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Woody species composition and structure of Kuandisha afromontane forest fragment in northwestern Ethiopia

Abiyot Berhanu[1] · Sebsebe Demissew[1] · Zerihun Woldu[1] · Motuma Didita[2]

Abstract To investigate the woody species composition, diversity and structure of Kuandisha Afromontane forest, vegetation and environmental data were collected from 53 plots of 10 m × 50 m for trees and shrubs and 265 subplots of 2 m × 4 m for seedlings were laid along eight transect lines. The local name, scientific name, abundance, DBH, height and percentage foliage cover of species were recorded. Environmental variables, namely altitude, latitude and longitude as well as disturbance levels were also recorded in each plot. Structure, basal area, importance value index (IVI) and species prioritization were analyzed using spreadsheet programs. Correlation coefficients, frequency, relative frequency, Shannon diversity index, Shannon evenness and vegetation classification were analyzed using an R package. Sixty-six species belonging to 40 families were recorded. Fabaceae was the most diverse family consisting of seven species, followed by Euphorbiaceae and Asteraceae. In terms of habit, 29 species were trees, 28 were shrubs, and 9 were lianas. The overall Shannon diversity index was 2.5. The frequency and relative frequency of woody species with DBH ≥2.5 cm ranged from 1.9 to 92.5 and 0.1 to 5, respectively. Seedling density varied among species ranging from five to 9938 individuals ha^{-1}. The total basal area of woody species having DBH ≥2.5 cm is 15.3 m^2 ha^{-1}. The IVI of species ranged from 0.13 for *Solanum giganteum* Jacq. to 28.4 for *Croton macrostachyus* Del. The woody vegetation was classified into five community types. Species richness, diversity and evenness of communities were strongly positively correlated. On the other hand, the correlation between disturbance and seedling density, and species richness was strongly negative. Thus, among the recorded woody species, a significant portion was either lacking regeneration or selectively removed for various purposes. The lack of seedlings of those species is mainly attributed to anthropogenic disturbances particularly free grazing. As a result, 14 tree, seven shrub and one liana species were prioritized for conservation and management interventions.

Keywords Basal area · Disturbance · Diversity · Importance value index · Kuandisha forest · Regeneration

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Corresponding editor: Zhu Hong

✉ Abiyot Berhanu
   abiyotmulu@gmail.com

[1] Department of Plant Biology and Biodiversity Management, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia

[2] Forest and Rangeland Plants Biodiversity Directorate, Ethiopian Biodiversity Institute, P.O. Box 30726, Addis Ababa, Ethiopia

Introduction

The vegetation of Ethiopia is extremely complex as a result of its great variations in altitude, moisture and temperature (Woldu 1999; Friis 2009; Friis et al. 2010). The Ethiopian highlands comprise more than 50 % of the land area with afromontane vegetation, with dry evergreen afromontane forests and grassland complex (DAF) forming the largest part (Yalden 1983; Bekele 1993; Teketay and Bekele 1995; Teketay 2005a). The DAF is found in much of the highlands in the northern, northwestern, central, southern,

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southeastern and southwestern parts of the country at altitudes between 1800 and 3000 m asl (Friis et al. 2010). According to Teketay (2005a), the dry afromontane forests are either *Juniperus–Podocarpus* forests or predominantly *Podocarpus* forests, both with broad-leaved species.

Characteristic canopy species of the DAF include *Juniperus procera* Hochst. ex Endl., *Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don) Cif, *Podocarpus falcatus* (Thunb.) R. B. ex Mirb., *Hagenia abyssinica* (Broce) I. F. Gmel., *Croton macrostachyus*, *Ficus* spp. and *Acacia abyssinica* Hochst ex Benth. (Demissew and Friis 2009; Friis et al. 2010). The subcanopy usually consisted of species such as *Allophylus abyssinicus* (Hochst.) Radlkofer, *Apodytes dimidiata* E. Mey. ex Am., *Bersama abyssinica* Fresen., *Cassipourea malosana* (Baker) Alston and *Celtis africana* Burm. f. Some of the shrub species and short stature trees included *Carissa spinarum* L., *Discopodium penninervium* Hochst., *Dombeya torrida* (J. F. Gmel.) P. Bamps, *Lobelia giberroa* Hemsl., *Myrsine africana* L., *Pittosporum viridiflorum* Sims and *Rhus natalensis* Krauss. The most dominant lianas are *Urera hypselodendron* (A. Rich.) Wedd., *Helinus mystacinus* (Ait.) E. Mey. ex Steud. and *Jasminum abyssinicum* Hochst. ex DC.

Nevertheless, the structure of forests with respect to DBH and height of trees is highly variable among various fragments of the DAF depending on the status of disturbance. In the undisturbed forests, the DBH of mature trees usually reaches up to 270 cm, while their height can reach up to 45 m (GTZ 2003; Yineger et al. 2008; Zegeye et al. 2011; Tadele et al. 2014). Species such as *Prunus africana* (Hook. f.) Kalkm, *Juniperus procera*, *Schefflera abyssinica* (Hochst ex A. Rich.) Harms, *Albizia schimperiana* Oliv., *Ekebergia capensis* Span., *Celtis africana* Burm. f., *Hagenia abyssinica*, *Croton macrostachyus* and *Cordia africana* Lam. have been reported to reach a DBH of between 80–270 cm and a height of 30–46 m in the DAF (Bekele 1993; GTZ 2003). In disturbed forests, the upper canopy species except few of them are usually removed for various purposes, and only short stature trees in the middle and lower canopy that have a DBH less than 50 cm and height less than 21 m remain in the forest (Bekele 1993; Friis et al. 2010).

On the other hand, the high forest cover of Ethiopia has been decreasing from time to time. About 35 % of the land area of Ethiopia was once covered with high forests before people settled in the highlands (Bekele et al. 1999). However, according to Bekele et al. (1999), the high forest cover was reduced to 16 % in the 1950s and to 3.6 % in the 1980s. Though the figures are inconsistent, it is now believed that about 3 % of the country is covered with high forests. The most important factors for the forest loss are anthropogenic, mainly for agricultural expansion and settlement. Large tract of forests is fragmented, and patches now exist in inaccessible, infertile and sacred areas. Fragmentation is a landscape-level process in which a specific habitat is progressively subdivided into smaller and more isolated forest patches (Laurance 2008). It involves changes in landscape composition, structure and functions across scales on a backdrop of a natural patch mosaic created by changing landforms and disturbances. Broad-scale destruction and fragmentation of native vegetation is a highly visible result of human land use. In its most extreme, fragmentation results in only small isolated remnants of the native original forest of varying size surrounded on all sides by other types of habitats such as agriculture, settlement and grazing land (Laurance et al. 1998, 2010; Laurance 2008).

A number of studies on Ethiopian afromontane forests have focused on species richness, diversity, population structure, forest gaps and their comparisons along environmental gradients (e.g., Bekele 1993; Teketay and Bekele 1995; Dalle and Fetene 2004; Alelign et al. 2007; Wassie et al. 2005, 2009; Zegeye et al. 2011). However, the northwestern parts of Ethiopia particularly forests in the Awi Zone have rarely been investigated (e.g., Tadele et al. 2014), and their status is not well known. The Kuandisha Forest is one such forest area for which the species composition, diversity and structure are unknown. The research objectives were to (1) document woody species composition and compare those species with characteristic species of similar vegetation types in Ethiopia; (2) assess species richness, diversity and structure of the forest; and (3) prioritize woody species for conservation and management interventions.

