Journal of Arid Environments 114 (2015) 14–21

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Intense use of woody plants in a semiarid environment of Northern Ethiopia: Effects on species composition, richness and diversity

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ARTICLE INFO

Article history:
Received 24 February 2014
Received in revised form
3 October 2014
Accepted 2 November 2014
Available online

Keywords:
Beta diversity
Disturbance
Invasive species
Open-access forest
Restoration

ABSTRACT

Human influences affect plant species diversity and composition in many tropical forest ecosystems. We assess the effects of human use of woody plants on plant species composition and diversity in an intensively used open-access forest in Northern Ethiopia, and compare these community attributes with those of relatively intact forest patches. In each of 90 20 × 20 m plots in the open-access forest, we counted the number of woody plant species in different growth stages, and compared with those of 48 same-sized plots in nearby intact forest patches. Forest utilisation resulted in major shifts in dominance, with the dominant species in relatively intact forests being absent in open-access forest, whereas those species dominant in the open-access forest were absent from intact forests. Open-access forest had a lower total number of species, individuals and beta diversity than relatively intact forests. Intensive forest utilization has resulted in the dominance of disturbance-tolerant native and invasive species. *Opuntia ficus-indica*, regarded as a problem weed in Ethiopia, was abundant in the open-access forest. Dominance of a few species in the open-access forest could cause local and landscape-scale species loss. Relatively intact forest patches are therefore important for biodiversity conservation and ecological restoration in northern Ethiopia.

1. Introduction

Forest ecosystems have been frequently altered through logging (Haugo et al., 2010; Lemenih and Bongers, 2011) and land use change (Tsegaye et al., 2010), affecting plant species composition and diversity (Burrascano et al., 2008). Directly or indirectly, human livelihoods depend on forests and forest products and harvesting of plants for domestic and commercial uses, such as energy supply and construction materials, are common in human-dominated forest ecosystems. Wood is the main energy source in developing nations, and worldwide fuelwood extraction exceeds the combined extractions for other purposes such as food, medicine and other products (FAO, 2006a). Along with the increase in human population density, there is growing demand for forest products such as fuelwood (Arnold et al., 2006; Ramos et al., 2008). This high demand increases the number of harvested plant species, which in turn can modify species composition and diversity (Bengtsson et al., 2000). Achieving sustainable use of forest products, where the annual rates of extraction do not exceed the annual increments, is particularly challenging where poverty prevails (Anthon et al., 2008).

Harvesting forest products for commercial purposes commonly targets large individuals. Selective removal of mature trees affects forest structure and seed availability, and results in changes to the plant community by influencing plant species regeneration and succession (Burrascano et al., 2008). Harvesting also creates forest gaps (Brokaw and Busing, 2000). Given that species respond differently to light, soil moisture, and nutrient availability in such gaps, these can potentially further alter species composition. In less disturbed mature natural forest, the abundance of old trees, dead wood and coarser woody debris is higher than in a disturbed early-successional forest ecosystems, creating additional microhabitats for plant seedlings and other organisms (Kuuluvainen and Laiho, 2004). Classical succession theory (Mueller-Dombois and Ellenberg, 1974) predicts that in a less disturbed forest ecosystem with a dense canopy cover, shade-tolerant species will be favoured, whereas light-demanding species are unlikely to survive. In contrast, the gap dynamic theory (Brokaw and Busing, 2000; Yamamoto, 2000) predicts that, in frequently disturbed forests, shade-tolerant species decrease when forest cover becomes more

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http://dx.doi.org/10.1016/j.jaridenv.2014.11.001
0140-1963/

patchy. In relatively dry areas, forest gaps are less important because individual shrubs or trees can conserve soil moisture and act as nurse plants for seedlings (Aerts et al., 2006, 2007).

Plant species have different functional attributes in ecosystems (Walker et al., 1999; Walker and Langridge, 2002). Some species, such as cultural keystone species (Garibaldi and Turner, 2004), are extensively used by people and often become much less abundant (Kituyi et al., 2001). If intensively extracted species regulate fundamental ecosystem processes (i.e. foundation species: Ellison et al., 2005) and determine conditions for other species, a reduction in their density can affect plant species composition, diversity, and ecosystem stability. Several studies have also shown that less abundant species can confer resilience to a disturbed ecosystem by replacing declining major, but functionally similar, species (e.g. Walker et al., 1999).

