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Effects of management and landscape composition on the diversity and structure of tree species assemblages in coffee agroforests

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ABSTRACT

Understanding the processes that influence tree species composition in agricultural landscapes is essential for conservation of tropical biodiversity outside of protected areas. We analyzed the effects of landscape composition (amount of surrounding forest cover) and farm management (conventional vs. organic) on the diversity and structure of woody plant species assemblages in Costa Rican coffee agroforestry systems. We utilized information from a GIS land-use database, surveys of 1-ha plots located in 14 coffee farms and 4 forest fragments, and farmer interviews on management practices. The coffee farms harbored over 100 tree species, including 19% of the native tree species found in the surrounding forests. The majority of tree species on the farms were native (82%) to the study area and originated from natural regeneration (73%). Among the tree species that regenerated naturally, 71% were dispersed by animals. On the other hand more than half of the individuals were non-natives (55%) and originated from planting, which resulted in low species similarity between farms and forests and a low density for most native species on the farms. Forest cover within a 1000 m radius around the farms varied between 4 and 38%. Increasing forest cover around the farms had a significant, positive effect on species richness; especially on tree species dispersed by animals, and on species similarity between farms and forests. This suggests that the connection to natural forests increases seed dispersal into adjacent farms. The number of regenerated species was higher on the organic farms, but tree species richness was not affected by management type. Although species assemblages on the coffee farms are strongly determined by natural regeneration, the number of individuals contributed by these processes is low. Tree species conservation in agricultural landscapes would greatly benefit from protecting remnant forests, from facilitating natural regeneration processes and promoting native trees on farms, with particular attention to rare species.

1. Introduction

Agriculture is a main driver of habitat destruction, fragmentation, and loss of biodiversity in the tropics (Harvey et al., 2008; Gibson et al., 2011). Conversely, it has been argued that the future of tropical biodiversity depends on the successful integration of rural livelihoods with conservation efforts in human-modified landscapes (Perfecto and Vandermeer, 2008; Philpott et al., 2008; Chazdon et al., 2009). Agroforestry can act as an intermediary between the dichotomy of managed ecosystems and natural forests by providing habitat for forest-dependent species and by increasing connectivity across altered tropical landscapes (Schroth et al., 2004). It is well established that agroforestry systems with low management intensities can increase the diversity of plants, vertebrates and arthropods in managed landscapes, and that agroforests may share a large proportion of species with adjacent natural forests (e.g., Baghwat et al., 2008; Perfecto and Vandermeer, 2008; Philpott et al., 2008; Clough et al., 2010; Dawson et al., 2013).

Understanding the processes that mediate diversity patterns in human-modified landscapes is essential for conservation outside the protected areas. However, very little is known about how

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species assembly is determined by processes such as dispersal, species sorting across different habitat types, or management practices in tropical agroforestry systems (Chazdon et al., 2009; Livingston et al., 2013).

One of the factors that affect species composition in agroecosystems is the surrounding landscape mosaic. Forest fragments may represent sources for biological diversity in agricultural landscapes. In addition, the proximity of natural forests determines the abundance and diversity of important functional groups including mammals, birds and arthropods – which act as predators, seed dispersers or pollinators (Ricketts, 2004; Tscharntke et al., 2008; Clough et al., 2010; Livingston et al., 2013). Few studies have analyzed the relationships between landscape composition and tree species present in agroforests (e.g., Faria et al., 2007; Sonwa et al., 2007; Dawson et al., 2013), although such relationships are well established for more mobile organisms. For instance, Tscharntke et al. (2008) and Clough et al. (2010) reported that the diversity and composition of birds and different insect taxa in tropical agroforestry systems were significantly altered by increasing distance to surrounding forests and by management intensification. Despite their interdependence, plant species similarity between agroforests and natural forests is often lower, compared to animals (Baghwat et al., 2008). This is partially due to the fact that trees are more directly subjected to farmers' management decisions, such as planting, pruning or removal of individuals.

Organic management may further enhance ecological benefits of agroforestry systems such as shade grown coffee farms (Philpott et al., 2007). Organic farming limits the use of agrochemicals like herbicides that can disrupt the natural regeneration of native tree species in conventional agricultural systems in the tropics (Esquivel et al., 2008). In addition, organic farmers rely more directly on services provided by trees – such as erosion prevention, watershed protection, pest control, or nitrogen fixation – benefits that may encourage organic farmers to plant or maintain certain tree species along with their crops (Muschler, 2000; Perfecto et al., 2007).

