differences, also decreased gradually across the gradient (Figure 4).

The overall tree species richness across all the studied farms through the inventory was 71 species (Appendix A). Tree species richness values per circle were sometimes similar between Forests and Polygeneric Shaded coffee plantations (Table 2), although the identity of the trees was frequently different (Appendix A).

A cluster analysis incorporating the complete set of variables measured in the study (14 variables, Table 2) indicated two groups of farms separated by the highest distance (Figure 5). A first cluster contains all Sun and Monogeneric Shade, and both of these management systems are further separated into two groups. A second cluster involves the Forests and Polygeneric Shaded farms, but they are not separated further into discrete groups as happened in the first cluster. Principal component analysis's output (Figure 6) revealed that the first two principal components accounted for 69.25% and 23.78% of the total variance respectively, and in total for 93.03%. Variables such as tree species richness,



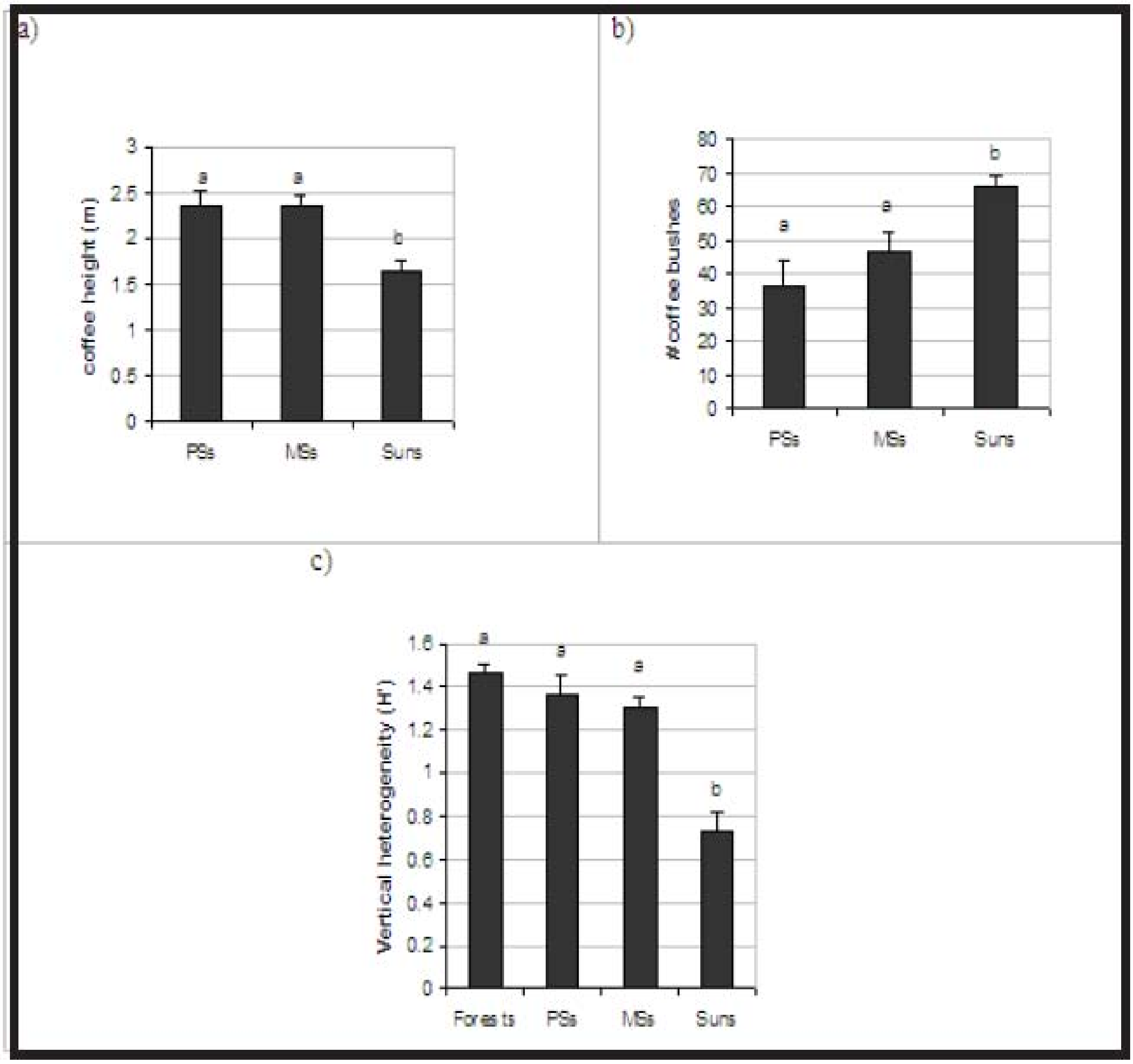
tree density and percentage of trees with epiphytes were important for the first factor, while percentage dominance of one tree and the number of coffee bushes were important for the second factor.