Materials and methods

Study area

The study area, known as Kuandisha Forest, covers about 190 ha between 11°11′04″ to 11°12′25″ N and 36°48′50″ to 36°49′59″ E in the Awi Zone, Amhara National Regional State (Fig. 1). The elevation ranges between 2132 m and 2365 m asl. The forest is one of the Community Based Integrated Natural Resources Management (CBINRM) project sites in northwestern Ethiopia.

The forest was heavily deforested in the 1990s; few large individuals of *Prunus africana*, *Albizia schimperiana*, *Schefflera abyssinica*, *Podocarpus falcatus*, *Euphorbia abyssinica* Gmel. and *Acacia abyssinica* were left on farms or in settlements or the forest. The forest is generally categorized as a dry evergreen afromontane forest and grassland complex vegetation (Friis et al. 2010) dominated by secondary forest and some emergent trees. The forest is surrounded on all sides by agricultural lands, settlements and pastures, which could be regarded as an afromontane

Fig. 1 Map of Kuandisha District in Amhara National Regional State showing the Kuandisha Forest
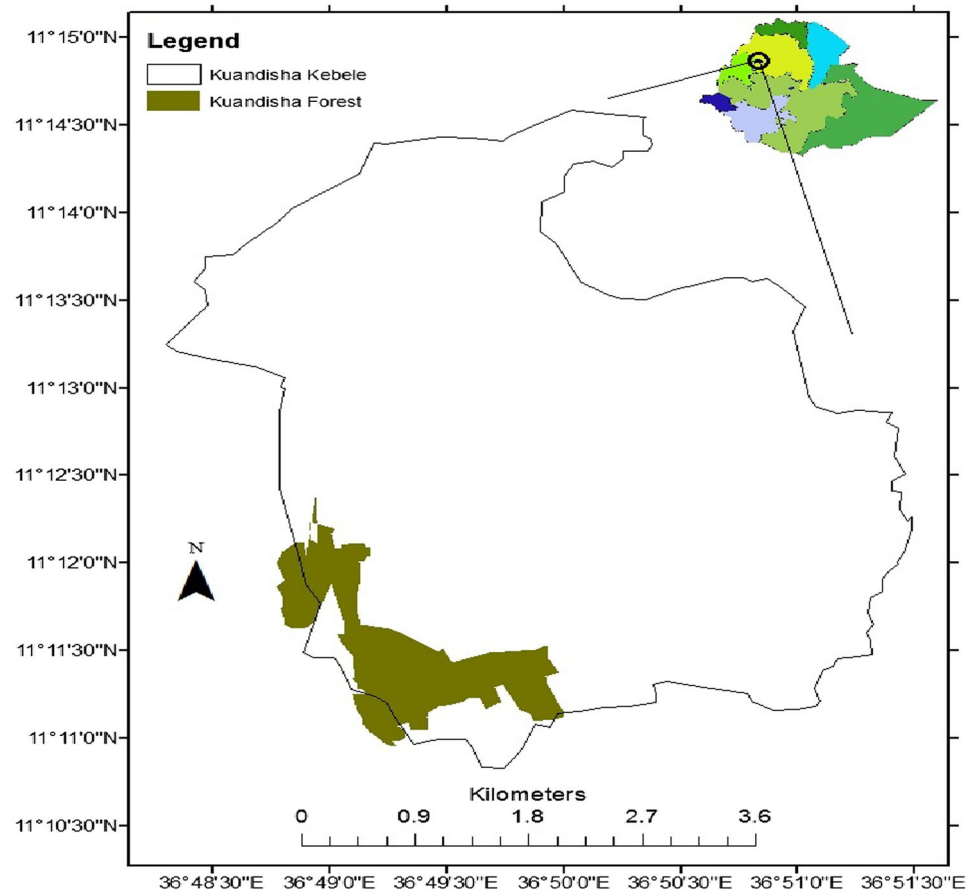
"island" in a human-made matrix of completely altered landscapes (Brown and Lomolino 1998).

The bulk of the plateau where this vegetation type occurs consists of volcanic rocks (Woldu 1999). Thus, the rocks are of early Tertiary volcanics (GSE 2010). The volcanic rocks are not uniform with respect to either vegetation or soil (Woldu 1999). The basalts that tend to predominate along the escarpment and on mountainous outcrops have poor internal drainage and are thus forested on slopes where the soils are phaeozems or truncated phaeozems. The flatter areas, where the soils are vertisols, carry grasslands. The rainfall is uni-modal (Gemechu 1977). The wettest months are May to October with high peaks in August, whereas the driest months are November to March. The annual precipitation is 1524 mm; 364 mm of precipitation falls in the wettest month (August) and 11 mm the driest month (January). The annual mean temperature is 18.8 °C with a maximum of 27.4 °C and minimum of 10 °C.

Vegetation data collection

In a reconnaissance survey in the first week of August 2014, homogenous stands were identified for sampling purposes. Plots, each measuring 500 m^2 (10 m × 50 m),

were established at 100 m interval from each other along a line transect. A total of 53 plots with a total area of 2.65 ha were set up using Suunto (Vaalta, Finland) compass along eight transect lines that were oriented east to west. Each transect was laid against altitudinal gradients to capture representative samples of the forest. The distance between any two adjacent transects was 200 m.

The name (local and scientific), percentage foliage cover and abundance of each woody species were recorded in each plot. Diameter at breast height (DBH) of trees with DBH ≥2.5 cm was measured using a tree caliper and diameter tape. When the ball of a tree was at breast height, diameter was measured above the tree ball. In cases where the tree or shrub branched at about breast height, DBH was measured separately for each branch. The heights of all individuals of trees with a DBH ≥2.5 cm were measured with a hypsometer (Nikon Laser Rangefinder Forestry Pro). Diameter for shrubs was measured at stump height (DSH). Local and scientific names and number of dead stumps were also recorded. Five 2 m × 4 m subplots were used to assess abundance and frequency of seedlings: four at the corners and one at the center nested within each 500 m^2 main plot (total area 40 m^2 per plot). A seedling in this study was defined as an individual tree or shrub species

with a DBH below 2.5 cm or a height below 1.5 m (Maria et al. 1995). The longest side of each subplot was parallel to the longest side of the main plot. A total of 265 subplots with total area of 0.21 ha were investigated.

Environmental data collection

Data on altitude, latitude and longitude for each plot were taken using a Garmin global positioning system (GPS). The extent of threats for each plot was determined based on a scale for disturbance after field observation and discussion with local people. The combined degree of disturbance within each sample plot was recorded on a scale of 0, negligible; 1, very light; 2, light; 3, moderate; 4, heavy; and 5, very heavy.

