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Effects of land-use changes on woody species distribution and above-ground carbon storage of forest-coffee systems

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ABSTRACT

As deforestation and fragmentation continue in tropical regions with high human use and disturbance of natural habitats, production landscapes such as agroforests and plantations may provide some forest-based services depending on tree selection, agroforest management and intensification. This is typical to southwest Ethiopia with strong human-dependence on forest biodiversity and ecosystem services. We examined the effects of land-use changes and fragmentation on woody species distribution and the relative importance of forest fragments and coffee farms in wood use and carbon storage. We sampled heartwood from 71 woody species in three land use types: natural forest fragments, smallholder semi-forest coffee farms and state-owned coffee plantations. We calculated wood density as an oven-dry biomass per fresh volume of heartwood core samples, and above-ground carbon biomass using allometric methods. We found that average wood density values were not correlated with fragment size. Mean wood density of species in forests was greater than in state-owned plantations. The two coffee systems can store 50–62% of the above-ground carbon biomass found in forests, indicating the need to incorporate coffee farms and forest remnants in carbon incentive, or climate mitigation and adaptation programs. To correlate species wood density with local wood preferences, we interviewed focus groups and households about the use-values of 51 farmer-appreciated species. There was a strong correlation between wood density and local wood-values signifying the concordance of species functional traits and ecosystem service values. Our results indicate the need to integrate functional traits and local ecosystem service uses in climate adaptation and mitigation by incorporating coffee agroforests with the conservation of natural forest remnants.

1. Introduction

If natural ecosystems continue to decline, human-dominated landscapes can play a vital role in maintaining biodiversity (Chazdon et al., 2009; Gardner et al., 2009) and ecosystem services (Schroth et al., 2004). Since much of tropical biodiversity is found outside protected areas (Chazdon et al., 2009), we need to incorporate production landscapes and ecosystem services into conservation programs. The capacity of production landscapes to provide ecosystem services depends on management and disturbance that affects the abundance and distribution of service providing species (Jose, 2009). Woody species distribution in human-dominated forests and agroforests varies as a function of species traits that are desirable for human use, and that are vulnerable to disturbance and fragmentation.

Wood density, the specific gravity of a wood important is for support and strength. It is one of the functional traits that are affected by fragmentation and disturbance (Carreno-Rocabado et al., 2012). Wood density is also related to wood provisioning and carbon storage (Cornelissen et al., 2003; Saranpaa, 2003; Chave et al., 2009). It affects the weight, strength, flammability, workability, and resistance to decay and termites of a wood and thus the use-value of wood for local people (see FAO, 2011).

In order to meet conservation and livelihood needs, bundling local ecosystem services with global values of biodiversity such as carbon storage and climate mitigation will be important. For this, studies that examine the effects of anthropogenic disturbance on ecosystem services and the complementary roles of production landscapes in local and global-scale provisioning and regulating services are essential. This study examines the effects of fragmentation and forest conversion, into agroforests, on woody species and associated ecosystem services and the role of production landscapes such as coffee agroforests in providing wood related ecosystem services.

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1.1. Effects of fragmentation and human filters on woody species and wood-related services

Fragmentation in this study refers to the conversion of a previously continuous forest into smaller forest patches isolated from each other by non-forested lands (see Fahrig, 2003) such as coffee farms, crop fields, plantations and settlements. Fragmentation and disturbance can affect woody species distribution and abundance as a function of their wood density values. Species with low wood density grow faster and are short-lived and less resistant to fire and herbivory than denser-wood species (Swenson and Enquist, 2007; Poorter et al., 2010; Martinez-Carbera, 2011) (Table 1). Alternatively, dense-wooded species or those with high wood density grow slower, and are more resistant to fire and herbivory but more vulnerable to fragmentation and edge effects than light-wooded species (Carreno-Rocabado et al., 2012). Fragmentation replaces dense-wooded and large canopy tree species with fast-growing pioneers that have low wood density (Laurance et al., 1997). Slik et al. (2008) concluded that average wood density in forests is a robust indicator of successional status and can be used as a conservation monitoring tool in tropical rainforests of Southeast Asia.

Forest fragmentation and conversion to agroforests may have implications on two kinds of ecosystem services: wood provisioning at local scales, and carbon stock potential. Wood provisioning services with respect to locally-valued wood qualities are determined by some wood traits influenced by wood density (see Walker, 1993). In managed forests and coffee farms, the quality, composition, and volume of wood people harvest may vary depending on the shade tree species. Coffee agroforests in tropical ecosystems maintain woody species that are used as coffee shade, fuel-wood, material culture, construction materials, and carbon biomass (Leakey et al., 2005; Rice, 2008; Jose, 2009; Tadesse et al., 2014a). In particular, southwest Ethiopian agro-ecosystems support millions of local people who largely depend on wood and non-wood resources in their day-to-day life.