Discussion

The results from this study showed that a qualitative classification of 12 farms into four management systems overall matched the quantitative analyses derived from 14 quantified habitat variables and the management index (Figure 1). The visual perception of management impact on the coffee farms is obvious at first glance. The qualitative classification in this study was based upon conspicuous arboreal

Figure 2. Means and standard errors of three habitat variables at the "tree" level. Number of trees (a); tree density or number of individual trees in 452m2 (b); percentage of canopy cover (or shade) (c); and percentage dominance of one tree species (proportion of individuals of the most abundant tree species by 100) (d). Plantains were the most abundant in sun coffee plantations. Forests (positive control) are the least managed systems in the coffee landscape. Bars labeled with different letters were statistically different at the 0.05 or lower level of significance.

characteristics within each farm, such (0.08-0.013) and in Monogeneric Shades as the overall appearance of the shade (0.27-0.57) (Figure 6). The second PC trees in terms of richness, density and probably captured most of the variability generated by soil and coffee bush



level of shade. The information from farmers was a second important criterion to decide *a priori* classification of the farms. Cluster analysis and principal component analysis were consistent to the qualitative classification, uncovering the definition of discrete groups of farms according to the management intensification and the *a priori* classification, but most important, showing the similarities between Forest and Polygeneric Shaded coffee (Figures 5 and 6). The principal component analysis technique captures most of the variability of the system and the type of variation captured by the first principal component (PC) strongly dominates all other types of variation. My interpretation is that the first PC (responsible for 69% of the total variance) was driven by the arboreal component of the habitat variables. This interpretation is supported by the high loadings (>0.83) of the first PC in both Forests and Polygeneric Shade, while these loadings were extremely low in Suns vegetation variables, with extremely high loadings in Suns (0.96-0.98). These results suggest that other studies comparing coffee farms of contrasting management systems or shade levels classified qualitatively are reliable at the broad scale even without reporting habitat measurements (e.g., Borrero 1986; Ibarra-Núñez and García-Ballinas 1998; Ricketts et al. 2001; Rojas et al. 2001).

The trends found in this study along the intensification gradient are consistent with changes found in the habitat by other studies. For example, the forest patches in Mas and Dietsch (2003) in Chiapas, Mexico were slightly richer in terms of tree species than the forest patches included in this study at Apía (12.9 and 11.67 tree species, respectively, in equivalent areas) and the same trend was found within the rustic coffee plantations of Chiapas, as compared to the Polygeneric Shaded coffee plantations of Apía (average 6.65 and 5.3 tree species respectively). Trees were taller (9.14m and 7.15m) but thinner (10.2 and 21.85cm dbh) in Chiapas than in Apía. In another study in Mexico, Soto-Pinto et al. (2002) reported an average tree height of 7.6m in shaded coffee plantations of Chilon, Mexico, which is consistent with the heights observed at Apía in this study (7.15m). Nevertheless, trees in Colombian plantations of Apía trees provided similar shade (canopy cover 78.9%) than the rustic plantations in Mas and Dietsch's study (73.3% average). However, canopy cover was unexpectedly lower in Soto-Pinto et al.'s (2002) traditional coffee plantations (46.6%) possibly because most of the trees in these coffee farms were planted fruit trees. The canopy cover measures in the intensified shaded system in this study were similar to both the values found by Mas and Dietsch (2003) (36.16%), and by Ambrecht and Perfecto (2003) (35%) (Figure 2). Armbrecht and Perfecto conducted their study in a different year

