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Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico

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ABSTRACT

Coffee production has attracted considerable attention globally, due to its economic, social, and ecological importance. The capacity of coffee farms to conserve the biodiversity and environmental benefits offered by adjacent forest ecosystems varies greatly in relation to varying cultivation strategies. However descriptions of these strategies are scarce and largely qualitative in nature, thus hindering comparisons between studies. A rigorous quantitative classification of this agroecosystem was undertaken, in order to address these concerns. For this purpose, a multivariate analysis was applied, in order to analyze the changes in the biophysical structure and management of 18 coffee plantations and three fragments of montane cloud forest, spanning a wide variety of cultivation intensities in central Veracruz, Mexico. This analysis identified five main classes of vegetation structure, ranging from sun exposed to rustic coffee plantations, with the mean height of shade trees, vertical vegetation diversity, tree richness and abundance and coffee plant density, representing the most important structural descriptors, referring to the farms studied. Analysis of the frequency and type of management practices employed (fertilization, weed and pest control) yielded three groups of farms ordered along a gradient, ranging from conventional to alternative practices. Together, these analyses yield a robust quantitative classification system for coffee farms in central Veracruz, which differs in several important ways from accepted qualitative classification schemes. As vegetation structure and management practices did not co-vary in this analysis, future studies should include standardized measurements of both dimensions used to describe coffee farms, in order to improve understanding of how intensification affects conservation potential and help to identify more sustainable production strategies.

1. Introduction

Coffee production is important both socio-economically and for conservation planning in Mexico and presents great diversity. Coffee agroecosystems occupy 3.2% (800,000 ha) of total land area, employ 282,000 producers, the majority of whom are small land holders and indigenous peoples and from which hundreds of millions of dollars in annual export revenues are generated for the country (Moguel and Toledo, 2004; Manson et al., 2008). A growing number of studies have highlighted the importance of structurally complex shade coffee, as an aid in the conservation of tropical montane forest biodiversity (Perfecto et al., 1996; Moguel and Toledo, 1999; Philpott et al., 2008). In Mexico, the conservation value of coffee farming is enhanced by its extensive overlap with remnants of tropical montane cloud forest (TMCF), notable for its high diversity per unit area and great number of endemic species (Rzedowski, 1996; Challenger, 1998).

A broad range of coffee management strategies are employed in Mexico, including simply replacing the shrub layer of natural forests with coffee plants, replacing the forest canopy with one or more exotic species, or removing the canopy completely and growing coffee in open sunlight (see Table 1). A more detailed description of these management strategies can be found in Moguel and Toledo (1999). However, most coffee in the country is still grown in the shade of a diverse array of tree species (Moguel and Toledo, 2004). As these more traditionally managed shade coffee plantations have lower production costs and typically contain significantly more forest species than the intensively managed farms (Greenberg et al., 1997a; Perfecto and Vandermeer, 2002; Perfecto et al., 2002; Arellano et al., 2005), there is considerable interest in using these farms as models, directed towards balancing conservation and economic needs and employing sustainable management practices (Gordon et al., 2007).

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Table 1
General description of 21 study sites in central Veracruz, Mexico, and their initial qualitative classification into five generalized subclasses of coffee intensification (*sensu* Nolasco, 1985; Moguel and Toledo, 1999). See López-Gómez et al. (2008) for a more complete description of these study sites.

