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Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia

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ABSTRACT

Land-use changes threaten biodiversity and ecosystem services. Some of the last remaining forest fragments in Ethiopia, and the world's only habitats that retain genetically diverse wild *Arabica* coffee populations, have experienced rapid recent conversion to coffee farms, plantations and agricultural fields. We examined patterns of remnant woody plant diversity in the remaining forests, and assessed the potential and limitations of coffee agroforests to maintain this diversity. We explored patterns of woody biodiversity, structure, and regeneration in forest fragments and on adjacent smallholder and large-scale state-owned shade-coffee farms. A total of 155 native woody species including rare/threatened species of *Baphia, Cordia, Manilkara*, and *Prunus* were recorded. Of these species, 56 (36.2%) and 18 (12%) were restricted to forest fragments and coffee farms respectively. Smallholder and large-scale coffee farms maintained 59% and 26% of the 155 recorded native woody species compared to the 137 species (88%) found in forest fragments. Native woody species regeneration in state-owned plantations was lower than in smallholder farms, which in turn was lower than forest fragments. Coffee farms could support a considerable portion, though not all, of the woody biodiversity of disappearing forests. Persistence of forest woody diversity and associated ecosystem services depends strongly on the scale and type of shade coffee cultivation pursued.

1. Introduction

As tropical deforestation and fragmentation continue, production landscapes will necessarily play important roles in biodiversity conservation (Bhagwat et al., 2008; Gardner et al., 2009). More than 90% of tropical biodiversity is found in human-modified landscapes, outside protected areas (Chazdon et al., 2009). In particular, agricultural landscapes such as shade coffee agroforestry systems (Moguel and Toledo, 1999; Mendez et al., 2007; Gole et al., 2008; Aerts et al., 2011; Hundera et al., 2013a), and home gardens and plantations (Hylander and Nemomissa, 2008, 2009) can serve as biodiversity refugia. However, the amount and composition of biodiversity retained in agroecosystems depends strongly on type of agriculture, and management practices (Harvey et al., 2008). A review by Bhagwat et al. (2008) compared agroforestry systems with nearby forests and showed that the conservation potential of different agroforests varied widely with the taxa in question. Scales and Marsden (2008) described that potentials for biodiversity conservation in agroforests depends on the type of agroforest that is strongly linked to management intensity (Jose, 2012), economic needs, and the extent of remnant forest within the landscape. Conservation must thus consider carefully the extent and limitations of biodiversity maintenance in production landscapes with particular land-use trajectories.

Traditional coffee agroforests have potential to do better than tea, coffee and oil-palm plantations since such agroforests incorporate shade trees in order to retain ecosystem services such as soil fertility, wood and non-wood products. Coffee agroforestry systems can potentially (1) protect biodiversity by providing heterogeneous and critical habitats, (2) buffer against overexploitation of forest biodiversity, and (3) serve as corridors and permeable matrices that connect meta-communities in natural landscapes (Perfecto et al., 1996). Coffee landscapes may have greater conservation potential in hyper-fragmented landscapes with long histories of human use and disturbance since much of the original forest vegetation is lost and modified.

Only 10% remains of the original vegetation in the Eastern Afromontane biodiversity hotspot with 75% endemism in vascular plants, 40% of it found in Ethiopia (White, 1981; Burgess et al., 2005; Birdlife International, 2012). Within Ethiopia, the large majority of moist Afromontane vegetation and biodiversity occurs in remnant forests in the southwest of the country. Although biophysical and anthropogenic conditions vary, humid Afromontane forests in Ethiopia maintain diverse emergent angiosperms in the overstory; shrubs, herbs, and ferns in the understory; and lianas,

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epiphytes, and lycopods (Friis, 1992). Beyond their high diversity and floristic endemism, these fragments are the only global natural habitats for genetically diverse wild populations of *Arabica* coffee (Gole, 2003; Aerts et al., 2013). Finally, most local people depend on these forests for ecosystem services and goods such as coffee, spices, forest honey, fiber, and fodder (Teketay, 1999; Senbeta and Denich, 2006; Schmitt et al., 2010a). With only a small and declining fraction of remnant forests left, we urgently need to understand the potential for and limitations of coffee agroforestry systems to maintain native woody diversity and associated ecosystem services. The forest fragments we studied are predominantly Afromontane rainforest vegetation and relatively protected, but little managed forests that may or may not have coffee in the understory.

Arabica coffee is the second most traded global commodity after petroleum and the backbone of the Ethiopian economy. Besides being the birthplace of coffee, Ethiopia is the fifth largest global producer of *Arabica* coffee (International Coffee Organization, 2013). In Ethiopia and the study region, coffee is produced under native tree canopies in wild (5%), semi-wild (10%) and plantation systems (85%) (Petit, 2007). Coffee is harvested in the wild either without management, or with management by planting coffee seedlings under natural forest canopy enriched with additional understory management (Wiersum et al., 2008). Semi-forest coffee management is less intensive than plantation coffee, although managing native forests for coffee production reduces specific functional groups or changes the microclimate (Senbeta and Denich, 2006; Aerts et al., 2011; Hundera et al., 2013b). Hundera et al. (2013b) described that intensifying semi-forest coffee to semi-plantation coffee in southwest Ethiopia reduces floristic diversity, stem density, and crown closure. We studied both state-owned (plantations) and smallholder (semi-forest and semi-plantation) coffee systems (Wiersum et al., 2008) adjacent to natural forest-fragments to examine the relative roles of each type of coffee farm in maintaining native woody species diversity, floristic structure and regeneration status.

