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Original research article

Patch area and current coffee management determine woody plant diversity in patches of semi-forest coffee embedded in an agricultural matrix

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ABSTRACT

Effective conservation of biodiversity in patches of (semi-) natural vegetation is dependent on an understanding of the influence of management as well as spatial and temporal factors. In southwestern Ethiopia coffee generally grown under a rather dense layer of indigenous trees (so called semi-forest coffee - SFC) often in patches embedded in an open agricultural landscape. The aim of the study was to disentangle what governs the variation in species richness of woody species among such patches. We collected data on species and possible explanatory factors in 40 × 40 m plots centered in 40 SFC patches, measured the patch area for 1987 and 2013, and the amount of surrounding SFC-area for each patch. We recorded the number of coffee stems and the level of disturbance caused by slashing of the understory vegetation. Species richness of large coffee shade trees (>20 cm in diameter) was higher in larger patches with even slightly better fit of the statistical models when the historical area was taken into account. However, most species of large trees also occurred as seedlings showing that there is still a potential to conserve these species in the patches. Coffee management negatively affected the richness and density of woody species, especially in the intermediate size class (1.6–20 cm diameter). Disturbances accompanying coffee management such as slashing of the ground vegetation also negatively affected tree seedling density as well as species richness. There was no effect of connectivity on species richness. Based on the combination of these results we conclude that small patches of semi-forest coffee had fewer species of large trees, not because of a lack of tree seedlings, but probably because of differentiated local extinctions, perhaps during the time when the species were intermediate sized. To maintain the species richness of large trees in semi-forest coffee patches, the sites need to be actively managed.

1. Introduction

Habitat loss is considered the major cause of declining biodiversity, especially in tropical forest ecosystems (Mortelliti et al., 2010; Botello et al., 2015). Since agricultural mosaic landscapes have become common on previously forested areas we

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need a better understanding of the drivers of species richness and composition associated with trees and embedded forest fragments in such landscapes (Chazdon et al., 2009; Gardner et al., 2009; Häger et al., 2015).

The number of species in a forest patch is affected by many different factors. A larger patch generally has higher species richness due to higher habitat heterogeneity or simply because more individuals are present (Rosenzweig, 1995). If the number of species increases with patch area also when comparing same-size plots (for example one plot in the center of each of the patches), it might be an indication that the pattern is instead related to colonization–extinction dynamics following predictions of island-biogeography and metapopulation models (MacArthur and Wilson, 1967; Munguía-Rosas and Montiel, 2014). Here, not only area through its effect on both extinction and colonization rates, but also isolation, by decreasing the colonization rate are regarded as an important predictors of patch species richness. The degree of the impact of isolation is also dependent on the matrix between the patches (Laurance, 1997; Bender and Fahrig, 2005). However, many other variables than area and isolation could affect the number of species in a patch and even change the predicted species–area relationship (Ewers and Didham, 2006). In human dominated landscapes where generalist species from the matrix can penetrate the patches, pronounced edge related effects and various effects of management will influence species richness (Hundera et al., 2013).

History of the past land use can also affect the biodiversity of the patches. This can arise due to time lagged responses of species to landscape change both regarding extinctions and colonizations (Jackson and Sax, 2009). Extinction debts could be caused by delays due to both changes in habitat quality, quantity and connectivity (Hylander and Ehrlén, 2013), changes which often goes hand in hand when forests are becoming fragmented (Hanski and Ovaskainen, 2002; Franken and Hik, 2004). For example, bigger trees in Amazonian forest fragments did go extinct only after two decades after fragmentation (Laurance et al., 2000). The length of the delay period can vary among species due to differences in life history traits. For example, short-lived plants might go extinct quickly after a landscape change compared to long-lived species which may persist (Morris et al., 2008). Therefore, recognition of the legacy of the historical land use plays an indispensable role in explaining the present-day vegetation patterns in fragmented landscapes (Lindborg and Eriksson, 2004; Ewers et al., 2013).

Coffee (*Coffea arabica* L.) is a major crop in SW Ethiopia. It is a native species in the understory of forests (Teketay, 1999), but is also actively managed in many different parts of the landscapes (Hundera et al., 2013). The most common traditional coffee cultivation system in Ethiopia is semi-forest coffee (SFC) characterized by an active management of coffee, but still under a more or less natural canopy of original forest trees (Senbeta and Denich, 2006; Aerts et al., 2011). It is not only the naturally occurring plants that are nurtured, but often farmers also practice enrichment planting with wild coffee seedlings or cultivars. SFC system is similar to the rustic coffee system in Latin America, where however the coffee shrubs grown under the original forest trees is not a native species (Hernandez-Martinez et al., 2009). SFC cultivation is affecting the biodiversity in Ethiopia in different ways. It hosts native woody plant biodiversity (Tadesse et al., 2014) and has contributed to an overall reduction of tree cover but also deforestation rates at coffee growing altitudes by buffering the conversion of larger forest remnants (Hylander et al., 2013). In addition, SFC patches have been found to support high bird species diversity (Buechley et al., 2015). On the other hand, SFC management includes the slashing of the undergrowth herbs and the removal of shrubs and emergent trees with the aim to increase coffee productivity (Senbeta and Denich, 2006; Schmitt et al., 2009). Coffee management often also includes the thinning of the upper canopies to allow more light to penetrate down to the coffee (Gole, 2003; Labouisse et al., 2008) and certain shade trees are favored over others (Hundera et al., 2013). In some landscapes with SFC management one can find numerous small SFC patches embedded in a matrix of agricultural fields. Such patches might have a legacy as forest fragments after agricultural expansion, but over the last 40 years some of the patches have actually increased in area as coffee has been planted at the edges of the patches (Hylander et al., 2013; Ango et al., 2014).

The study aims at understanding the variation in species richness of woody plants in SFC patches in a mosaic landscape in SW Ethiopia. For this purpose we investigated 40 SFC patches surrounded by an open agricultural landscape, of which half of them have increased and the rest have decreased in area over the last 25 years. We studied small patches that in general have a rather homogenous management (pers. observation) due to only one or in a few cases a few owners. We explored how historical, spatial and management factors influenced species richness and density. Specifically we hypothesized that: 1. seedling densities would decrease with increasing levels of disturbance due to slashing; 2. coffee cover would negatively influence density and species richness of similar sized plants due to the management for avoiding competition; 3. Focal sites surrounded by high cover of SFC-areas would be more easily colonized than more isolated areas; and 4. the historical patch area would better explain the present species richness than current patch area for trees with large diameter, due to the inherent time lag between a tree seedling and a big tree. An improved understanding of the processes generating the species richness patterns of SFC patches would not only increase our general understanding on how species richness is governed in fragmented human dominated landscapes, but also guide conservationists since SFC patches probably house the last forest associated biodiversity in some regions (Tadesse et al., 2014).

2. Methods

2.1. Study area

The study was carried out around the town of Agaro in southwest Ethiopia, Oromia National Regional State, Gomma district located at 7°48′-7°53′N and 36°33′-36°36′E (Fig. 1). The area is characterized by a rolling topography and is dissected by many streams. The district is a variegated landscape of annual crop fields and semi-forest coffee patches. The closest