Figure 3. Means and standard errors of three habitat variables at the "coffee bush" level. Coffee height (a); density of coffee bushes in $78.5m^2$ (b); vertical heterogeneity (Shannon Index H') (c). Means labeled with different letters were statistically different at the 0.05 or lower level of significance.

in the same farms used by Mas and Dietsch, but despite the high dynamic (pruning) management in shaded coffee plantations, the values obtained in the two independent studies were extremely similar. In the present study, plantains (*Musa* x *paradisiaca* L.) planted in a barrier fashion provided 28.8% canopy cover in Sun coffee plantations. Canopy cover deserves special attention because it is likely to be influencing biological activities through physiological responses of the associated biota inside the farms (e.g., Kaspari and Weiser 2000).

Tree density found in this study is also consistent to Soto-Pinto et al. (2000): 463 shade trees/ha in traditional shaded coffee plantations of Chilon (Mexico) *versus* up to 508 trees/ha in the Polygeneric Shaded coffee plantations in this study (Table 2). The comparative discussion here points out that a categorical (subjective) classification is consistent with results obtained from direct measurements in coffee plantations of different countries and different studies. These results provide a basis for further reliable studies synthesizing information or making comparative analyses in literature reviews, and also for reliability of scientific assessment for Shade Coffee certification programs.

Although this study suggested overall consistency in habitat changes along the gradient of intensification of coffee production and across similar studies, it also showed some inconsistencies. Variables such as average tree height and percent epiphytes did not change the same way in Colombia as reported by Mas and Dietsch (2003) and two explanations are offered here. The first explanation is that the energy that the farmer invests in pruning can be directed differently depending on the type and age of the shade tree. For example, trees were thicker, smaller and provided more than double canopy cover in Monogeneric Shades planted with *Inga* spp. as compared to those planted with *Cordia allidora* (76% vs 37%) (Table 2). *C. allidora* is pruned laterally to stimulate straight vertical growth since its wood is highly valuable in the market and an additional source of income for farmers. A second possible explanation is that the percentage of

