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Locally endangered tree species in a dry montane forest are enhanced by high woody species richness but affected by human disturbance

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ABSTRACT

Understanding the relationship between biotic, abiotic and disturbance factors in dry degraded forests is crucial for effective conservation of endangered plant species. We studied the relationship between two locally endangered tree species, *Olea europaea* subsp. *cuspidata* and *Juniperus procera*, and environmental conditions in the Hugumburda dry Afromontane forest in Northern Ethiopia. We surveyed species richness of woody plants, herbaceous plant cover, soil and human disturbance factors from 70 plots (20 m × 20 m). The abundance of both species was positively correlated with each other, and with woody species richness and elevation. Moreover, the biomass of both species correlated positively with total tree biomass and number of *O. europaea* cut stumps. The positive relationship between *O. europaea* trees and cut stumps suggests that illegal selective logging is taking place in *O. europaea*-dominated areas. Based on the observed relationships we predict that conserving woody species may result in an increase in the abundance of both *O. europaea* and *J. procera* in the forest.

1. Introduction

In the tropics, human-induced natural forest degradation has become a serious problem (Lamb et al., 2005; Parrotta et al., 1997; Watson et al., 2014), and threatens the abundance of multi-purpose plant species. The cover of the world's natural forests is decreasing annually by 0.5% (Brockerhoff et al., 2013), which is reducing the benefits received from these areas by way of ecological services (Isbell et al., 2017; Teketay, 2001). To protect degraded forest with the aims of conserving endangered plant species in situ and maintaining ecological services, a program of establishing National Forest Priority Areas has been launched in different biodiversity hot-spots, including natural forest (M. Bekele and Berhanu, 2001; Margules et al., 2002; Veríssimo et al., 2002; Watson et al., 2014). But simply establishing protected areas may not be sufficient to conserve endangered plant species (Schemske et al., 1994). Therefore, studying the relationship between biotic and abiotic factors in protected areas may contribute positively to the goal of restoring degraded areas (Callaway and Walker, 1997; Holl et al., 2000; Michalet et al., 2006).

One of the determinants of plant species coexistence, and a key factor controlling plant species composition and distribution, is the relationship between biotic factors, such as richness and abundance of plant species, and the abiotic components of an ecosystem (Kimmins, 2009; Maestre et al., 2010; Shirima et al., 2015). For biotic factors, plant-plant interactions can involve either facilitation or competition (Leigh, 1999; Maestre et al., 2005). Facilitation, in which the presence of one species positively influences the abundance of another, is common in arid environments. It is relevant when conserving endangered tree species because such species may depend on interactions with others for their persistence. For instance, pioneer plants may facilitate the growth and abundance of the later plant species by ameliorating site conditions (Duncan and Chapman, 2003; Gómez-aparicio et al., 2004). In addition to biotic factors, abiotic factors such as elevation (used as a proxy for temperature), slope and soil parameters, together with natural and human-induced disturbances, also determine the plant-species composition and diversity in a forest (Williams-Linera and Lorea, 2009). For instance, in dry Afromontane forests, late successional plants are more abundant at higher elevation than low elevations (Aerts et al., 2011).

The Hugumburda forest is one of the 58 National Forest Priority Areas in Ethiopia, established to conserve biodiversity in the face of severe forest degradation in recent decades (Woldemichael et al.,

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2010). Dry montane forests have relatively low woody species richness, and this particular forest area is dominated by the late successional plant species, *Olea europaea* subsp. *cuspidata* (here after *O. europaea*) and *Juniperus procera* (hereafter *J. procera*) (Betemariam, 2011). The local communities use both *O. europaea* and *J. procera* in several ways, such as for farm implements, fuelwood, construction material, and medicine. In this study, we focus on these two species because they are threatened by over-exploitation and are considered locally endangered (Berhe and Negash, 1998; CBD, 2009; Negash, 2003; Viswanathan, 1986). Woldemichael et al. (2010) and Betemariam (2011) have previously studied vegetation structure in the study area, but we still lack information on how these two species relate ecologically to each other and to various biotic, abiotic and disturbance factors in the forest. Such knowledge is urgently needed for developing effective conservation measures.

This study examines how biotic, abiotic and disturbance factors influence the abundance and biomass of these two key dry Afromontane forest species. We pose three questions: (1) Is there a relationship between the abundance of *O. europaea* and *J. procera*? (2) How do abundance and biomass of these species correlate with biotic and abiotic variables? (3) Are the abundances of the two species affected by human disturbance?

2. Methods and materials

2.1. Study area

Hugumburda national forest priority area (12° 36′N, 39° 31′ E) is situated in southern Tigray, Ethiopia. Elevation ranges from 1860-2700 m above sea level. Average annual rainfall ranges from 800-1000 mm. Mean daily temperature is 14–22.4 °C, with a minimum of 8.8–10.7 °C in October and a maximum of 34.3 °C in June (Worku, 1998). The topography of the study area is mainly undulating to sharp terrain. Soils are shallow, with leptosols and regosols as the dominant soil types.