Botanical identification

Woody plant specimens encountered inside and outside the sampling plots were collected and pressed to compile a complete list of species. Specimens were identified and confirmed at the National Herbarium (ETH), Ethiopia. Nomenclature follows that of Edwards et al. (1995, 1997), Tadesse (2004) and Hedberg et al. (2003, 2006, 2009a). Botanical names and authorities were verified using volume 8 of the *Flora of Ethiopia and Eritrea* (Hedberg et al. 2009b). Voucher specimens are deposited at ETH.

Data analysis

Data preparation

Two initial 3-column data tables were constructed in an Excel (Microsoft) worksheet and saved in the CSV (comma delimited) format. The first column represented the sample ID (Plots), the second column the taxon ID (Species) and the third column the abundance or percentage foliage cover of the species in the sample (Abundance or Cover). The percentage foliage cover was transformed to ordinal scales and assigned to one of the nine cover-abundance classes according to the modified 1–9 Braun–Blanquet scale (DCR-DNH 2011): 1 = ≤0.1 %, 2 = >0.1 to 1 %, 3 = >1 to 2 %, 4 = >2 to 5 %, 5 = >5 to 10 %, 6 = >10 to 25 %, 7 = >25 to 50 %, 8 = >50 to 75 %, and 9 = >75 %. The 3-column data with either abundance or cover in the third column, were imported to "labdsv" package in R version 3.2.1 (R Core Team 2014) and matrified to carry out the analysis for various parameters.

Forest composition and diversity

Species richness or alpha diversity, the Shannon–Wiener diversity index and evenness were calculated by importing the matrified abundance data into "vegan" package in R 3.2.1 (Oksanen et al. 2014; R Core Team 2014). The diversity index focuses on the relative species richness and abundance and/or the pattern of species distribution/evenness (Maguran 1988; Krebs 1999). The value usually falls between 1.5 and 3.5, rarely exceeding 4.5.

Forest structure

Tree and shrub density was expressed as the number of individuals of a species per hectare. The overall density was expressed as the sum total of all individuals of all species in a hectare. The density ratio of individuals of all species with DBH greater than 10 cm to greater than 20 cm were used to analyze the proportion of lower DBH classes to higher DBH classes. Generally, the following formulas were used to calculate relative density, frequency and relative frequency:

$$R_{de} = \frac{N_i}{\sum_{i=1}^{s} N_i} \times 100, \tag{1}$$

where, R_{de} is the relative density of a species and N_i is number of individuals of the ith species (s);

$$F = \frac{P_i}{\sum_{i=1}^{s} P_i} \times 100, \tag{2}$$

where, F is the frequency of a species and P_i is number of plots in which the ith species (s) was recorded;

$$R_{fr} = \frac{F_i}{\sum_{i=0}^{s} F_i} \times 100, \tag{3}$$

where, R_{fr} is the relative frequency of a species and F_i is frequency of the ith species (s).

Species population structure, defined as the frequency distribution of individuals of a species in defined DBH and height classes (Teketay 2005a), was analyzed for the entire forest and each woody species based on defined DBH and height classes. Diameter was classified into nine classes at 5 cm intervals, and height into 10 classes of 5 m intervals. DBH classes (cm) were 2.5–7.5, 7.6–12.5, 12.6–17.5, 17.6–22.5, 22.6–27.5, 27.6–32.5, 32.6–37.5, 37.6–42.5 and >42.5. The height classes (m) were 1.5–5, 5.1–10, 10.1–15, 15.1–20, 20.1–25, 25.1–30, 30.1–35, 35.1–40, 40.1–45 and >45. The number of individuals within each DBH and height class were summed, and histograms were constructed to determine the population structure and regeneration status of each woody species using Microsoft Excel.

Basal area (m^2 ha^{-1}), measured as the cross-sectional area of a tree or shrub at breast height or stump height, respectively, was computed from the measurement of DBH/DSH in spreadsheet programs as follows:

$$B_a = \pi d^2/4, \tag{4}$$

where $\pi = 3.14$, B_a is basal area, and d is DBH (m).

However, since DBH was measured in centimeters, the formula was modified in such a way that the B_a will be in square meters. Thus, $B_a = \pi d^2/40{,}000$ or $0.0000785d^2$, where d is DBH in centimeters. The mean basal area of all investigated plots was converted to mean basal area per hectare.

$$R_{do} = \frac{B_i}{\sum_{i=0}^{s} B_i} \times 100, \tag{5}$$

where R_{do} is relative dominance and B_i is mean basal area of the ith species (s).

The importance value index (IVI) indicates the relative ecological importance of a given woody species at a particular site (Kent and Coker 1992). The IVI was determined from the summation of the relative values of density, frequency and dominance of each woody species. Species were grouped into five classes based on their IVI values: class 5 = <1, class 4 = 1–20, class 3 = >20–40, class 2 = >40–60, class 1 = >60. The lower the IVI value of a given species, the higher priority was given to that species for conservation purposes and vice versa (Zegeye et al. 2011; Dalle 2015).

The cover–abundance data were analyzed and classified using the Cluster and Vegan packages in R 3.2.1 (Oksanen et al. 2014). After determining the optimal number of clusters, a hierarchical agglomerative clustering technique using Euclidean distance and Ward's method was used to classify plots that produced a dendrogram and cluster IDs. Ward's method is commonly used and the most robust among the hierarchical classification techniques (Scheibler and Schneider 1985; Singh 2008; Woldu 2014). After identification of the major clusters, characteristic species of plant communities were identified by importing the cover–abundance data matrix and cluster IDs into R to produce an importance value table (synoptic table). Synoptic tables are often used in vegetation classification to identify the characteristic species for specific classes or types (Woldu 2014). The major communities were named using the identified characteristic species, species with the highest mean cover–abundance value, in each cluster.

Results and discussion

Floristic composition and diversity

Sixty-six indigenous woody species belonging to 40 families and 61 genera were recorded (Supplementary Appendix S1). Sixty species were recorded inside the plots, whereas six species (*Acanthus sennii* Chiov., *Podocarpus falcatus*, *Juniperus procera*, *Senna septemtrionalis*, *Lantana trifolia* L. and *Cordia africana* Lam.) were recorded outside the plots. *J. procera* and *C. africana* were planted in the compound of Kuandisha Michael Church, which is located at the southern edge of the forest. Fabaceae is the most diverse family, followed by Euphorbiaceae and Asteraceae. In terms of habit, 29 species are trees, 28 shrubs and nine lianas. The highest species richness recorded in a plot was 32, and the least was 12. On average, 20 species per plot were recorded. Seven endemic species (10.6 %), namely, *Acanthus sennii*, *Clematis longicauda* Steud. ex A. Rich., *Vepris dainellii* (Pichi-Serm.) Kokwaro, *Millettia ferruginea* (Hochst.) Bak, *Rhus glutinosa* A. Rich. subsp. *glutinosa*, *Solanecio gigas* (Vatke) C. Jeffrey and *Vernonia leopoldi* (Sch. Bip. ex Walp.) Vatke, were recorded (Table 1). More woody species were recorded in this study than found in similar studies in the DAF such as in the Zengena forest (Tadele et al. 2014). However, fewer species were recorded than in other similar forests such as in the Zege peninsula (Alelign et al. 2007), the Tara Gedam and Abebaye forests (Zegeye et al. 2011) and the Menagesha-Suba forest (Beche 2011).

