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Conservation of tree species of late succession and conservation concern in coffee agroforestry systems

Vivian Valencia[a,*], Shahid Naeem[a], Luis García-Barrios[b], Paige West[c,d], Eleanor J. Sterling[e]

[a] Department of Ecology, Evolution, and Environmental Biology, Columbia University, New York, NY 10027, USA
[b] El Colegio de la Frontera Sur, Apartado Postal 63, San Cristóbal, Chiapas 29200, Mexico
[c] Department of Anthropology, Barnard College, New York, NY 10027, USA
[d] Department of Anthropology, Columbia University, New York, NY 10027, USA
[e] Center for Biodiversity and Conservation, American Museum of Natural History, New York, NY, USA

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ABSTRACT

Shade-grown, montane coffee agroforestry systems have the potential to conserve native tree species of conservation concern (CC) and typical of old growth or late succession (LS) forests in montane cloud forests. However, it remains unclear how preferential selection by farmers for or against certain tree species and diameter sizes affects CC and LS trees distribution and abundance. To address this issue, we investigated how management practices may inadvertently compromise the potential of agroforestry systems to serve as reservoirs for CC and LS trees. We sampled tree diversity in 31 coffee farms and 10 forest sites in La Sepultura Biosphere Reserve in Chiapas, Mexico and assessed the relative importance of shade tree density, basal area, proportion of *Inga* spp. trees, previous land use, and age of fallow (for farms established on land with an agricultural history) on the proportions of CC and LS trees. We then examined if tree size distributions differed between farms and forests, and whether land use legacies mediated the impact of the explanatory variables of interest. These analyses found that management practices that sought to increase the proportion of *Inga* spp. trees had the largest negative impact on the proportions of trees of LS and CC, but the magnitude of the effects were dependent on land-use legacy. We also found that tree size distributions differed between farms and forests among smaller trees (5–20 cm diameter at breast height, (DBH)), but not among larger trees (>30 cm DBH). These findings suggest that in order to increase the conservation potential of coffee agroforestry systems, particularly for farms established on land with an agricultural history, it is important to promote farmers' tolerance of tree species other than *Inga* spp. and preferred tree species.

1. Introduction

Montane cloud forests (MCFs) are considered a conservation priority worldwide due to their high levels of biodiversity with exceptional concentrations of endemic species (Hamilton et al., 1995; Bubb et al., 2004; Toledo-Aceves et al., 2011). MCFs make up less than 2.5% of the world's tropical forests, but harbor a disproportionately high species richness (Bubb et al., 2004). In Mexico, MCFs are recognized as the terrestrial ecosystem with the highest concentration of diversity, harboring approximately 10% of the Mexican flora in less than 1% of the territory (Rzedowski, 1996; Pineda and Halffter, 2004). This ecosystem is severely threatened by climate change (Pounds et al., 1999; Ponce-Reyes et al., 2012) and anthropogenic disturbances, mainly land use conversion to agriculture (Ramírez-Marcial et al., 2001; Muñoz-Villers and López-Blanco, 2008; Martínez et al., 2009). As a result, up to 60% of trees in MCFs in Mexico are threatened by extinction to some degree (Gonzalez-Espinosa et al., 2011).

In coffee agroforestry systems, coffee is cultivated under the canopy of shade trees. Coffee agroforestry systems, which overlap in range with MCFs, may play an important role in providing a habitat for tree species of conservation concern and for old-growth or late succession tree species. However, research has challenged this assertion by showing lower proportions of tree species of conservation concern (CC) and late succession (LS) in coffee agroforests relative to surrounding forests (Méndez et al., 2007; Aerts et al., 2011; Valencia et al., 2014). It remains unclear what

* Corresponding author at: Department of Ecology, Evolution, and Environmental Biology, Columbia University, 1200 Amsterdam Avenue, New York, NY 10027, USA.
E-mail address: vv2188@columbia.edu (V. Valencia).

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processes may be undermining the potential of coffee agroforestry to support higher proportions of CC and LS trees.

In this study, we focus on factors associated with coffee agroforestry management that affect structural complexity and tree composition. Additionally, we explore how land use legacies may affect the potential of coffee agroforestry systems to conserve CC and LS trees. Management practices for optimizing coffee production may inadvertently compromise the potential of agroforestry systems to serve as habitat for CC and LS tree species by altering tree structure and composition of the agroforest by preferentially selecting for or against trees of certain species (Soto-Pinto et al., 2001; Anglaaere et al., 2011; Sambuichi et al., 2012; Valencia et al., 2015) and sizes (Soto-Pinto et al., 2001; Rolim and Chiarello, 2004; López-Gómez et al., 2008; Asase et al., 2010; Valencia et al., 2014), and by modifying shade tree abundance (López-Gómez et al., 2008; Correia et al., 2010; Valencia et al., 2014).

Research in Mexico and Central America has described management strategies that seek the gradual replacement of canopy trees by *Inga* spp. and other preferred trees for the benefits associated with coffee production and for the provisioning of secondary goods, such as timber and firewood (Soto-Pinto et al., 2001; Peeters et al., 2003; Albertin and Nair, 2004; Bandeira et al., 2005; Valencia et al., 2015). Farmers' decisions to keep or remove trees from the system may also be influenced by tree size (i.e., diameter). For example, farmers often refrain from removing relatively large trees (Sambuichi, 2002; Asase et al., 2010; Anglaaere et al., 2011) both because of logistical difficulties in removal and to avoid potential damages on their crops and surrounding vegetation when the tree and its branches fall. On the other hand, small trees are subject to removal. For example, sapling and seedlings are routinely removed during weeding practices. Therefore, decisions to remove or keep trees based on their size can result in tree size distributions that are atypical of natural forests (Rolim and Chiarello, 2004; Senbeta and Denich, 2006) and after continuous practice, coffee agroforestry systems can begin to resemble secondary forest (Soto-Pinto et al., 2001). This outcome, in which management inadvertently leads to agroforestry systems that resemble secondary rather than primary forest, however, does not always occur (Asase et al., 2010).

