Both forest fragmentation and coffee cultivation negatively affect epiphytic orchid diversity in Ethiopian moist evergreen Afromontane forests

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ABSTRACT

The moist evergreen Afromontane forest of SW Ethiopia has become extremely fragmented and most of the remnants are intensively managed for cultivation of coffee (*Coffea arabica*), with considerable impacts on forest structure, biodiversity and ecosystem functioning. We assessed the effect of coffee forest management and forest fragmentation on epiphytic orchid diversity. We selected large and small intensively managed forest sites and compared their epiphytic orchid diversity with the diversity of natural unfragmented forest. We surveyed 339 canopy trees using rope climbing techniques. Orchid richness decreased and community composition changed, from the natural unfragmented forest, over the large managed forest fragments to the small managed forest fragments. This indicates that both forest management and fragmentation contribute to the loss of epiphytic orchids. Both the removal of large canopy trees typical for coffee management, and the occurrence of edge effects accompanying forest fragmentation are likely responsible for species loss and community composition changes. Even though some endangered orchid species persist even in the smallest managed fragments, large forest fragments are better options for the conservation of epiphytic orchids than small forests. Our results ultimately show that even though shade coffee cultivation is considered as a close-to-nature practice and is promoted as biodiversity conservation friendly, it cannot compete with the epiphytic orchid conservation benefit generated by large unmanaged moist evergreen Afromontane forests.

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1. Introduction

Tropical forest landscapes have been subject to dramatic changes in terms of habitat loss and fragmentation (Foley et al., 2005; Lambin et al., 2003; Laurance, 2007), and a considerable part of the remaining forests has been converted into tree plantations or is strongly managed and disturbed (Dirzo and Raven, 2003; Gibson et al., 2011). Forest fragmentation poses a threat to plant populations, and ultimately to plant species richness, through the occurrence of genetic erosion, resulting from inbreeding, genetic drift and reduced gene flow within small and isolated populations (Honnay and Jacquemyn, 2007; Young et al., 1996). Furthermore, forest fragmentation may negatively affect pollinator abundance

and diversity, as fragments can become too small to sustain pollinator communities, or too isolated to attract a large diversity of pollinators. This may jeopardize pollination efficiency and plant reproductive success, and therefore, ultimately also reduce plant species richness (Aguilar et al., 2006; Tscharntke and Brandl, 2004).

Next to changes in their size and spatial configuration, also the habitat quality of many tropical forests has become affected. First, a relative increase in edge habitat, typical of small and irregularly shaped fragments, has altered the microclimate in large parts, or even in the whole forest fragment (Gehlhausen et al., 2000; Pinto et al., 2010; Ramos and Santos, 2006). Second, many tropical forests have become strongly affected by human disturbance and forest management, especially in more densely populated areas (e.g., Aerts et al., 2011). Wood extraction through removal of canopy trees is very common and may have important consequences for the forest microclimate and for pollinator abundance and behavior, possibly affecting plant reproduction and species diversity (Benítez-Malvido and Martínez-Ramos, 2003; Eckert et al., 2010; Padmawathe et al., 2004).

Orchid epiphytes are important elements of tropical forest biodiversity (Haro-Carrión et al., 2009; Hietz, 2005) and can be

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expected to be very susceptible to the consequences of both forest fragmentation and forest disturbance for three reasons. First, epiphytic orchids are canopy dwelling organisms, often characteristic of large trees which are preferentially harvested during exploitation (Köster et al., 2009; Murren, 2002; Sodhi et al., 2008); second, these species typically depend on the specific forest micro-climate, characterized by high air humidity, low radiation and buffered temperature extremes (Larrea and Werner, 2010; Werner et al., 2005); third, they often rely on rather specialized pollinators that may be absent in highly managed or small and isolated forest fragments (Hietz, 1998; Murren, 2002). For these reasons, vascular epiphytes have been proposed as reliable indicators of overall forest ecosystem health and forest quality (Hietz, 1998; Nadkarni and Solano, 2002).

So far, the loss of epiphytic orchids has mainly been documented from disturbed and fragmented South and Central American forests (Haro-Carrión et al., 2009; Hietz, 2005; Köster et al., 2009; Moorhead et al., 2010), whereas data from tropical Africa are very limited (but see Hylander and Nemomissa, 2008). This highlights the need for more research in Africa, which sustains the second largest contiguous tropical forest in the world (Gibson et al., 2011). Additionally, the set-up of most studies does not allow disentangling the effects of forest fragmentation vs. forest management, as the smallest forest fragments are usually the most intensively managed (but see Köster et al., 2009). Here, we focus on the epiphytic orchid diversity of the remaining Ethiopian moist evergreen Afromontane forests. Most of these forests have become extremely fragmented through conversion of large forested areas into other land uses (Reusing, 2000). Furthermore, many of the remaining forests, where coffee (*Coffea arabica*) occurs as a natural understorey shrub, are intensively managed for coffee cultivation (Aerts et al., 2011; Schmitt et al., 2009).