The comparison of the species composition of the Kuandisha forest to vegetation types in Ethiopia (Friis et al. 2010) indicated that the species belong to four vegetation types. Sixty-four percent of the species ($n = 42$) belong only to the DAF vegetation type; 25 % ($n = 16$) are shared with moist evergreen afromontane forest vegetation type (MAF); 9 % ($n = 6$) with *Acacia–Commiphora* woodland (ACW); one species with *Combretum–Terminalia* woodland (CTW) and one species with DAF, MAF and ACW. *Dombeya quinqueseta* is reported to occur in the CTW, mostly on rocky slopes at 850–1900 (–2200) m asl in Ethiopia (Vollesen 1995). The species occurs at 2252 m asl in the Kuandisha forest, marking the upper limit of its natural geographic range extending to the DAF. Moreover, 10 and six of the most dominant/characteristic species in Kuandisha forest were also characteristic species in the DAF and MAF, respectively. Most of the characteristic species belong to the undifferentiated afromontane forest (subtype 5a) and afromontane woodland, wooded grassland and grassland (subtype 5c) of the DAF (Friis et al. 2010). Thus, it is reasonable to conclude that the vegetation of Kuandisha forest belongs to the DAF, in agreement with the findings of Friis et al. (2010). On the other hand, 13 species (20 %)—*Lepidotrichilia volkensii* (Giirke) Leroy, *Brucea antidysenterica* J. F. Mill., *Capparis tomentosa* Lam., *Carissa spinarum*, *Clematis longicauda*, *Cordia africana*, *Croton macrostachyus*, *Dombeya torrida*, *Maesa lanceolata* Forssk., *Protea gaguedi* J. F. Gmel, *Vepris dainellii*, *Hippocratea africana* (Willd.) Loes. and *Justicia schimperiana* (Hochst. ex Nees) T. Anders. were also reported from the wooded grassland of the western Gambella Region (Awas et al. 2001).

Table 1 Family, habit and altitudinal distribution of endemic species

Species	Family	Habit	Altitudinal distribution (a.s.l.) (m)
Acanthus sennii	Acanthaceae	Shrub	1700–3200
Clematis longicauda	Ranunculaceae	Liana	1350–3300
Millettia ferruginea	Fabaceae	Tree	1000–2500
Rhus glutinosa subsp. *glutinosa*	Anacardiaceae	Tree	1800–3300
Solanecio gigas	Asteraceae	Shrub	1750–3350
Vepris dainellii	Rutaceae	Tree	1750–2500
Vernonia leopoldi	Asteraceae	Shrub	1850–2850

The distribution was based on specimen records in the National Herbarium of Ethiopia (ETH)

The Shannon–Wiener diversity index for the Kuandisha forest was 2.5, which is lower than other dry evergreen afromontane forests such as the Zengena forest (Tadele et al. 2014), Zege forest (Alelign et al. 2007), Menagesha-Suba forest (Beche 2011) and Tara Gedam and Abebaye forests (Zegeye et al. 2011). This difference could be due to the higher altitudinal ranges and sizes of these other forests (e.g. Alelign et al. 2007) and to very severe anthropogenic disturbances in our study area; a low diversity index is usually associated with high disturbance (Maguran 1988; Krebs 1999).

Forest structure

Woody species frequency and density

The frequency of woody species with DBH ≥2.5 cm in the Kuandisha forest ranged from 1.9 to 92.5 %. Fifty-five percent of the species were absent in most of the plots belonging to frequency class A (Fig. 2). On the other hand, four species—*Acacia abyssinica*, *Rytigynia neglecta* (Hiern) Robyns, *C. macrostachyus* and *Maytenus arbutifolia* (A. Rich.) Wilczek—were most frequent in frequency class E. Two species, namely, *C. macrostachyus* and *M. arbutifolia*, were the most frequent, followed by *R. neglecta* and *A. abyssinica*. The relative frequency of species ranged from 0.12 to 6 %. The highest relative frequency was documented for *Croton macrostachyus*, followed by *Maytenus arbutifolia*, *Rytigynia neglecta* and *Acacia abyssinica* with RF of above 5 %. Generally, 7 % of species had RF of above 5, 43 % between 1 and 5, and 50 % below 1 %.

The total stem density of Kuandisha forest was 3086 stems h⁻¹, comparable to Zege Peninsula forest (Alelign et al. 2007), but higher than in the Zengena forest (Tadele et al. 2014) and Tara Gedam and Abebaye forests (Zegeye et al. 2011). Eleven species had more than 100 stems ha⁻¹. *C. spinarum* (422) had the highest density followed by *C. aurea* (374), *M. arbutifolia* (331), *B. abyssinica* (256), *C. macrostachyus* (235), *R. neglecta* (194), *P. stellatum* (153), *A. schimperiana* (148), *A. lahai* (134), *R. abyssinica* (111)
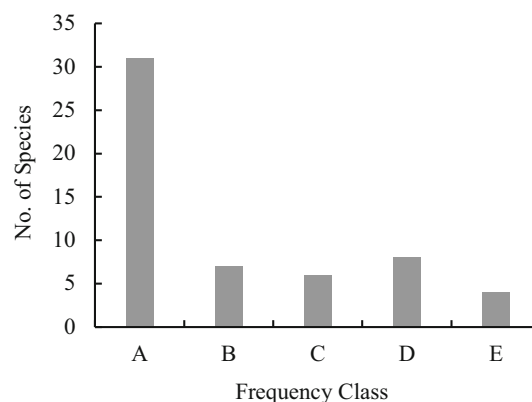
Fig. 2 Number of species in each frequency class (*A* 1–20 %, *B* 21–40 %, *C* 41–60 %, *D* 61–80 %, *E* 81–100 %)

and *A. abyssinica* (102). Sixty-nine percent of the species (*n* = 45) had a density of less than 100 stems ha⁻¹. The density of species with DBH greater than 10 cm was 312 stems ha⁻¹, while those with DBH greater than 20 cm was 38 stems ha⁻¹. The ratio of the overall density of species with DBH greater than 10 cm to those greater than 20 cm was eight, indicating the dominance of small individuals over large individuals, which could be clearly attributed to forest destruction in the 1990s and later and to the selective cutting of trees in the higher DBH classes. Similar trends were reported elsewhere in Ethiopia but at ratios much lower than in the present study (Bekele 1993; Yineger et al. 2008; Tadele et al. 2014). The relative density of woody species ranged from 0.01 to 14 %. The highest relative density was documented for *Carissa spinarum*, followed by *Calpurnia aurea*, *Maytenus arbutifolia*, *Bersama abyssinica*, *Croton macrostachyus* and *Rytigynia neglecta*. Generally, 10.7 % of the species had a relative density above 5, 21.4 % between 1 and 5, and 68 % below 1 %.