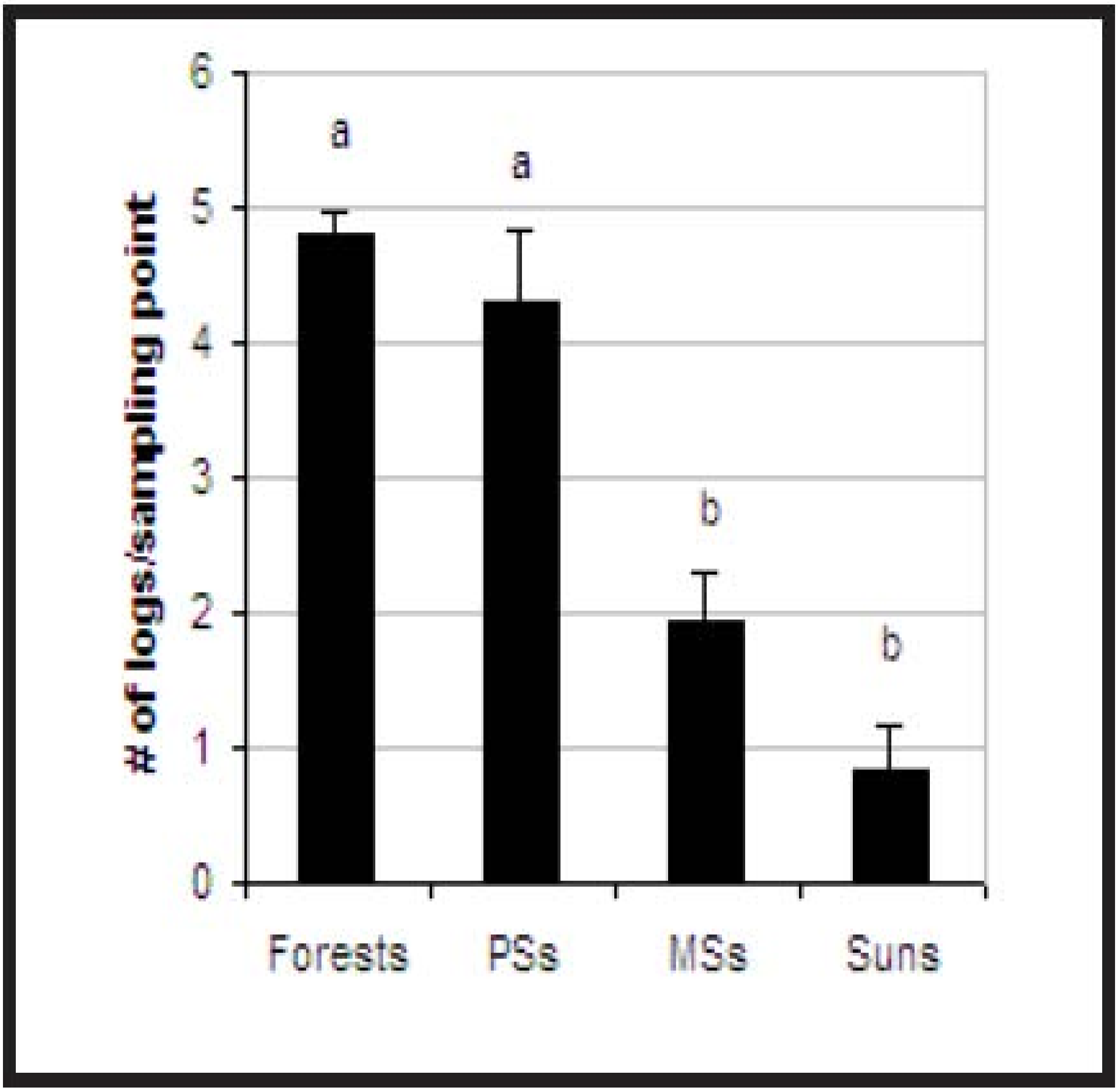
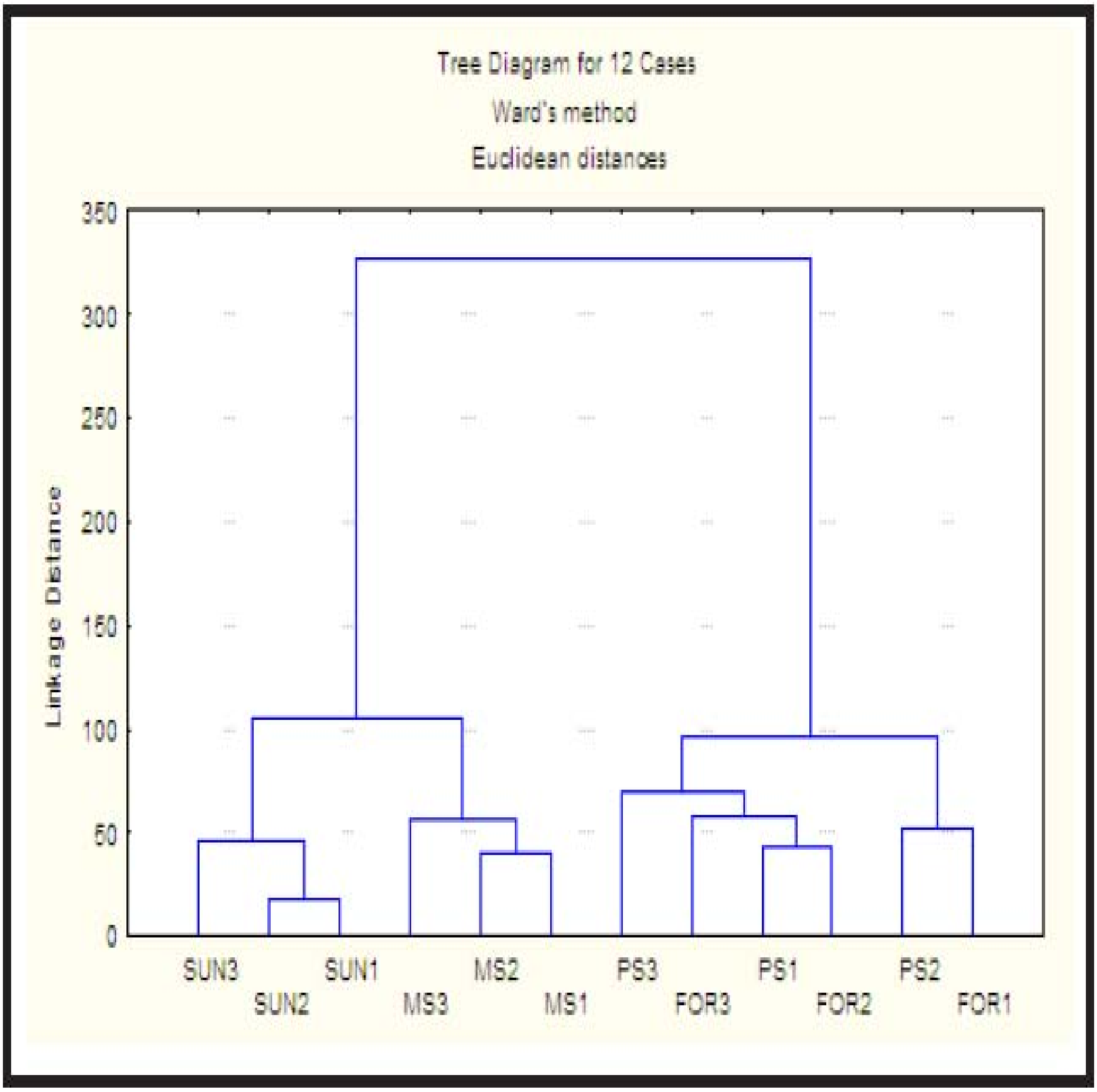