The coffee cultivation intensity typically ranges from almost no interventions in the so-called forest coffee system (FC), to semi-forest coffee (SFC) systems where the canopy layer is manipulated, shrubs are removed and the herbaceous understorey is cleared to reduce interspecific competition, and to increase coffee yield quality and quantity (Aerts et al., 2011; Labouisse et al., 2008). The SFC sites are generally dominated by early-successional species such as *Croton macrostachys*, *Millettia ferruginea* and *Albizia gummifera* while in the FC systems, the prevalent species are Afromontane rainforest late-successional species such as *Prunus africana*, *Syzygium guineense* and *Olea welwitschii* (Gole et al., 2008; Hundera et al., 2012) (Fig. D1). The SFC system in Ethiopia is somewhat similar to the rustic coffee system in Latin America where coffee shrubs were introduced under the original forest trees (Hernández-Martínez et al., 2009), though in Ethiopia coffee shrubs are naturally occurring in the understory and coffee populations are genetically more diverse (Aerts et al., 2012). As management in SFC forests mainly happens through removal of large canopy trees, it can be expected to be associated with the direct removal of suitable habitat for epiphytes, but also with changes in microclimate, because gaps in the canopy lead to rising air temperature, decreasing air humidity and increasing through-fall of rainwater (Acebey et al., 2003; Dietz et al., 2006).

The overall objective of this study was to assess the relative effects of coffee forest management vs. forest fragmentation on the species diversity and community composition of epiphytic orchids in Ethiopian moist evergreen montane forests. Therefore, we selected study sites that are intensively managed for coffee cultivation (SFC system) from both large forest remnants and from small forest remnants, and we compared their epiphytic orchid diversity with the diversity of natural, unmanaged continuous forests (FC system). Insights in the relative effects of forest fragmentation vs. forest management on epiphytic orchids may contribute to a more effective conservation strategy of this important species group, and because of the indicator function of epiphytic orchids, it can provide important information with respect to general ecosystem health of Ethiopian moist evergreen Afromontane forests.

2. Materials and methods

2.1. Description of the study area

The study was performed in the Manna and Gera districts of the Jimma region in southwestern Ethiopia (Fig. 1). We selected 21 forest fragments that were strongly managed for coffee cultivation (SFC) from the Manna district. Six of these forests were large (5 fragments in the range of 14–24 ha; one fragment, Fetche, ~100 ha) (Large Managed Forest, LMF), and 15 were small (0.5–9 ha) (Small Managed Forest, SMF). In the SMF, 88 canopy trees were sampled for epiphytic orchids, while in the LMF 112 canopy trees were sampled. As a reference, 139 trees were surveyed in the continuous and undisturbed natural forest (>100,000 ha) of the Gera area (Large Natural Forest, LNF). To cover spatial variation in a similar way as in the fragmented forests, five forest blocks of ca. 5 ha were randomly established, at least 200 m from the forest edge, and the sampled trees were randomly selected from each block. The overall number of trees that were sampled across the three forest types totaled 339.

2.2. Field survey

Only large canopy trees standing well apart and separated from each other by at least 25 m were selected (Gradstein et al., 2003). These trees were expected to be richest in epiphyte species due to their large and highly diversified crowns, and because they have been longest available for colonization and establishment by epiphytes (Krömer and Gradstein, 2003). Double-rope climbing techniques (Fig. D2) and binoculars were used to survey the trees completely for the presence or absence of epiphytic orchid species. As an abundance measure of each species on each tree, we counted individual plants. Orchid species nomenclature and data on rarity and conservation status within Ethiopia were obtained from Demissew et al. (2004). Voucher specimens were collected in a digital herbarium (Appendix E). For each tree sampled, also the tree species, tree diameter at breast height (DBH (m)), tree height (m), and elevation (m a.s.l.) were recorded. Elevation was assumed to provide a good proxy for differences in local climatic conditions (mainly precipitation) between sampling points. To get a complete picture of the species richness, a plot of 10 m × 10 m around each sampled tree was also surveyed for additional epiphytic orchid species that may be confined to the lower forest stratum (Gradstein et al., 2003). Because no orchid species could be found that were occurring in the plot and not in the central tree, all the reported analyses and results apply to the surveyed canopy trees.

2.3. Data analysis

For all trees, orchid species richness (S) and true diversity (the exponent of Shannon's diversity index or Hill's $N1 = e^{H'}$) (Hill, 1973; Jost, 2006) were calculated. Species turnover or beta diversity (β) was calculated for each forest type separately (LMF, SMF and LNF), as the total species richness divided by the average richness per tree (λ/α). We used EstimateS 8.2 (Colwell, 2009) (randomization without replacement, 500 runs) to perform sample based rarefaction (Mao Tau species accumulation curves) and to calculate incidendence-based estimations of species richness for each forest type (Chao2 and a first order Jackknife richness estimator). Non-metric multi-dimensional scaling (NMS) on the orchid abundance data was performed to quantify the orchid community