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Research paper

Trees in a human-modified tropical landscape: Species and trait composition and potential ecosystem services

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HIGHLIGHTS

- Several tree traits are non-random distributed in the human-dominated landscape.
- Exotic fruit trees were more abundant on croplands.
- Three functional traits were associated with exotic species.
- Indigenous trees species were abundant on wooded sites and homesteads.
- No functional traits were exclusively associated with indigenous species.

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ABSTRACT

Worldwide, large areas of the tropics are transformed into simplified ecosystems characterised by altered tree species composition and diversity. Human activities in these landscapes have a strong effect on the land cover and exert a selective force on tree species and functional traits, hereby potentially shaping the distribution of ecosystem services in the landscape. The aim of this study was to asses how the land use determines tree species assemblages, their associated traits and potential ecosystem services, which was studied for 589 systematically sampled locations in the Afromontane highlands of Taita Hills (SE Kenya). Several tree traits were non-random distributed in the human-dominated landscape. For instance, on croplands (70% of the sampled locations) belonged 66.5% of the observed species to the exotic tree species group. This group was characterised by significantly larger seeds and fruits, corresponding with the abundance of many fruit trees. Also three functional traits (i.e. economic function, nitrogen fixation and agroforestry potential) were clearly associated with this group. The cloud forest tree species group and small-leaved indigenous group were significantly more present on woodes sites and homesteads (~42%). However, no functional traits were unique for both indigenous groups, implying that farmers may exchange them by exotics, which could be catalysed by the loss of local knowledge about indigenous tree resources and benefits. Other indigenous species, including endemic or late-successional species were rare or absent in the matrix and their conservation can only be guaranteed by protecting the remaining indigenous forest fragments.

1. Introduction

The human population growth causes a rising demand for resources, including food, fibber and fuel, which induces conversion of indigenous forests to agricultural fields, exotic tree plantations and settlements (Carreño-Rocabado et al., 2012; Ellis, Antill, & Kreft, 2012; Hilderbrand, Watts, & Randle, 2005; Norris

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et al., 2010; Pellikka et al., 2013). Research in deforested landscapes has so far mainly focused on the indigenous forest relicts. This has contributed to the perception of a segregated landscape with two apparently independent and conflicting entities, namely the forest relicts as biodiversity refuges and the irrelevant matrix (Carreño-Rocabado et al., 2012; Perfecto & Vandermeer, 2008). However, there is growing consensus that these landscapes do not consist of independent entities, but have ecologically interacting components (Burel et al., 2013; Mendenhall, Karp, Meyer, Hadly, & Daily, 2014). For instance, trees in the matrix may function as stepping stones or dispersal foci for many forest plants, as seeds accumulate under their canopies after visitation by forest frugivores (Herrera & Garcia, 2010). This implies that the future of tropical forest biodiversity not only depends on an effective management of the indigenous forest relicts, but of the complete landscape (DeClerck et al., 2010; Gardner et al., 2009; Perfecto & Vandermeer, 2008).

Remnant trees, i.e. isolated scattered trees persisting in a matrix originally occupied by forest, as well as isolated planted trees are common features in many human-modified forest landscapes worldwide (Herrera & Garcia, 2009; Manning, Fischer, & Lindenmayer, 2006). Their occurrence is strongly influenced by human interventions in the landscape (Metzger, 2000). First, direct interventions favour useful (e.g. nutritious, medicinal or ornamental) tree species in homegardens, agricultural fields or managed forests to provide goods and services (Burkhard, Kroll, Nedkov, & Muller, 2012; DeClerck et al., 2010). Second, non-forested areas have largely lost the shaded and tempered forest microclimate, are inaccessible to species of low dispersal capacity and have high levels of seed predation and seedling herbivory, which may catalyse extinction of indigenous species and invasion of exotic species (DeClerck et al., 2010; Metzger, 2000). Especially shade-tolerant species and species with zoochorous and barochorous seed dispersal appear to be more strongly influenced by habitat modifications. Species composition changes may result in a reduction or loss of ecosystem services such as carbon storage and sequestration, although it is recognised that converted land can also provide substantial ecosystem services (Barrett, Valentim, & Turner, 2013; Douglas et al., 2013). For instance, leguminous trees in farmland may provide valuable ecosystem services such as nitrogen fixation and fuelwood production, which can enhance agricultural productivity and income. Therefore, a better understanding of the benefits of remnant or scattered trees is essential for developing effective management options, particularly within tropical regions with intense land use pressure.