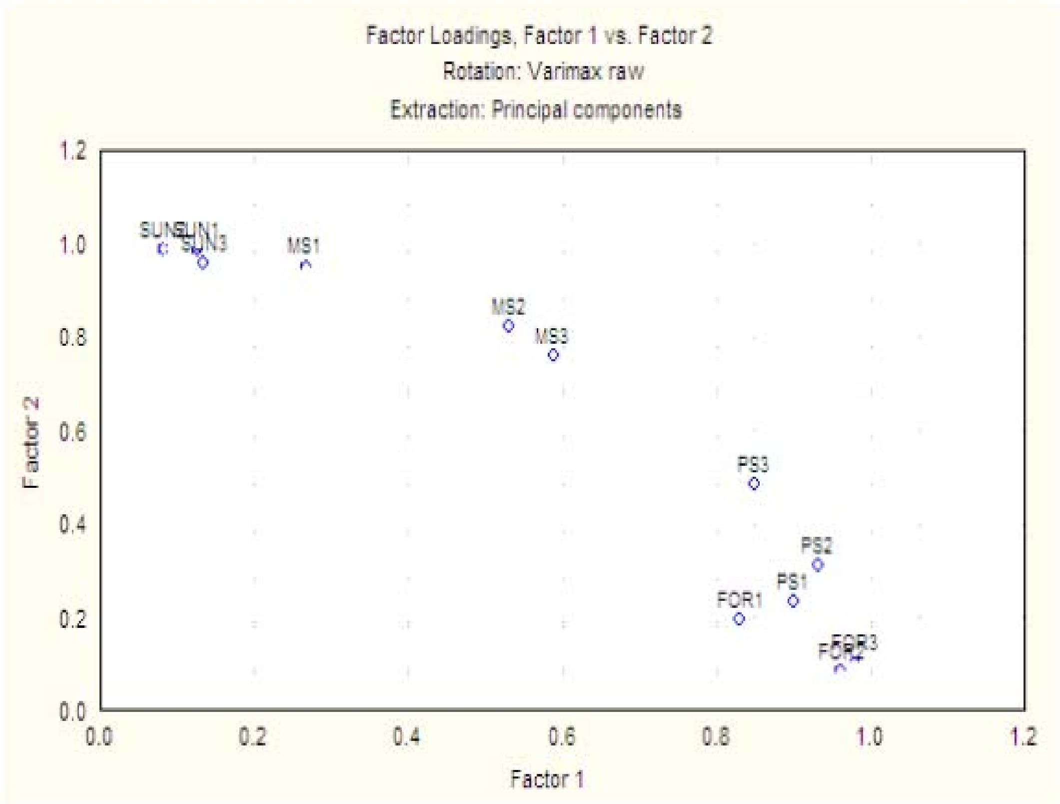