This study aimed to understand the effects of landscape composition (the amount of forest cover within a 1000 m radius around each farm) and management practices (conventional vs. organic) on tree species assemblages in Costa Rican coffee agroforestry systems. We utilized information on landscape composition from a GIS land-use database, field data on tree species diversity from 14 coffee farms and 4 nearby forest fragments, farmer interviews on farm history and management, as well as information on seed dispersal mechanisms. It was expected that tree species diversity and species similarity between farms and forests will increase with increasing forest cover around the farm and that organic farms will show higher diversity and similarity with forests than conventional farms. It was also expected that farms surrounded by forest will show a higher number of naturally regenerated species and a higher proportion of animal dispersed tree species in comparison with more isolated farms. Finally it was hypothesized that the utility of a given tree species would determine its frequency across the farms, as farmers should prefer tree species with higher perceived utility.

2. Methods

2.1. Study site

This study was conducted between 2008 and 2013 in the Western Central Valley of Costa Rica. Data were collected on 14 coffee farms (7 conventional and 7 certified organic) and 4 forest fragments located within the Rio Grande watershed (9.98°N, 84.40°W, Fig. 1). The farms were assessed between November 2008 and April 2011. Forest fragments were assessed between November 2011 and April 2013. Elevation at the study sites ranged from 800 to 1250 m a.s.l. Farms varied in size from 1.4 to 24.5 ha. Forest fragments varied between 10 and 80 ha in size and consisted of mature secondary forest with patches of old growth forest. Annual rainfall ranges between 2000 and 2500 mm, with a distinct dry season from December to May. All study sites were located either in premontane wet forest or in the tropical moist (transition to premontane) forest according to the Holdridge Life Zone classification (ITCR, 2008).

Organic farms were chosen first, due to their limited number within the study area, and then 7 topographically similar conventional farms were selected. All farms had coffee crop areas >1 ha with a cover of shade trees. Farms had been cultivating coffee for at least 15 years and previous land uses included forests, annual crops (maize, beans, plantains, tobacco) or pastures. All organic farms were certified for at least 7 years prior to the time of the study. Forest fragments were selected based on local land use maps (scale 1:10,000) from 1991 and 2008 (IGNCR, 1991; IGNCR, 2008). These maps were based on imagery from 1989 and 2005, respectively. We selected forest fragments located within the Rio Grande watershed that were found within the same elevation range as the farm sites, and had a minimum area of at least 10 ha on both the historic and current land use maps.

2.2. Data collection

Forest cover was determined within a 1000 m radius around each farm based on the assumption that most trees have the ability to disperse within this range (Corlett, 2009). The amount of forest cover around the farms was extracted from a revised land-use database, provided by the Costa Rican Geographic Institute (IGNCR, 2008) using ArcGIS 10.0 (ESRI, 2011) (Fig. 1).

Structured interviews with farmers on farm history and management were conducted between 2008 and 2013. Interview questions focused on previous land use, time since land conversion to coffee, time since organic certification, and means of tree establishment on each farm. The owners of all 14 farms were interviewed, with one exception. In the case of the remaining farm, information was obtained from the owner of the neighboring coffee farm who indicated that he was thoroughly familiar with the management and history of the property. A list of all tree species found within 1 ha on each farm (see details on methods below) was presented to the respective land owner. To compile these lists, local common species names were used. Common names for less known tree species were taken from León and Poveda (2000). If a common name applied to several species, as for instance in the case of *Inga* spp., or in the case of less known species, images from plant identification books (Zamora-Villalobos and Pennington, 2001; Zuchowski, 2005; Condit et al., 2011) were used to clarify uncertainties. Farmers were asked to indicate if a given species was remnant, planted or regenerated naturally on their coffee farm. All farmers were readily able to determine which species were planted or large remnant trees from previous land uses. In the vast majority of the cases they were also able to indicate which tree species had regenerated naturally on their coffee farm. Across all 14 agroforests, farmers classified the origin of tree species in 291 out of 307 cases (each case being the presence of a given species on a specific farm, coming from a total of 100 species). There were only 16 cases (14 species) in which farmers indicated that they were not aware of the presence of a species that was previously identified during data collection in their coffee agroforests. These species were assumed to have regenerated naturally.

A 1-ha plot was established at the approximate center of each farm. Farm plots were usually 100 m × 100 m. In some cases plot shape varied in order to fit a 1-ha study area within the perimeter