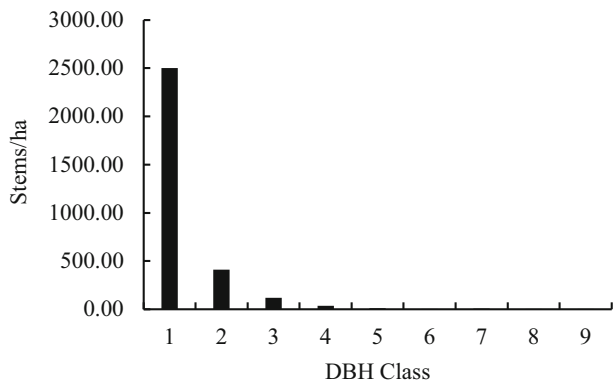#### Diameter and height class distribution

The density of woody species with DBH ≥2.5 cm was the highest at the lower DBH classes and tended to decrease

toward higher classes (Fig. 3). Trees such as *Prunus africana*, *Millettia ferruginea* and *Albizia schimperiana* were unusually absent in the higher DBH classes, possibly due to selective logging.
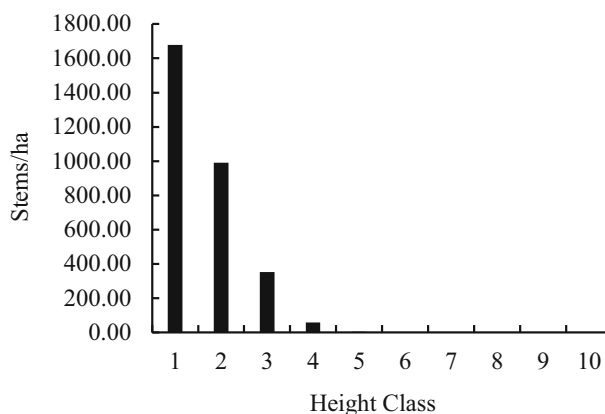
The highest DBH was recorded for *S. abyssinica* (240 cm), followed by *Ficus sur* Forssk. with a DBH of 80 cm. *A. abyssinica* and *C. macrostachyus* occurred in most DBH classes. The distribution of overall species density in height classes tended to decrease up to the sixth height class though the values for the fifth and sixth height classes were too low to be visible in the graph (Fig. 4). *Ficus sur* was the only tree species with heights above 25 m, reaching 30 m. No trees were found above 30 m. Generally, the upper stratum of the forest consisted of *Acacia abyssinica*, *Ficus sur*, *Croton macrostachyus*, *Euphorbia abyssinica* and *Schefflera abyssinica*. The second stratum constituted various species such as *Dombeya torrida*, *Allophyllus abyssinicus*, *Bersama abyssinica*, *Buddleja polystachya*, *Carissa spinarum* and *Grewia ferruginea* Hochst. ex A. Rich.

Basal area and dominance

According to Bekele (1993), basal area (BA) provides a better measure of the relative importance of tree species than simple stem counts. Accordingly, *A. schimperiana*, *F. sur*, *A. abyssinica*, *S. abyssinica*, *A. dimidiata*, *B. abyssinica*, *E. abyssinica* and *C. macrostachyus* with DBH values greater than 42 cm contributed 25 % of the BA. Generally, the lower and higher DBH classes contributed most for the total BA (Fig. 5). Accordingly, the total BA of woody species with DBH ≥2.5 cm was 15.3 m² ha⁻¹. The BA is considerably lower than in similar forest fragments such as the Wof-Washa forest (102 m² ha⁻¹), Jibat forest (50 m² ha⁻¹), Denkoro forest (45 m² ha⁻¹) and Tara Gedam forest (115.4 m² ha⁻¹) (Bekele 1993; Ayalew 2003; Zegeye et al. 2011). The lower total BA is mainly
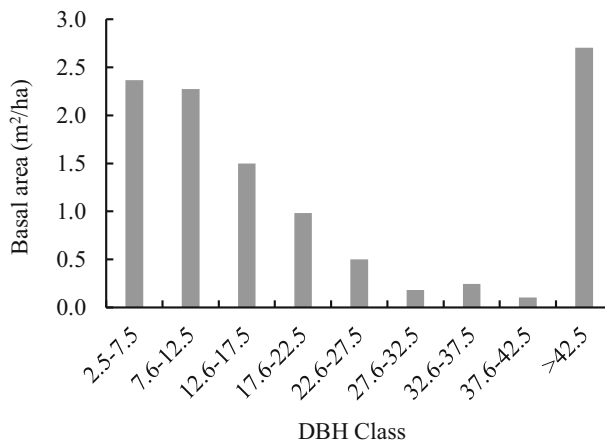
Fig. 4 Distribution of overall woody species density in height classes (m). (*Class 1* 1.5–5; *2* 5.1–10; *3* 10.1–15, *4* 15.1–20, *5* 20.1–25, *6* 25.1–30, *7* 30.1–35, *8* 35.1–40, *9* 40.1–45, *10* >45)

attributed to lower DBH of woody species (Bekele 1993). For example, many of the largest trees that had been found in the undisturbed Wof-Washa dry Afromontane forest were individuals with a DBH up to 200 cm (Bekele 1993). In terms of species dominance, four species, namely, *C. macrostachyus*, *S. abyssinica*, *A. abyssinica* and *A. schimperiana* ranked in the top four with dominance value (per ha) of 2.3, 1.9, 1.8 and 1.6, respectively. Similarly, *C. macrostachyus* had the highest relative dominance, followed by *Schefflera abyssinica*, *Acacia abyssinica*, *Albizia schimperiana*, *Carissa spinarum*, *Bersama abyssinica* and *Calpurnia aurea* with relative dominance ≥5 %. Generally, 12.5 % of species had RDO of above 5, 19.6 % between 1 and 5, and 67.8 % below 1 %.

Importance value index

The importance value index (IVI) of species ranged from 0.13 to 28.4 (Supplementary Appendix S2). Six species,

Fig. 3 Distribution of overall woody species density among DBH classes (cm). *Class 1* 2.5–7.5, *2* 7.6–12.5, *3* 12.6–17.5, *4* 17.6–22.5, *5* 22.6–27.5, *6* 27.6–32.5, *7* 32.6–37.5, *8* 37.6–42.5, *9* >42.5)

Fig. 5 Distribution of basal area (m² ha⁻¹) in DBH classes (cm). (*Class 1* 2.5–7.5, *2* 7.6–12.5, *3* 12.6–17.5, *4* 17.6–22.5, *5* 22.6–27.5, *6* 27.6–32.5, *7* 32.6–37.5, *8* 37.6 –42.5, *9* >42.5)

namely *Croton macrostachyus*, *Carissa spinarum*, *Calpurnia aurea*, *Acacia abyssinica*, *Albizia schimperiana* and *Maytenus arbutifolia* had IVI of 20 and above. The first 17 species (based on their rank) contributed 81.5 % of the IVI. Generally, 18 species have IVI of less than 1; 33 species IVI of 1–20 and 5 species IVI of 20–40. Other studies such as Zewdie (2007), Bantiwalu (2010) and Tadele et al. (2014) documented higher IVI for some tree species such as *Allophyllus abyssinicus*, *Bersama abyssinica* and *Prunus africana* than the current study in similar vegetation types, perhaps due to selective cutting of species in the higher DBH classes in the Kuandisha forest. Some of the species with higher IVI values in this forest are among the characteristic species in the DAF elsewhere (Demissew and Friis 2009; Woldu 1999).