Figure 4. Means and standard error of one variable at the "soil level": number of logs per sampling point or $4m^2$ area. Errors are shown at the top of each bar and bars with different letters were statistically different at the 0.05 level.

trees with epiphytes was strongly influenced by the number of trees existing in the plantations. If there is only one isolated tree in Sun coffee and it happens to have an epiphyte it would represent 100%, therefore I propose the



use of raw number of epiphytes instead Figure 5. Cluster analysis output (variable 5, Table 2). It is remarkable with data from all habitat varithat none of the Monogeneric Shaded ables. Ward's method for linkage coffee farms contributed many epi- and Euclidian distances were phytes in the system as compared to used in the analysis. the Polygeneric Shaded farms. The density of trees in Polygeneric Shaded coffee plantations doubled that in Monogeneric Shaded farms, but there were 54 times as many epiphytes (Table 2), a fact that cannot be easily explained as a sampling effect. The reason for this "overpopulation" of epiphytes could be related to epiphyte metapopulation dynamics as well as to the presence of seed dispersers related in turn to the diversity of "supporting" trees (Vandermeer and Carvajal 2001). Tree



Extraction: Principal components				
		% total	Cumul.	Cumul.
	Eigenval	Variance	Eigenval	%
1	8.31041	69.25344	8.31041	69.25344
2	2.85423	23.78528	11.16465	93.03873

diameter at breast height (dbh) was also surprisingly higher in all shaded coffee systems than in forests (Table 2). This result is likely a consequence of tree age distribution in the successional process that takes place in these forests. The number of logged trees was unexpectedly high in one of the Polygeneric Shaded coffee plantations (Table 2) and this measurement suggests that this was a much more shaded and diverse rustic plantation before its conversion into organic production for coffee exportation.

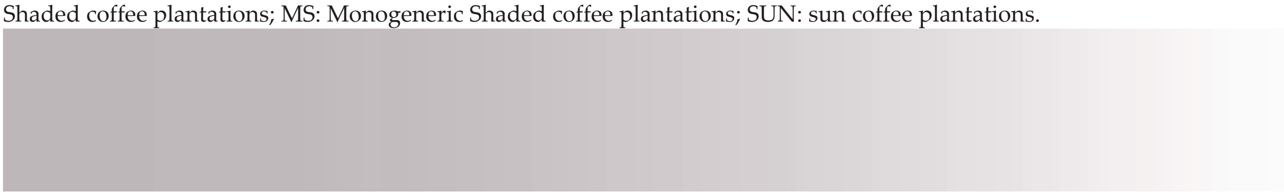
Results from this study strongly suggest the importance of taking into account the "arboreal" stratum variables for the management index, since almost all of them were significantly different among management types (Figure 2, Table 2). Most importantly, the means of all arboreal variables for Polygeneric and Monogeneric Shaded coffee plantations in Figure 2 were significantly different, with a clear intensification gradient that distinguishes these two types of shaded coffee farms

(Figure 1). These results confirm the great importance of providing a quantitative basis in the certification of shade grown coffee (e.g., Rainforest Alliance or Conservation International).

Several general conclusions emerged from this study. A high correspondence was detected between the initial qualitative classification and the results of quantifying habitat variables of 12 farms along an increasing gradient of Colombian coffee production. This high concordance was mainly a consequence of the presence, diversity and structure of the arboreal vegetation in the farms (first component PCA Figure 6). Most of the changes in vegetation variables detected in this study were consistent with other studies in coffee plantations (Soto-Pinto et al.2000; Armbrecht and Perfecto 2003; Mas and Dietsch 2003). Finally, Mas and Dietsch's management index proved to be useful in describing the intensification of coffee production.

The implications of this study are of high relevance to a recent debate regarding shaded coffee certification and conservation programs (e.g., http:// www.eco-labels.org/home.cfm). Questions have been recently raised about the real benefits of promoting shade-grown coffee among consumers as valuable for conservation of biodiversity if no distinction is made regarding differently shaded coffee plantations (Rappole et al. 2003). If such a distinction needs to be made, this study provides an additional step toward this goal.

Figure 6. Principal component analysis output plot considering the variables involved in the calculation of the Management Index. The codes refer to the management systems and the farms. FOR: Forests; PS: Polygeneric Shaded coffee plantations; MS: Monogeneric Shaded coffee plantations; SUN: sun coffee plantations.