Smallholder coffee production systems (c. 700,000 ha and 90% of total production in the region), practiced by over 15 million smallholder farmers throughout the nation, are more prevalent than large-scale, state-run coffee production (c. 21,000 ha, 5% of total production) (Petit, 2007). The smallholder farms in the study region range from 0.5 to 3 ha and are composed of wild forests, semi-cultivated forests, plantation and homegardens that vary in management intensity (Weirsum et al., 2005; Tadesse, 2013). The smallholder coffee system in this study comprise semi-forest coffee (67% of our samples), and smallholder managed sand semi-managed and plantations (33%). Only fewer than 10% of small farms are more intensified (less than 10% shade cover, with more coffee density per hectare) and are usually found around homesteads (Tadesse, pers. obs.). Those adjacent to forest fragments were less intensified.

Management in Ethiopia's smallholder coffee farms involves both cultivated and semi-cultivated production, as well as wild coffee, with shade tree selection based on both annual thinning of the original understory vegetation and frequent planting of woody species desirable for shade and other purposes (Senbeta and Denich, 2006; Aerts et al., 2011). In addition to clearing the understory vegetation, farmers frequently tend, transplant, coppice, harvest and replace shade trees for various purposes including beehive construction, fuel wood, furniture and timber.

The state-owned coffee plantations were established mainly between 1975 and 1988 from various landlord-managed and private coffee farms, nationalized after the 1974 revolution, and some recently converted adjacent forests (Teppi Coffee Plantation Enterprise, TCPE, 2010). The three state coffee farms in this study represent the second-largest government plantation area in Ethiopia (2482 hectares) and also cultivate fruits, spices, and some honey (TCPE, 2010). Although the majority of shade tree species on government farms remained protected at least since early 1980s except if lost by fire or wind fall (TCPE, 2010), people have been replacing native tree species with many native and introduced legumes and shade tree species. Management in these farms is more intensive than the smallholder farms, includes use of machinery (tractors), manual labor for weeding, some use of herbicides and fertilizers, clearing of understory shrubs, and harvesting of coffee that are modified coffee varieties and other tree fruits. Besides native shade tree species, >10 exotic coffee-shade tree species are being introduced in mainly in the state-owned plantations (Tadesse, 2013).

Previous studies on biodiversity conservation in coffee agroforests in southwest Ethiopia focused on woody species diversity (Senbeta and Denich, 2006; Schmitt et al., 2010a), mosses and ferns (Hylander and Nemomissa, 2008, 2009), and epiphytic orchids (Hundera et al., 2013a). There are few comparative ecological studies that measure and compare the diversity , structure and regeneration of native woody species among forests and different forms of coffee cultivation (Aerts et al., 2011; Hundera et al., 2013b). However, there are no known studies that included the more intensified state-owned coffee plantations in the region. We explored the diversity, size structure and regeneration of woody species in remnant forests and the two distinct coffee cultivation systems that continue to expand in southwest Ethiopia. We hypothesize that woody species diversity and regeneration declines as forests are converted into traditional smallholder coffee agroforests and into plantations. We expected that semi-forest and semi-plantation coffee systems have greater roles in conserving native woody species diversity than more intensively managed state-owned coffee plantations.

2. Methods

2.1. Study area

To explore species distribution and diversity patterns among coffee farms and forest-fragments, we studied (1) 18 natural forest patches (2) three state-owned coffee plantations and (3) 39 smallholder coffee farms in 2010 and 2011. We sampled all the three land-cover types that were adjacent to each other with comparable biophysical and climate conditions. The study region included two districts of southwest Ethiopia (1) Yeki (618 km^2 area) in the Sheka zone (7.2°N, 35.3°E) and (2) Bonga region (2764 km^2 area) in the Kaffa Zone (36.1°E, 7.1°N) (Fig. 1). Rainfall in the region is uni-modal with mean annual precipitation of >1600 mm and a mean monthly temperature that ranges from 18 °C to 23 °C (National Meteorological Services Agency, 2008). The two study regions were selected based on the presence of a mosaic of coffee agroforests and forest fragments.

2.2. Data collection

To quantify woody biodiversity, we sampled 115,400-m^2 plots from 18 forest-fragments of varying size (with a total of 29,794 ha) using transects that run from forest edge to core at 250 m intervals. For larger fragments of >10 ha, we sampled on transects along forest edges (at 300 m from forest fringes) and in forest cores. We also sampled 39,400-m^2 plots, each owned by different smallholder farms distributed across different elevations and adjacencies to forest fragments and state-owned plantations. A total of 40,400-m^2 plots were established in the 3 large state-owned plantations (2200 ha), with more plots in larger farms, using systematic random sampling to capture variation in elevation, and management histories (from old to newly established farms).