Species population structure

An analysis of population structures can provide an estimate of the regeneration status of woody species (Teketay 2005a). Various studies have revealed various population structures of species in dry evergreen Afromontane forests of Ethiopia. For instance, Teketay (2005a), Alelign et al. (2007), Yineger et al. (2008), Bantiwalu (2010), Beche (2011) and Tadele et al. (2014) reported various population patterns in similar forests in Ethiopia.

Consequently, three species population patterns, in agreement with the results of Teketay (2005a), were recognized in the Kuandisha forest (Fig. 6). The first pattern is an inverted J-shape, which indicates the presence of large number of individuals at lower DBH classes with a gradual decreasing trend toward higher DBH classes. A few species such as *A. abyssinica* and *C. macrostachyus* had this pattern.

The second pattern indicated the presence of numerous individuals at lower DBH classes and the absence of individuals at intermediate or higher DBH classes. A number of species such as *Allophylus abyssinicus*, *Apodytes dimidiata*, *Dovyalis abyssinica*, *Ekebergia capensis*, *Grewia ferruginea*, *Pavetta abyssinica* and *Teclea nobilis* were in this category.

The third pattern revealed the absence of individuals at the lower DBH classes and in a few non-intermediate DBH classes; some individuals were present in some DBH classes. Some species such as *Euphorbia abyssinica* and *Schefflera abyssinica* were categorized under this group. *S. abyssinica* is known to have rarely an epiphytic nature (Bamps 1989).

Seedling regeneration

Seedling density (per ha) varied among species ranging from five for *Clematis longicauda* to 9938 for *Maytenus arbutifolia*. The total density was 26,159 individuals ha^{-1}.

M. arbutifolia, *R. neglecta*, *V. auriculifera*, *C. anisata* and *P. stellatum* had more than 1000 seedlings ha^{-1}. Similar results were reported for *M. arbutifolia*, *V. auriculifera* and *C. anisata* from the afromontane forests of southwestern Ethiopia (Tesfaye and Berhanu 2006). Seedling density was considerably higher than in the Zege, Tara Gedam and Abebaye forests and Zengena forests (Alelign et al. 2007; Zegeye et al. 2011; Tadele et al. 2014), which could be attributed to the relatively younger secondary forest nature of Kuandisha forest than those forests that are mature and have attained their climax stage elsewhere (Bekele 1993). Forest undergrowth such as seedlings for coffee production was also frequently cleared in the Zege Peninsula forest (Alelign et al. 2007). Generally, in the present study 65 % of the species had seedlings, whereas 35 % of the species did not have seedlings. Trees such as *Cordia africana*, *Dracaena steudneri*, *Ekebergia capensis*, *Erythrococca trichogyne* and *Steganotaenia araliacea* lacked seedlings. Moreover, endemic species, namely, *Acanthus sennii* and *Vepris dainelii* did not have seedlings.

Woody plant communities

The woody vegetation classification of Kuandisha forest at the 25-dissimilarity level resulted in five major woody species associations or plant communities: *Maytenus arbutifolia–Carissa spinarum* community, *Carissa spinarum–Justicia schimperiana* community, *Calpurnia aurea–Acacia abyssinica* community, *Acacia abyssinica–Pterolobium stellatum* community and *Bersama abyssinica–Croton macrostachyus* community (Fig. 7; Table 2). The description of each community or woody plant association is provided as follows.

   I. The *Maytenus arbutifolia–Carissa spinarum* community occurs between altitudes 2222 and 2344 m asl. Dominant species are *M. arbutifolia* and *C. spinarum*. Some of the species at the tree layer include *A. abyssinica*, *C. macrostachyus* and *S. abyssinica*. Some of the species at the shrub layer include *Acacia lahai*, *B. abyssinica* and *Rosa abyssinica*. Five liana species, namely, *P. stellatum*, *Embelia schimperi*, *Jasminum abyssinicum*, *Clerodendrum myricoides* and *Clematis longicauda* also occur in this community. This community is highly disturbed as it is found near forest edges.

  II. The *Carissa spinarum–Justicia schimperiana* community occurs between 2232 and 2336 m asl. Dominant species are *C. spinarum* and *J. schimperiana*. A significant number of tree species, namely, *A. schimperiana*, *E. abyssinica*, *F. sur*, *Dovyalis abyssinica*, *S. abyssinica*, *C. macrostachyus*, *L. volkensii*, *P. africana* and *M. obscura* occur in this
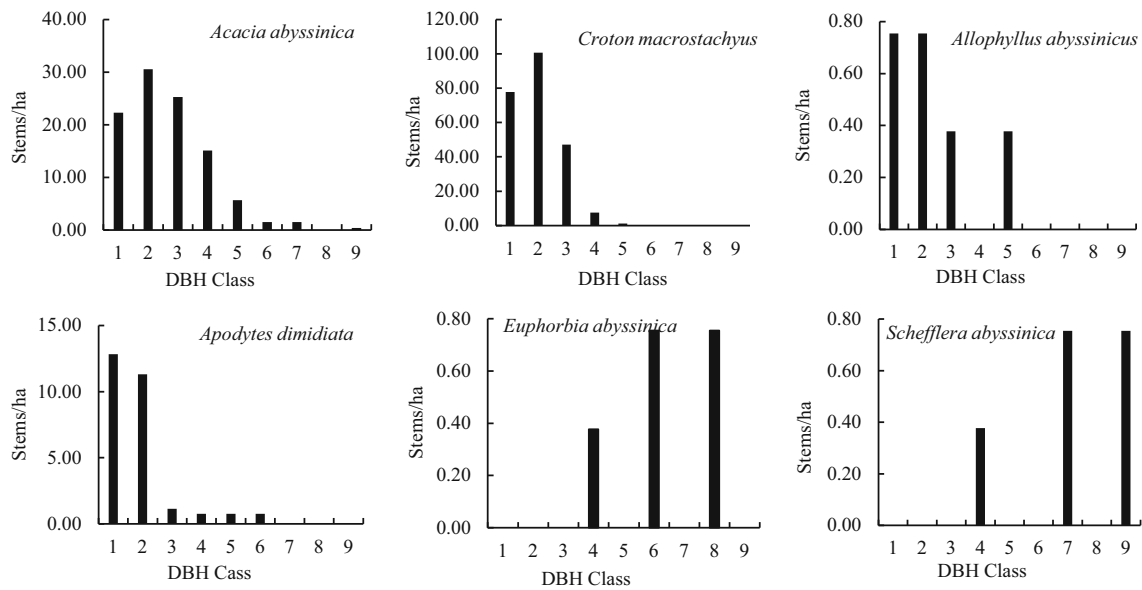
Fig. 6 Population structure of representative species in DBH classes (cm) of each group. (*class 1* 2.5–7.5; *2* 7.6–12.5; *3* 12.6–17.5; *4* 17.6–22.5, 22.6–27.5, 27.6–32.5; *7* 32.6–37.5; *8* 37.6–42.5; *9* >42.5)