SCIENTIFIC NAME	F1	F2	F3	P1	P2	P3	M1	M2	M3	S1	S2	S3
Acacia melanoxylon R. Br.							1					
Acalypha macrostachya Jacquin		1										
Aegiphila mollis Moldenke												
Albizzia carbonaria Britton					1	1						
Alchornea glandulosa Endlicher & Poepp.			18	1								
A. grandiflora Muell. Arg.			2									
Allophylus occidentalis (Sw.) Radlk.		4	3									
Andira inermis (W. Wright) Kunth						1						
Boehmeria caudata Swartz		1										
Cecropia angustifolia Trecul			1	1								
Cedrela odorata L.			1		3	1				1		
Citrus sinensis L.		2			2					1	1	
Cordia acuta Pittier	1											
C. alliodora (R. et P.) Cham .			2				16					
Coussapoa villosa Poep. & Endlicher			3		1							
Cupania cinerea P. et. E.						1						
Duranta mutisii L. f.	1											
Erythrina rubrinervia Kunth												

Eucaliptus globulus						1						
Euphorbia neriifolia Linneaus	1											
Ficus andicola Standley					1							
F. glabrata Kunth			1									
Fraxinus chinensis Roxburgh									1			
Gliricidia sepium (Jacq.) Steud.					2							
Guadua angustifolia Kunth												
Guettarda sabiceoides Standley	1											
Heliconia griggsiana L. B. Smith			1									
Heliocarpus popayanensis Kunth	2											
Hyeronima scabrida (Tul.) Muell-Arg.	2											
Inga aff. *densiflora* Benth.					1							
I. densiflora Benth.			3	6	4							
I. edulis Mart.				4	5	7		9	8			
I. marginata (Vahl.) Willd.		3										
I. oerstediana Bentham	4											
Juglans neotropica Diels						1						
Lafoensia punicifolia DC.												
Leucaena leucocephala (Lam.) De Wit						1						
Macrocnemum roseum (Ruiz & Pavón) Weddell					2							
Mangifera indica L.						1						
Miconia caudata (Bonpl.) de Candolle					2						1	
Montanoa quadrangularis Schultz Bip.	10		10									
Musa x acuminata L.		1										
M. x balbisiana L.		1	4									
M. x paradisiaca L.		1		10	21	2	1	2		1		3
Myriocarpa stipitata Bentham		11										
Myrsine coriacea (Sw.) R. Brown	1		6									
Nectandra lineatifolia (R. & P.) Mez	4											
Ocotea smithiana O.C. Schmidt	1											
Ormosia colombiana Rudd.						1						
Palicourea acetosoides Wernham	8											
P. angustifolia Kunth	1											
P. ovalis Standley	2											
Persea americana Miller				2		2						
P. coerulea (R. & P.) Mez												
Poulsenia armata (Miq.) Standley												

P r unus i n t e g r if o lia (C. Presl) Walp.			2									
P s id iu m g ua jav a Linnaeus					1							
S a m anea s a m a n (Jacq.) M errill						1						
S aur aui a c uat r e c a s ana R. E. Schultes	16											
S enna s pec t a b ilis (DC.) Irwin & Barneby var. spectabilis												
Sip ar una as p er a (R. & P.) A. DC.	1											
S o l anum a p h y d odendr on S. Knapp			1									
S. w r ig ht i Bentham						1						
T abebui a c h r y s ant ha (Jacq.) Nicholson									1			
T e t r or c h i d i u m r ubr i v eni um Poepp. & Endlicher			1		1							
T o x i c odendr on s t r i at um (Ruiz & Pavón) Kuntze	14		2									
T r em a m i c r ant h a L.	2	1			1							
T r i c hant er a gi g ant ea (H. et B.) Nees					5							
U r e r a ca r a ca san a (Jacq.) G riseb.		6				1						
V e r bes i na ar bo r e a Kunth	5		1									
V i bur num c o r n if ol i u m Killip & Sm ith	2											
Z ant hox y lu m r h o if o liu m Lam			1									
Num ber of individuals	79	32	63	24	53	23	18	11	10	3	2	3
# of species	20	11	19	6	16	15	3	2	3	3	2	1

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