In Ethiopia, anthropogenic disturbance is one of the main factors affecting plant community composition and diversity in forest ecosystems, particularly in forests close to human settlements and urban areas (Bhattacharya and Abdul Salam, 2002; Pote et al., 2006). In open-access forest, anthropogenic disturbances can change species composition and diversity substantially, potentially altering ecosystem function and resilience. Moreover, biophysical characteristics of the environment are also important component that affects species composition and diversity (Zhang and Dong, 2010). Although important, anthropogenic disturbance variables are often difficult to quantify and therefore have to be assessed with proxies. Relevant proxies for the utilisation of forest in developing countries used in this study are presence of animal dung, presence of dead plants, distance to nearest village, number of harvested branches, canopy cover, total number of stumps and presence of exotic plant species. Effects of utilization are likely to vary with environmental conditions like altitude, slope, landscape position and soil type. Thus, it is important to control for such factors when studying the impact of intense forest utilization. The main focus of this paper is to assess how forest utilisation affects the relative abundance, species richness and diversity of tree species in intensively used forests in Tigray, Ethiopia. Specifically, we ask: 1) how does tree species composition in different life stages (seedlings, saplings and adults) and harvested trees (stumps) associate with human disturbance? We predicted that intensively used species, particularly the adults, would be strongly associated with anthropogenic variables and that utilised forest would be characterised by early successional species. 2) How does human disturbance- and environmental variables and forest utilization impact the relative abundance of tree species, species richness, evenness, and alpha (within a plot), beta (species turnover within a forest utilisation type), and gamma (total number of species within a forest type) diversity? We predicted that highly utilised species would decrease in abundance and that selective harvesting of trees would decrease evenness, richness as well as diversity measures.

2. Materials and methods

2.1. Study area

This study was carried out in Derge'ajen, Enderta district in the south-eastern, Tigray Ethiopia, which is situated in 12°15′ − 14°50′ latitude and 36°27′ − 39°59′ longitude. The study area is located along the Rift Valley escarpment between the Dessea and Hugumburda natural forests reserves, a topographically heterogeneous area with high plant and animal diversity, although overgrazing and deforestation are causing major environmental changes. Soils of the area are mainly shallow and infertile. The dominant soil types, based on FAO guidelines for soil description and classification (FAO, 2006b), are leptosols, cambisols and regosols. Cultivated and grazing land together cover a large portion of the total land cover; the natural regional vegetation cover is sparse with only small fragmented forest patches, mostly located around churches, natural reserve forests, and restored exclosures. The main energy sources in Ethiopia are woody biomass, dried animal dung and crop residues. Of the total national energy consumption, 97% is from biomass of which 78% is woody biomass (WBISPP, 2004). In Tigray, rural households collect fuelwood close to their settlements and sell it in the nearest urban market to generate income. The study area is one of the main sources of firewood supply to the region capital, Mekelle, and Quha, a smaller town located ca. 7 km southwest of Mekelle.

2.2. Data sampling and statistical analysis

Ten transects, 200 m apart, were located along the landscape in an open-access forest in Derge'ajen, Enderta, Tigray. Along each transect we located nine 20 × 20 m plots at 200 m intervals, giving 90 plots in total in the 3.6 km^2 open-access forest. The locations of some of the plots were slightly adjusted if they were originally located in open grazing and cultivated land. The plots were situated between 2215 and 2581 m.a.s.l. We recorded all live and dead woody plants in each plot, and measured diameter at breast height (DBH), height and crown diameter of each dead and live tree. The number and diameter of harvested branches and stumps were also recorded. Canopy cover was determined from two perpendicular diagonal crown diameters. Based on DBH and plant height, the plants were classified into the following growth stages: adults (height > 1.3 m and DBH ≥ 5 cm); saplings (height > 0.5 m and DBH < 5 cm); and seedlings (height ≤ 0.5 m) (Berhane et al., 2013). Landscape position (summit, back slope or foot slope), slope and major soil types were described and the presence of animal dung and exotic plant species were recorded in each plot. Elevation was measured using Global Positioning System (GPS) and slope was measured using a clinometer. The distance from each plot to the nearest village centre was determined using UTM coordinates.

For comparison, we obtained similar data from 48 plots within 16 church forest patches (3 plots in each forest patch, all of the same size as those plots in the open-access forest). The forest patches are located around the Ethiopian Orthodox churches that has been protected for centuries due to religious beliefs that cutting of trees is offencive (Wassie and Teketay, 2006; Berhane et al., 2013). These forest patches are remnants of the previous vegetation in the study area. Although they are generally intact there are variable degrees of protection in that some are fenced and some are not (Berhane et al., 2013). These forests are therefore well-suited for comparing woody plant species abundances and dominance with those in the open-access forest. The church forests occurred at the same altitudinal range as the 90 plots in the open-access forest, and were located 23.5 ± 12 km (mean ± SD) km from those plots.

We recorded the total number of individuals of each species, and the associated species richness, in different growth stages. Relative abundance was calculated from the number of individuals of a species proportional to the total number of individuals of all species. Dominance of species was evaluated based on the relative abundance of specific species. Relative frequency of each species was the proportion of plots in which that species was recorded. Plant species attributes, such as tolerance to disturbance, successional position (early vs late), ability to fix nitrogen, species origin and invasiveness, were determined from the databases of World Agroforestry centre (www.worldagroforestry.org).

Multivariate statistical analysis was used to describe the variation in species composition of stumps, adults, saplings and seedlings in the open-access forest in relation to possible explanatory variables among the abiotic environmental conditions and human