Understanding the effects of fragmentation and human filters is important for management and conservation that integrates local needs with the conservation of biodiversity and ecosystem services. Studies that examined the effects of fragmentation on woody species distribution and associated ecosystem services in relation to wood density and carbon biomass are very scanty in southwest Ethiopia. Here we asked whether woody species distribution is affected by fragmentation with respect to its differential effects on dense and lighter-wooded species.

We hypothesize that dense-wooded species decline when forests are converted into agricultural landscapes partly due to intrinsic vulnerability of such species to disturbance, and due to human preferences for fast-growing and light-wooded species in managed landscapes, or human filters. Here, we define human filters as human-mediated woody community assembly that is determined by human preference and realized through planting, encouragement and protection of woody species for their ecosystem services. Human filters may also lead to community disassembly via over-harvesting and logging of species in agroforests and forest fragments. To understand human-induced effects on woody species with respect to wood density, we compared variations in average wood density values of species assemblages between natural forests and coffee farms.

Table 1
Adaptive significance of species with low and high wood density with respect to growth, survival, defense, and resistance to fragmentation and disturbance (Source: Chave et al., 2005; Wright et al., 2007; Poorter et al., 2010; Martinez-Carbera, 2011; Carreno-Rocabado et al., 2012)

Adaptive significance	Wood density	
	Low	High
Growth rate	Fast	Slow
Size (height and DBH)	Large	Small
Crown size	Wider/deeper	Narrower
Succession stage	Early	Later
Survivorship	Poor	Long-lived
Resistance to herbivore, pathogens and fire	Low	High
Resistance to fragmentation and disturbance	High	Low
Effects of human filters	Varies	Varies

1.2. Aboveground carbon biomass and prospects for climate mitigation

Carbon storage is another ecosystem service provided by woody species and affected by land-use changes and fragmentation. About 50% of above-ground living biomass is made up of carbon in forests and agroforests (Clark et al., 2001), and approximately 20% of global greenhouse gas emissions are from forest degradation and forest conversion to agricultural landscapes (Denman et al., 2007).

Agroforests are agricultural areas with >10% tree cover, and they account for 46% of the agricultural area covering about a billion hectares (Zomer et al., 2009). Although carbon biomass potential of agroforests vary depending on species composition and management, globally they sequester about 1.9 Pg (1.9 billion tons) of above-and below-ground carbon over 50 years (Albrecht and Kandji 2003; Nair et al., 2009). In some coffee growing regions of Indonesia, shade coffee agroforests, depending on shade tree density and composition, can store up to 75% of the above-ground carbon stored in the adjacent remnant forests (van Noordwijk et al., 2002; Kessler et al., 2012).

Coffee agroforests have great potential in carbon biomass and climate adaptation (Jose and Bardhan, 2014; Verchot et al., 2007). Estimates on the potential of agroforests in Africa in terms of aboveground carbon biomass range from 1.0 to 18.0 $Mg\,C\,ha^{-1}$ (Nair and Nair, 2014). However, agroforest intensification in the form of reduction in shade tree diversity and density reduces carbon storage capacity (Tscharntke et al., 2005; Robinson et al., 2009; de Paula et al., 2011). Traditional agroforests are being intensified into plantations with reduced shade tree density and diversity in southwest Ethiopia (Tadesse et al., 2014a). Carbon stock potential decreases through frequent logging and tree mortality around forest edges and through the replacement of large canopy trees that store high carbon with fast-growing pioneer trees of smaller size and low wood density and with lianas that sequester much less carbon (Laurance et al., 1997; Laurance et al., 2006). We were interested in how much carbon stock potential is at stake if we lose certain native trees by fragmentation or forest conversion into coffee agroforests in southwest Ethiopia. We estimated the aboveground carbon biomass in coffee farms and adjacent forest fragments using wood density and allometric measurements from living aboveground biomass of woody species.

Woody biodiversity conservation and ecosystem service delivery in traditionally diverse coffee agroforests in southwest Ethiopia will depend on conservation incentive programs such as reducing emissions from deforestation and degradation ($REDD^{+}$) and clean development mechanism (CDM). If $REDD^{+}$ is implemented sustainably, it can effectively promote forest management and agricultural practices that increase tree cover for both climate change mitigation and adaptation globally (IPCC, 2014). This requires estimating the amount of carbon biomass stored in forests and agroforests. This study will provide useful information about implications of carbon sequestration in coffee agroforests of southwest Ethiopia to conservation and the livelihoods of small-scale farmers. We estimated the potential of carbon incentives from such programs based on the carbon retention potential of forests and agroforests in the region.