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Shade tree diversity, carbon sequestration, and epiphyte presence in coffee agroecosystems: A decade of smallholder management in San Ramón, Nicaragua

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ABSTRACT

Coffee smallholder management practices have received attention for their potential to conserve biodiversity and sequester carbon by maintaining structural complexity, high canopy diversity, and minimal external inputs. We conducted shade tree surveys on 95 1000 m^2 research plots over a 10-year period to identify patterns of shade tree density and diversity, epiphyte presence, and carbon stocks within smallholder shade coffee systems of northern Nicaragua. We also analyzed each of these parameters with respect to management by comparing collectively- and individually-managed farms. Our results indicate that the overall shade tree density has decreased over time ($F = 42.597$, $p < 0.001$), but that diversity remained constant. Carbon stocks in coffee systems also showed a decreasing trend over time ($F = 2.981$, $p = 0.056$), most likely due to the decreasing tree densities. Epiphytic plant presence increased over time despite decreased host tree densities, suggesting either a change in management or improved habitat conditions for epiphytes. Research plots on individually-managed coffee farms generally had higher shade tree densities than those on collectively managed farms ($t = 2.141$, $p = 0.037$), but we found no differences in shade tree species richness or carbon stocks ($t = 0.573$, $p = 0.568$). We conclude that smallholder coffee farmers continue to conserve both shade tree diversity and epiphyte communities.

1. Introduction

Since the 1990s, coffee agroecosystems have received attention for their potential as refuges of planned and associated biodiversity (Harvey and Villalobos, 2007; Perfecto et al., 1996; Somarriba et al., 2004; Vandermeer and Perfecto, 2007). By maintaining a diversity of shade trees above a coffee crop, farmers contribute to *in situ* biodiversity conservation (Dawson et al., 2013). Shade trees, in turn, provide a number of ecosystem services—the goods and services from ecosystems that directly or indirectly benefit humans (Carpenter et al., 2006). Shaded coffee systems generate provisioning ecosystem services such as food, fuel and building materials, and regulating services such as water conservation, erosion control, nutrient maintenance and carbon storage (Nair et al., 2009). Shade trees within farms and forest fragments near agroecosystems also provide ecosystem services such as pollination (Priess et al., 2007; Ricketts, 2004; Tscharntke et al., 2008) and biological pest control (Wilby and Thomas, 2002). At the landscape scale, shade trees facilitate the movement of organisms through the agroecological matrix (Perfecto and Vandermeer, 2002; Vandermeer and Carvajal, 2001; Vandermeer et al., 2010), providing connectivity between forest fragments (Chazdon et al., 2011; Dawson et al., 2013; Harvey et al., 2008).

Biodiversity increases with structural diversity within coffee agroecosystems (Moguel and Toledo, 1999). For example, trees increase structural diversity by providing habitat for birds, ants and epiphytes. Epiphytic plants, in turn, create microhabitats and increase plant biomass and surface area on trees (Nadkarni et al., 2001; Sillett, 1994). Epiphytes—orchids, ferns and vines—and bryophytes, such as moss species, often create habitat for invertebrates and provide resources such as nesting materials, nectar, fruit and water reserves for larger tropical species (Benzing, 1990; Cruz-Angon and Greenberg, 2005; Hylander and

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Nemomissa, 2008). It has also been suggested that because of this they may act as keystone species (Moorhead et al., 2010).

Up to half of plant species richness in tropical forests may be composed of epiphytes (Benzing, 1990) and they have the potential to naturally colonize coffee systems because most are wind-dispersed (Solis, 2002). Many farmers believe most epiphytes are harmful to coffee yields and commonly remove them from shade trees and coffee bushes in both Latin America (Cruz-Angon and Greenberg, 2005). Indeed, a recent study on a large coffee farm in Veracruz, Mexico found that coffee productivity (in terms of fruits and flowers) was significantly higher under shade trees from which epiphytes had been removed (Toledo-Aceves et al., 2013). Still, many certification programs require that farmers allow epiphytic plants to grow in the shade canopy to support local biodiversity (Mas and Dietsch, 2003; Mas, 1999). Despite certification stipulations, pressure to intensify coffee production and increase yields could result in farmers removing epiphytes and thus decreasing biodiversity.

Research in Mesoamerica shows that some smallholder production methods can serve both ecological and social functions by simultaneously conserving biodiversity (Daily et al., 2003; Estrada and Coates-Estrada, 2002) and increasing food security and rural incomes (Pretty et al., 2003). In general smallholder farmers are more likely to have an intimate knowledge of land, produce diverse crops, conserve traditional varieties and prioritize labor and knowledge inputs instead of chemical inputs (Nazarea, 2006; Netting, 1993).