Here, the results of a landscape, tree species and trait composition study from the Taita Hills in south-east Kenya are presented. This study comprised agricultural fields, exotic tree plantations, urban settlements, rocky areas and indigenous Afromontane cloud forest relicts. The objectives of the study were to asses whether differences in landscape configuration (e.g. land cover composition and distance to indigenous forest or town) in a deforested and human-modified landscape are reflected in tree species and trait occurrence and their potential ecosystem services. It was hypothesised that: (1) there is a non-random distribution of tree traits in the landscape; (2) the density of trees with multiple provisioning services (i.e. food, fodder, firewood) is higher in the neighbourhood of areas with higher human activity; (3) exotic tree species provide different services than indigenous tree species and these traits are more economically valorised.

2. Materials and methods

2.1. Study area

The Taita Hills Afromontane cloud forests (south-east Kenya – 3°20′S, 38°15′E –Fig. 1a) form the northernmost component of the Eastern Arc Mountains, which are known as a biodiversity hotspot (Burgess et al., 2007). The forests are home to many endemic and endangered forest dependent species (e.g. *Dorstenia christenhuszii*, *Coffea fadenii*) (Chase, Thijs, Kamau, & Fay, 2013; Thijs et al., 2014a). Archaeological research revealed that the clearance of these forests started about 2300 BC, with a deforestation peak during the last 200 years due to a rapid population growth (Hildebrandt, 1877; Pellikka, Lotjonen, Sijander, & Lens, 2009; Schmidt, 1989). Currently, only 440 ha of indigenous forest persists in 12 forest relicts, of which 9 are smaller than 10 ha (Aerts et al., 2011; Beentje & Ddiang'ui, 1988; Pellikka et al., 2009). The agricultural activities in the area are characterised by small-scale subsistence farming (e.g. maize, banana, beans, cassava; farm size: 0.16–4 ha) and supplementary irrigation practice is common because rainfall is too erratic to ensure stable production. A study area of 19 km^2 was defined in the centre of Taita Hills (Fig. 1b), because it is crucial to increase landscape connectivity and it is therefore recognised as a target area for rehabilitation (Adriaensen, Githiru, Matthysen, & Lens, 2006). This study provides pertinent information and data to other projects whose main outcome would be a model on forest connectivity of the Taita Hills (Aben et al., 2012; Githiru, Lens, Adriaensen, Mwang'ombe, & Matthysen, 2011; Lens, Van Dongen, Norris, Githiru, & Matthysen, 2002).

2.2. Land cover composition

Within the study area, 589 sample points were systematically sampled along 25 east-west oriented transect lines. The distance between transect lines and between individual sample points was 200 and 150 m, respectively. At each location, the elevation was determined with a GPS (Garmin GPSmap 60CSx) at the plot centre. Subsequently, the land cover composition was determined in a circular plot (sample point as centre, radius 50 m) using the Land Cover Classification System (LCCS) of the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) (Di Gregorio, 2005). Spatial variables were calculated in as the horizontal distance from the plot centre to the edge of the nearest element of indigenous forest, road, house and town (i.e. cluster of houses with one or more shops, often at the intersection of roads). Spatial data analysis was performed in ArcGIS 9.2 (ESRI, Redlands, CA).

2.3. Tree species composition

At each sample point, an inventory of the mature trees (woody individual ≥5 m) was performed by plotless (i.e. distance-based) sampling, because the density of trees in the matrix was too low for convenient quadrat sampling. Therefore, the Byth robust *T*-square density estimator (Fig. 2) was used: $D_{TSB} = 1/\left(2 \cdot \sqrt{2} \cdot x_1 \cdot x_2\right)$, where D_{TSB} is the tree density (stems per ha), x_1 the distance (m) from the sample point (SP) to the closest (CI) tree and x_2 the distance (m) from the CI to its nearest neighbour tree (NN), occurring in the half-plane at the far side of the line through the CI that is perpendicular to the line from the SP to the CI (Engeman, Sugihara, Pank, & Dusenberry, 1994). Every specimen was identified according to the nomenclature of the Flora of Tropical East Africa; the diameter at breast height (DBH) and tree height were measured for each individual.

2.4. Tree species traits

Trait data was collected for each recorded species, based on published floras and databases, herbarium records (East African Herbarium, Kenya) and field observations (Appendices A and B). We focused on five groups of traits (Table 1): (i) Biogeographical traits comprise the species natural distribution (Dorrough &