Fig. 7 Dendrogram showing sampling plots in each cluster (community type/association)
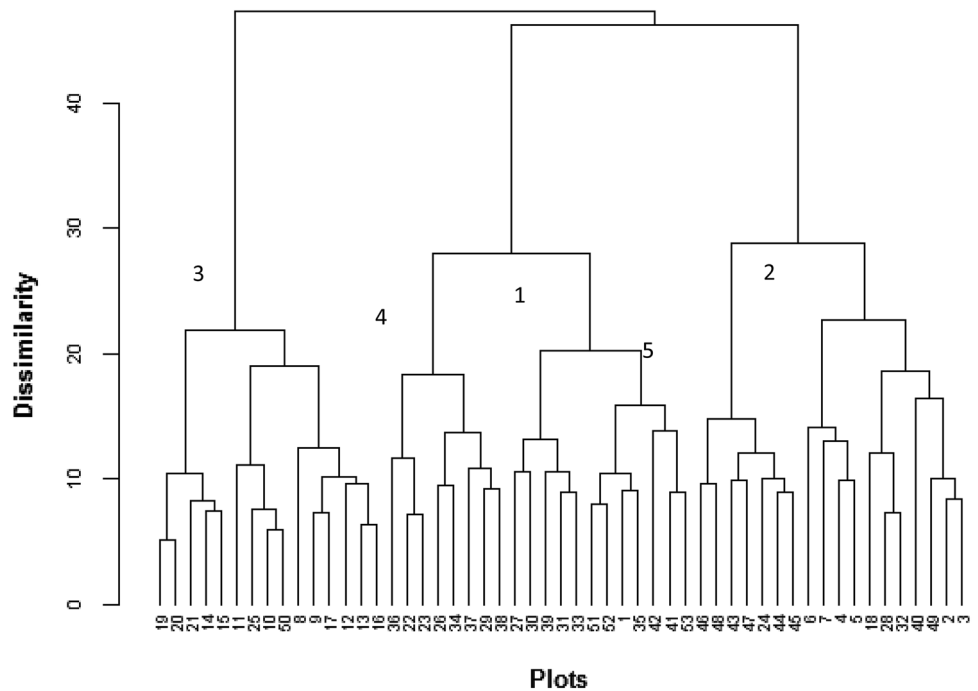
community. The shrub layer includes *B. abyssinica*, *R. neglecta*, *M. arbutifolia*, *C. aurea* and *M. lanceolata*. Many of the liana species, namely, *P. stellatum*, *C. myricoides*, *E. schimperi*, *Urera hypselodendron*, *Phytolacca dodecandra*, *J. abyssinicum* and *C. longicauda* also occur here.

III. The *Calpurnia aurea–Acacia abyssinica* community occurs between 2260 and 2350 m asl. Dominant species are *C. aurea* and *A. abyssinica*. The tree layer includes species such as *A. abyssinica*, *C.*

macrostachyus, *A. schimperiana* and *Ekebergia capensis*. The shrub layer includes *R. neglecta*, *C. anisata*, *R. abyssinica*, *A. lahai* and *B. antidysenterica*. Five liana species, namely *E. schimperi*, *P. stellatum*, *J. abyssinicum*, *C. myricoides* and *C. longicauda* occur in this community.

IV. The *Acacia abyssinica–Pterolobium stellatum* community occurs between 2229 and 2317 m asl. Dominant species are *A. abyssinica* and *P. stellatum*. The tree layer consists of species such as *A.*

Table 2 Synoptic mean cover–abundance value for species reaching ≥2.0 in at least one community type, (*Community CI* community 1, *CII* community 2, *CIII* community 3, *CIV* community 4, *CV* community 5, values in bold refer to characteristic species)

Species	Communities				
	CI	CII	CIII	CIV	CV
Acacia abyssinica	4.7	2.0	**4.3**	**6.4**	3.9
Acacia lahai	4.4	2.0	3.1	2.9	3.3
Albizia schimperiana	2.0	5.1	3.3	4.8	5.7
Apodytes dimidiata	3.0	2.0	2.0	2.0	3.1
Bersama abyssinica	3.8	5.2	3.4	2.8	**6.1**
Brucea antidysenterica	2.7	2.0	3.1	2.0	2.4
Calpurnia aurea	2.0	3.2	**4.6**	3.8	3.8
Carissa spinarum	**5.6**	**7.1**	2.5	4.7	4.0
Clausena anisata	2.3	2.5	3.3	2.6	2.0
Clematis longicauda	2.0	2.0	2.0	2.0	2.7
Croton macrostachyus	3.6	3.6	4.2	4.1	**5.9**
Dovyalis abyssinica	2.0	4.5	2.0	2.0	2.0
Ekebergia capensis	0.0	2.0	2.0	2.0	3.3
Euphorbia abyssinica	0.0	4.0	0.0	0.0	0.0
Ficus sur	0.0	4.5	0.0	0.0	2.0
Justicia schimperiana	0.0	**6.0**	0.0	0.0	0.0
Lepidotrichilia volkensii	0.0	3.5	0.0	0.0	0.0
Maesa lanceolata	2.6	2.6	2.5	2.0	3.7
Maytenus arbutifolia	**6.7**	3.2	2.7	3.1	3.9
Maytenus obscura	3.2	3.0	2.1	2.7	2.8
Pterolobium stellatum	3.0	4.1	2.9	**5.6**	2.0
Rosa abyssinica	3.6	2.0	3.1	2.6	3.7
Rytigynia neglecta	2.2	3.3	3.4	3.2	2.9
Schefflera abyssinica	3.5	4.0	0.0	0.0	0.0
Vernonia auriculifera	2.2	2.4	2.4	2.5	3.2

Species richness, diversity and evenness varied among the five community types (Table 3). The highest richness was found in community II, followed by communities IV, I, III and V. In terms of diversity, community II had the highest diversity index, followed by communities IV, V, I and III. The highest evenness was detected in community V, followed by communities II, IV, I and III, which also corresponded to the diversity indices

abyssinica, *A. schimperiana*, *C. macrostachyus* and *M. obscura*. The shrub layer includes *C. spinarum*, *C. aurea*, *R. neglecta*, *M. arbutifolia*, *A. lahai*, *B. abyssinica*, *C. anisata*, *R. abyssinica* and *Vernonia auriculifera*. Liana species such as *P. stellatum*, *E.*

schimperi, *J. abyssinicum*, *U. hypselodendron*, *C. myricoides* and *C. longicauda* occur in this community.

V. The *Bersama abyssinica–Croton macrostachyus* community occurs between 2132 and 2365 m asl. Dominant species in this community are *B. abyssinica* and *C. macrostachyus*. The tree layer includes *C. macrostachyus*, *A. schimperiana*, *A. abyssinica*, *E. capensis*, *A. dimidiata* and *M. obscura*. The shrub layer consists of species such as *B. abyssinica*, *C. spinarum*, *M. arbutifolia*, *C. aurea*, *R. abyssinica*, *M. lanceolata*, *Teclea nobilis*, *A. lahai*, *V. auriculifera* and *R. neglecta*. Liana species include *C. longicauda*, *E. schimperi*, *P. stellatum*, *J. abyssinicum*, *U. hypselodendron* and *C. myricoides*.