The total study area is ca. 8103 ha, and includes plantation forest, disturbed natural forest and some settlements and agricultural fields on the fringes of the forest. The area was previously densely forested with substantial numbers of the dominant indigenous plant species such as *Juniperus procera, Olea europaea* subsp.*cuspidata, Nuxia congesta, Cassipourea mallosana* and *Olinia rochetiana* (Betemariam, 2011; Sileshi and Abraha, 2014; Woldemichael et al., 2010). Although the forest is protected, making it illegal to cut trees, and is guarded by ca. 50 forest rangers, illegal logging still occurs.

2.2. Study species

Olea europaea occurs primarily in arid areas between 1250 and 3100 m a.s.l. Adult trees are commonly 15 m high, but can reach 25 m (Friis, 1992). The species occurs in marshy areas, dry lands, stony places and on mountain sides, where it tolerates a wide range of environmental conditions, including frost and drought (Bekele-Tesemma and Tengnäs, 2007). The wood is commonly used for fencing, making farm implements and manufacturing home furniture. The unique fragrance of the smoke of burnt *O. europaea* wood flavors and enhances traditional drinks and repels insects. The species is a medicinal plant in southeastern Ethiopia.

Juniperus procera is one of the characteristic tree species of dry Afromontane forests of Ethiopia. It is evergreen and can be up to 45 m tall at an age of 150 years. It is most abundant in the transition zone between dry and semi-evergreen forest. It often occurs together with *O. europaea* and *Podocarpus falcatus* (Berhe and Negash, 1998; Pohjonen and Pukkala, 1992). Its economic importance is considerable, being a raw material for home furniture, poles, fences and in the manufacture of lead pencils. Although globally categorized as a Least concern species (IUCN, 2017), *J.procera* suffers from widespread logging and its population is declining in Ethiopia. Thus, it needs an in-situ strategy for conservation (Aynekulu et al., 2009; CBD, 2009; Negash, 2002; Viswanathan, 1986).

2.3. Field data collection

Seventy 20 × 20 m plots were positioned on forested slopes at elevations of 2233–2503 m a.s.l. The plots were distributed about 100 m apart along parallel transects placed perpendicular to three local terrain ridges, each transect running from the top to the bottom of the ridge. The distance between neighboring transects was ca. 150 m.

In each 20 × 20 m main plot, we identified, counted and recorded all adult trees and shrubs to species level. We measured stem diameter at breast height (DBH) of individual trees, basal diameter (BH) for each shrub, and the heights of both (West, 2009). The abundance and species identities of saplings were recorded in one 5 × 5 m sub-plot, placed in the center of each main plot. The number and identities of seedlings were recorded in five 1 × 1 m small plots, one placed in the center of each main plot and four at the corners of each 5 × 5 m sub-plot. We also visually determined the percent cover (to the nearest 1%) of herbaceous species within each 1 × 1 m small plot. For calculating species richness, we used plant height and diameter at breast height to classify each woody individual into adult, sapling or seedling: adults (DBH ≥ 2 cm), saplings (height ≤ 1.3 m and DBH ≤ 2 cm) and seedlings (height ≤ 0.3 m).

We sampled environmental conditions in the same plots as vegetation data. To quantify human disturbance, we used a tape measure to quantify the total length (m) of human footpaths in each main plot, using these tracks as one indicator of disturbance. We also counted the number of cut *O. europaea* stumps. Slope and elevation were measured in the center of each main plot with a clinometer and a handheld GPS respectively. For each of the 70 main plots, two separate soil samples were collected for soil moisture content (by soil core samplers) and chemical analysis. For soil chemical analysis we used a composite of five samples (top soil to 15 cm depth) collected at the center of each 1 × 1 m plot. The soil samples were sealed in a double plastic bag to preserve the soil moisture. All soil samples were transported to Mekelle Agricultural Research Center laboratory in Mekelle. Soil moisture was measured gravimetrically (Black et al., 1965). The composite soil samples were then air-dried at a room temperature and sieved through a 2-mm mesh. Soil pH (at 1:2.5 soil/H_2O), electrical conductivity and soil organic matter (Walkley-Black method) were measured using standard techniques (Nelson and Sommers, 1996). Soil depth was measured in the field by digging a pit at the center of the main plot down to bedrock.

2.4. Data analysis

2.4.1. Data preparation

To determine total woody species richness, we pooled all woody species (trees and shrubs) occurring in each main plot (adults), sub-plot (saplings) and small plots (seedlings). Woody species abundance was the number of adult individuals of each species counted in each main plot (expressed as a density, number per m^2). Herbaceous cover was estimated as percentage cover and converted to proportions before data analyses.

The Above-ground biomass (AGB) of adult trees was calculated using the allometric equation developed by Chave et al. (2014).

$$AGB = 0.0673 * (WD * DBH^2 * H) \exp 0.976 \quad (1)$$

Where WD = wood density (g/cm^3), DBH = diameter at breast height (cm) and H = height (m).

For all tree species, we used an average wood density value of 0.612g/cm^3 obtained from the global wood density database (Ministry Of Environment, 2016; Zanne et al., 2009).