Site	Area (ha)	Sampling points (#)	Preliminary classification
CAÑ	298.6	10	Forest fragment: comprised of a mix of native species, with no management.
PAR	31.5	10	
MAS	30.1	10	
MIR	140.5	8	Rustic: similar to a forest with the understory replaced by coffee. Management includes manual weed control and occasional pruning of coffee plants. Dominated by small rural producers.
VBM	113.8	10	
ORD	195.9	10	Traditional polyculture: comprised of different combinations of native and introduced trees which are typically fruit-bearing species. Management is similar to rustic plantations with the addition of annual fertilization. Pesticides are typically absent. Usually managed by small and medium-sized producers.
VCS	113.8	10	
ESM	19.3	10	
ARM	15.7	10	
ZOP	10.2	10	
ALU	6.4	5	
PAM	3.2	2	
ONZ	1.9	5	
AUR	1.3	5	
PAN	0.7	2	
MOR	10.5	5	Commercial polyculture: most of the natural canopy is removed and replaced by a limited number and diversity of shade trees with some commercial species. Management is particular for each crop and dependent on an elevated of fertilizers, pesticides, and synthetic fertilizers. Usually managed by small and medium-sized producers.
AXO	0.6	3	
VSE	113.8	10	Shaded monoculture: natural canopy completely replaced by a small number (1–2) of non-native tree species. Management includes specialized coffee varieties dependent on pronounced use of fertilizers, pesticides, and synthetic fertilizers, together with selective and systematic pruning of coffee plants. Usually managed by medium-sized and large producers.
MTZ	17.3	6	
CAM	60.0	[a]	Sun coffee: no shade trees present and a high dependence on agrichemicals as described with shade monocultures.
SOL	45.0	10	

[a] Management data obtained by interviews with the grower, most structural variables assigned a value of 0.

Typologies or classifications based on types or categories are a useful tool for systematically organizing available knowledge and identifying useful patterns and discrete groups in complex systems (Gabriel, 2003). A review of recent ecological studies of coffee plantations revealed that 76% (coffee management category (CA) in Table 2) use some type of typology in order to categorize coffee production systems and help to elucidate the effects on the conservation of biodiversity, caused by intensifying coffee production. The most common typology used for coffee farms in Mexico, and occasionally for other parts of Latin America, is that proposed by Nolasco (1985) and refined by Moguel and Toledo (1999). This classification system is largely qualitative and identifies five more or less homogeneous subsets of coffee production strategies, including low impact strategies such as rustic and traditional polycultures, as opposed to more intense systems such as shade monocultures and sun exposed coffee plantations (Table 1).

Although it provides a useful starting point, this qualitative classification presents a number of problems, thus limiting improvement in the understanding of how changes in coffee production intensity affect biodiversity, as well as prohibiting the generation of more appropriate management recommendations for this important agroecosystem. In particular, this classification only partially explains variations within and between different management strategies. Nolasco (1985) presupposes direct linear correlations between changes in biodiversity, vegetation structure, management intensity and socio-economic conditions of coffee farms, but these have not been empirically demonstrated (Mas and Dietsch, 2003; Manson et al., 2008). His classification also manifests a bias towards structural rather than management variables and a lack of consistency in the selection of the type and overall number of variables, used to describe coffee farms (Table 2). Such problems make comparisons between studies difficult and retard efforts to evaluate the role played by coffee plantations in the conservation of tropical biodiversity (Rappole et al., 2003a,b; Philphot and Dietsch, 2003; Mas and Dietsch, 2003). It also becomes difficult to identify regimes of management and vegetation structure that provide maximum conservation value, at a minimal economic cost (Perfecto and Armbrecht, 2003; Perfecto et al., 2005; Gordon et al., 2007).

In the light of these problems, the current study applies a multivariate analysis to the gradient of coffee production intensity in central Veracruz, Mexico, in order to generate a new rigorous, quantitative classification system, based on both biophysical and management variables. This new quantitative classification is subsequently compared to the widely used qualitative classification, in order to identify key distinctions that might help to improve descriptions of the differences between coffee production systems, identify the most important descriptors referring to these differences, as well as providing basic guidelines for a standardized system, which describes the various production strategies in coffee agroecosystems.

2. Methods

2.1. Study region and site selection

This study was carried out in the mountainous region of central Veracruz between 1000 and 1350 m, which is considered an optimal altitude for the production of high quality coffee (Marchal and Palma, 1985). Annual precipitation varies between 1350 and 2200 mm, and annual temperatures range from 12 to 19 °C (Williams-Linera et al., 1995). There are three well defined seasons in this region comprising: a cold-dry season running from late October or early November to March, a warm-dry season from