Generally, some of the characteristic species in the Kuandisha forest were also recorded as dominant species in moist (e.g., *Carissa spinarum* and *Croton macrostachyus*) and dry (e.g., *Maytenus arbutifolia* and *Allophylus abyssinicus*) evergreen afromontane forests elsewhere in Ethiopia (Bekele 1993). *Carissa spinarum* and *Croton macrostachyus* have wide ecological ranges in Ethiopia (Gilbert 1995; Leeuwenberg 2003).

The study revealed that the Shannon diversity index and species evenness were highly positively correlated ($r = 0.69$, $p < 0.005$); the more diverse a community is, the more even is the distribution of individuals of species in that community. The correlation between species richness and diversity was also positively strong ($r = 0.87$, $p < 0.005$). On the other hand, there was a positively weak correlation between species richness and evenness ($r = 0.24$, $p > 0.005$). Similar findings elsewhere suggest that there are positive and strong correlations among species richness, diversity and evenness (Stirling and Wilsey 2001). In terms of habit, community II consisted of the highest tree richness followed by IV, I, V and III (Table 4). Shrub richness was more or less similar among communities in that, except for community I and IV the three communities had the same number of species. Communities II and IV, and III and V have equivalent number of liana richness. The least liana richness was recorded in community I. The correlation between richness of lianas and trees was positively strong ($r = 0.6$, $p < 0.005$). Similar studies have shown that liana richness was strongly

Table 3 Species richness, diversity and evenness of plant communities in Kuandisha forest

No.	Name of community	Species richness	Diversity index (H′)	Evenness (J′)
I	*M. arbutifolia–C. spinarum*	36	3.10	0.86
II	*C. spinarum–J. schimperiana*	43	3.38	0.90
III	*C. aurea–A. abyssinica*	32	2.99	0.86
IV	*A. abyssinica–P. stellatum*	37	3.18	0.88
V	*B. abyssinica–C. macrostachyus*	31	3.16	0.91

Table 4 Liana, shrub and tree richness in the five plant communities

Community	Habit			Total
	Liana	Shrub	Tree	
I	5	19	12	36
II	7	17	19	43
III	6	17	9	32
IV	7	17	13	37
V	6	15	10	31
Total	9	28	29	66

positively correlated with tree richness (Kharkwal et al. 2007).

Forest disturbance and species prioritization for conservation

Forest disturbance

Disturbances in dry afromontane forests include wind throw, natural and manmade fires, landslides, grazing, tree felling and clearing for cultivation (Teketay 2005b). In the present study, free grazing and selective cutting were the most important disturbance regimes. Species richness of trees and shrubs were strongly negatively correlated with disturbance ($r = -0.58$, $p < 0.005$). Similarly, seedling density was strongly negatively correlated with disturbance ($r = -0.66$, $p < 0.005$). Consequently, the disturbance intensity ranged from moderate (score 2–3) in ten plots to heavy (score 4) in 14 plots and very heavy (score 5) in 29 plots. According to Økland (1990), disturbance encompasses sudden events affecting the vegetation by increasing the density-independent mortality. Old and new stumps were observed in all plots, which indicated how severe the anthropogenic impact was in the Kuandisha forest. For example, dead stumps of 27 species were recorded. *Acacia lahai* was the most important species, followed by *A. abyssinica*, *Croton macrostachyus*, *Carissa spinarum*, *Albizia schimperiana*, *Maytenus arbutifolia*, *Bersama abyssinica*, *Maesa lanceolata* and *Calpurnia aurea*. Individuals of *A. lahai* were debarked wherever the species was found. According to local informants, the bark is utilized for house construction and tying bundles of firewood.

Some characteristic species of the dry evergreen afromontane forest such as *Olea europaea* subsp. *cuspidata* and *Hagenia abyssinica* are absent in the Kuandisha forest. *H. abyssinica* is a dominant tree in the upper part of the afromontane forest belt in Ethiopia, with altitudinal ranges of 2450–3250 m asl (Hedberg 1989). Thus, its absence in the Kuandisha Forest could be primarily attributed to the habitat being unsuitable because the highest point in this forest is 2365 m asl. On the other hand, *O. europaea* subsp.

cuspidata is found in *Juniperus–Podocarpus* forests at altitudes between 1700 and 2700 m asl elsewhere in Ethiopia (Green 2003). Despite the habitat suitability of the study area for *O. europaea* ssp. *cuspidata*, the species could have been completely eradicated for firewood and construction purposes. According to Bekele (2005), seedlings of *O. europaea* subsp. *cuspidata* are sensitive to disturbance and require shade for successful establishment and growth. On the other hand, regardless of the wide distributional range of *J. procera* elsewhere in Ethiopia at altitudes 1500–3000 m asl (Friis 2009), the species is naturally absent in the Kuandisha forest. Seed predation has been noted to play its own role in reducing the seedling population of woody species such as *J. procera* in the dry evergreen afromontane forests of Ethiopia (Teketay 2005b).

Species prioritization

Species with lower IVI value were prioritized for conservation. Generally, 14 tree, seven shrub and one liana species received top priority status for conservation and management interventions. The tree species are *Allophyllus abyssinicus*, *Dovyalis abyssinica*, *Dombeya torrida*, *Dracaena steudneri*, *Ekebergia capensis*, *Erythrococca trichogyne*, *Vepris dainelii*, *Millettia ferruginea*, *Rhus glutinosa* subsp. *glutinosa*, *Schefflera abyssinica*, *Lepidotrichilia volkensii*, *Ehretia cymosa*, *Schrebera alata* and *Steganotaenia araliacea*. The shrub species include *Buddleja polystachya*, *Dombeya quinqueseta*, *Hypericum revolutum*, *Osyris quadripartita*, *Rhamnus prinoides*, *Rubus steudneri* and *Vernonia amygdalina*. *Phytolacca dodecandra* was the only liana species placed in the top priority for conservation and further management interventions.

Conclusion and recommendations

The study revealed that the Kuandisha forest is mainly a dry evergreen afromontane forest and grassland complex vegetation. The forest is mainly secondary forest/scrub. It is also one of the richest forests in species composition. For instance, the number of species and communities is comparable to other high forests elsewhere in Ethiopia. Moreover, the forest harbors a number of endemic species.

However, the disturbance level from grazing and selective logging is still very high and is the main threat for many woody species. As a result, a significant number of woody species were either not regenerating or were selectively removed for various purposes. For example, the total basal area of woody species was lower, and the proportion of individuals with DBH greater than 10 cm to DBH greater than 20 cm was very high compared with similar forests in Ethiopia. Some species such as *J. procera*

and *O. europaea* subsp. *cuspidata*, which are characteristic species in the DAF in Ethiopia, are naturally absent in the Kuandisha forest.

Thus, we recommend conservation and management actions for the priority species and the entire forest. We suggest that farming and free grazing inside the forest be abandoned. Moreover, bare areas in the forest should be planted with prioritized species. The cut and carry system of grass from grazing areas can be another viable option to reduce the pressure from the forest. An investigation on soil seed banks should receive paramount priority so that additional realistic management interventions can be proposed.

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