Over time, gradual felling and replacement of trees in which certain species are systematically favored or eliminated has been found to lead toward homogenization (i.e., convergence) in species composition in farms (Bandeira et al., 2005). However, because generally there is a lack of synchrony in the development stage of each farm, the ensemble of coffee farms may still conserve a higher number of species at the landscape level than at the farm level (Bandeira et al., 2005; Valencia et al., 2014). High levels of beta diversity (e.g., between farm differences in diversity) have been found important to attenuate diversity loss at the landscape level (Solar et al., 2015). However, as the process of biotic homogenization continues over time, spatial diversity will be reduced (McKinney and Lockwood 1999) undermining the potential for diversity conservation at all spatial levels.

Management practices that disturb tree structure and composition may drive coffee agroforestry systems to resemble early successional states in terms of community composition, such as a high proportion of pioneer trees (Peña-Claros, 2003; Muñiz-Castro et al., 2011); and structurally, such as lower stand basal area, higher tree densities, lower variation in the distribution of stem diameters, and absence of large trees compared to mature forest (Clark, 1996; Aide et al., 1996; Guariguata and Ostertag 2001; van Breugel et al., 2006). Some studies have found decreasing (Goodall et al., 2015) or no changes (Richards and Méndez, 2014) in tree density at least in the short term (e.g., 10 years). Early successional systems, such as secondary forests, may still harbor significant levels of diversity (Peh et al., 2006; Barlow et al., 2007; Chazdon et al., 2009; Dent and Joseph Wright, 2009), but may not necessarily be a safe haven for the tree species of CC and LS that are at risk of disappearing from MCFs. Although it is understood that biological impoverishment can alter biogeochemical and dynamic properties of ecosystems (Naeem et al., 2012) and that rare species support distinct and vulnerable functions (Mouillot et al., 2013), it is difficult to anticipate the ecological consequences of losing CC and LS tree species. However, given the biodiversity loss crisis that we are facing (Barnosky et al., 2011), lack of concrete understanding of repercussions of the loss of CC and LS tree species is no reason to overlook the threat these species are facing.

The objective of this study is to uncover the management processes that may explain variability in the proportion of trees of CC and LS in coffee agroforests. We hypothesize that farmers' tree selection criteria that favors certain tree species, in particular *Inga* . spp., to the detriment of other trees, is the most important factor in driving reductions in the proportions of trees of CC and LS. The consequences of farmers' modification of shade tree density on the proportion of LS and CC trees are more difficult to predict. Intuitively, because higher shade tree density often results in higher richness (Méndez et al., 2007), one may think that higher shade tree density leads to a higher probability that a tree may be either of CC or LS. However, we hypothesize that agroforestry stands with high shade tree densities do not necessarily result in higher proportions of CC or LS trees. We additionally propose that farmers' selection and elimination of trees based on tree size (i.e., diameter) inadvertently leads to a reduction in a stand's basal area and to anomalous size distribution, which may be detrimental to the conservation of trees of CC and LS. By "anomalous," we mean that the size distribution is atypical of what one would expect from an old-growth or late succession forest. Finally, we expect that farms established on forests are more likely to hold a higher proportion of CC and LS trees than farms established on fallow land. "Fallow land," in this study, was clear-cut and is therefore more likely to resemble an early successional system. We expect that older fallows will be more likely to hold higher proportions of LS trees than younger fallows because a longer time period for forest recovery is needed for LS species to establish after early colonization by pioneer species (Chazdon, 2003). This study aims to contribute to the development of certification guidelines, government regulations, and conservation strategies that may incentivize practices that support the conservation of CC and LS trees in coffee agroforestry systems.

2. Data & methods

2.1. Study site

This study was conducted in La Sepultura Biosphere Reserve (LSBR) located in the Sierra Madre mountain range in Chiapas, Mexico (16°00′18″–16°29′01″N and 93°24′34″–94°07′35″W; 167,309 ha). LSBR is characterized by a rugged terrain with elevation ranging between 60 m.a.s.l. and 2550 m.a.s.l. (CONANP, 2013). Mean temperature ranges between 24 °C and 38 °C; at high elevation points, temperature ranges between 15 °C and 18 °C. The dominant soil type is eutric regosol and characteristics, such as texture and soil material, are homogenous in the study area (Valdivieso-Perez et al., 2012; CONANP, 2013). Annual rainfall varies between 2000 and 2500 mm and rainy season extends from May to October. LSBR encompasses a diversity of ecosystems, including short tree savanna, tropical deciduous forest, evergreen seasonal forest, pine forest, pine-oak forest, oak forest, montane rainforest, evergreen cloud forest, and evergreen cloud shrub (CONANP, 2013). The study site encompasses primarily montane rainforest and evergreen cloud forest.

In the Biosphere Reserve's buffer zone (92% of total area), human activities must be compatible with what the conservation authority