These factors point to the importance of supporting rural livelihoods in conjunction with conserving biodiversity and ecosystem services. Tools to identify important habitats for biological conservation are abundant (Myers et al., 2000; Richards and Mendez, 2014). However, fewer strategies exist that simultaneously prioritize conservation of ecological habitat, cultural traditions, and agricultural practice in rural areas (Harvey et al., 2008). For this reason, Harvey et al. (2008) suggest the use of "rural hotspots", which are areas where "traditional smallholder livelihoods are most vulnerable and where agroecological systems and knowledge are being rapidly lost" (10). In many cases, landscapes composed of smallholdings are more likely to sustain biodiversity conservation than those containing large plantations involved in export agriculture (Rosset, 2000). Thus, policies that support smallholder farmers are also likely to support flora and fauna that depend on these same landscapes (Castillo and Toledo, 2000; Harvey et al., 2008).

Recently, interest on agroforestry systems has shifted from production and food security benefits to include greater emphasis on climate change mitigation, carbon storage capacities (Mendez et al., 2012; Segura et al., 2006), and biodiversity conservation (Kirby and Potvin, 2007; Mendez et al., 2009; Richards and Mendez, 2014). Though much of the latter literature highlights the need to include smallholder farmers (Dawson et al., 2013; Perfecto and Vandermeer, 2008; Schroth et al., 2009; Toledo and Moguel, 2012; Tscharntke et al., 2011), the focus has largely remained at the landscape scale (Wollenberg et al., 2012; Richards and Mendez, 2014 and little is known about long-term patterns of diversity and sequestration capacity in smallholder agroecosystems (Maas et al., 2009).

Worldwide, at least 4.3 million coffee producers are smallholders, farming on less than 10 ha of land (Jha et al., 2011; Rahn et al., 2013). In Mesoamerica, over 300,000 farmers and 1,700,000 seasonal workers cultivate approximately 809,000 ha of coffee (Castro et al., 2004; Escamilla and Diaz, 2002; Flores et al., 2002), and approximately 68% of farmers are considered micro-producers, growing less than 2 ha of coffee (CEPAL, 2002; Jha et al., 2011). Though the percentage of area farmed by smallholders remains relatively low (18% in Central America according to Jha et al., 2011), the traditional farm management practices of many smallholder farmers have been shown to more closely mimic forest habitats, support wildlife populations, and maintain high levels of carbon stocks (Toledo and Moguel, 2012).

There are two different types of coffee cooperatives in Nicaragua, credit and marketing cooperatives that channel the harvests from individually managed farms into international markets, and cooperatives that provide these services and manage part or all their farms collectively. By the early 2000s, most co-ops operated in a manner closer to the former model, however, they often had common land titles and in some cases managed the coffee plots, forests, and pastures collectively.

In Nicaragua, it is common for several primary level cooperatives to unite and form a cooperative union or second level cooperative. These second level cooperatives can take advantage of economies of scale as they export coffee, manage certification systems (e.g., organic and fair trade), and seek access to lower interest pools of credit. Many smallholder farmers join cooperatives to more easily access to credit, gain better coffee prices through sales to certified markets, receive technical assistance, and to improve land tenure security (Bacon, 2010; Enriquez, 2010). There are roughly 40,000 coffee farmers in Nicaragua, more than 90% are smallholders, managing less than 10 ha of coffee production area, and more than 50% of these small-scale farmers are affiliated with a cooperative (CENAGRO, 2011). The support for and networks surrounding cooperatives and other local institutions may prove essential for decreasing vulnerability of rural livelihoods and confronting climate change (Agrawal, 2010; Bacon, 2010), as well as preserving ecosystems (Mendez et al., 2009).

This research identifies patterns of shade tree density and diversity, epiphyte presence, and carbon stocks over a 10-year period within smallholder coffee systems of northern Nicaragua. We examined how organized smallholders manage agroecosystems and how these practices either support or discourage biodiversity and carbon sequestration over time. More specifically, we focused on the following objectives:

- Analyze changes in tree and epiphyte diversity and abundance over time.
- Analyze changes in above ground tree C stocks over time.
- Assess the effects of collective vs. individual farm management on tree and epiphyte biodiversity and tree C stocks.

2. Methods

2.1. Site description

We conducted this study in five coffee cooperatives in the district of Matagalpa, Nicaragua: three in the Yasica Sur district (12°55′30″ N and 85°50′00″ W; 400–1000 m a.s.l.) and two near the small town center of San Ramon (85°50′23″ W and 12°55′25″ N, 639 m a.s.l.). Coffee in this region is grown in elevations between 400–2000 m a.s.l. (Segura et al., 2006) and the ecological landscape can be categorized as a sub-tropical humid forest, with annual precipitation between 600–2000 mm $year^{-1}$ (Segura et al., 2006). The department of Matagalpa is the second-largest hub for coffee commerce in the country, yielding an average of 774 kg ha^{-1} (INIDE, 2009). In the 2008–2009 growing season, 33,219 ha of land in the department was dedicated to coffee, nearly 1/3 of Nicaragua's total coffee production area (INIDE, 2009).

The five primary level cooperatives are associated with a regional cooperative union that oversees administrative support, provides producers with credit, access to specialty markets and technical assistance, and exports the coffee. In San Ramon, the primary cooperatives engage in different types of coffee farm management, as determined by their origin and history. These