J. For. Res.
DOI 10.1007/s11676-017-0466-8

ORIGINAL PAPER

Genecological zones and selection criteria for natural forest populations for conservation: the case of *Boswellia papyrifera* in Ethiopia

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Received: 8 February 2016 / Accepted: 11 June 2016

Abstract Rapid changes in land-use in the *Combretum–Terminalia* woodlands of northwestern Ethiopia are mainly due to the increases in commercial farming and immigration. We used integrated ecological and social data collection techniques, including subdivision of the vegetation zone, vegetation survey, focus group discussions and key informant interviews, to identify genecological zones and set criteria for selection of viable populations of *Boswellia papyrifera* (Del.) Hochst in Ethiopia for conservation. Interviews of senior experts were supported with a rating method and involved 43 respondents and focused on identifying and weighting criteria and indicators of selection in a participatory way to prioritize populations for conservation. Using mean annual rainfall data, we reclassified the *Combretum–Terminalia* woodland vegetation region into three moisture zones (wet, moist and dry), and designated them as genecological zones for *B. papyrifera* conservation. A total of 35 woody species were identified at Lemlem Terara site in Metema district, and the Shannon diversity index and evenness were 2.01 and of 0.62, respectively. There were 405 adult trees, and 10 saplings and 3314 seedlings per ha. The trees were medium-sized with overall mean diameter at breast height (dbh) of 16.9 (±9.5) cm. Seedling recruitment was poor due to grazing, crop production and fire incidences. Through a multi-criteria decision analysis, five criteria and 20 quantitative indicators were identified and weighted to prioritize populations for conservation. These criteria in their descending order of importance are (1) forest ecosystem health and vitality, (2) forest cover and population structure of *B. papyrifera*, (3) productive function of the forest, (4) biological diversity in the forest, and (5) socioeconomic benefits of the forest to communities. Multivariate tests in the general linear model revealed significant differences among researchers and non-researchers in rating the criteria and indicators, but not among foresters and nonforesters. Hence, participatory multi-criteria decision analysis should involve people from various institutions to rectify decisions on conservation of the species. Careful evaluation of the investment policy environment and engaging those government bodies that are responsible to allocate the dry forests for commercial farming is recommended before the proposed criteria are applied to select populations for conservation, thus ensuring subsequent use of the outcomes of such exercises and better reconciling conservation and agricultural production increment goals.

Keywords Agricultural expansion · *Combretum–Terminalia* · Indicators · Multi-criteria decision analysis method (MCDA) · Settlement

Introduction

Forest genetic resources are important to humans and to life on Earth in general, but they are under continuous threat due to forest cover reduction and degradation,

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Project funding: This work was financed by CIFOR through its Community Forestry Project in Ethiopia funded by the Austrian Development Agency (Project No. 2008/03).

The online version is available at http://www.springerlink.com

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competition for other land-uses, climate change, ecosystem modification, overharvesting and spread of invasive species (FAO 2014). Efforts to conserve forest genetic resources have so far involved identifying the level of threat by preparing the Red List for species (IUCN 2012), understanding species genetic diversity and structure (Derero et al. 2011; Ayele et al. 2011; Addisalem et al. 2016), and introducing tools to monitor trends in genetic diversity (Graudal et al. 2014). Furthermore, priority-setting exercises based on criteria and indicators, designing systematic approaches such as genecological zoning (Graudal et al. 1997), and establishing protected area network and other conservation mechanisms have been developed.

As a broader strategy, introducing a system of genecological zoning, which considers natural vegetation, edaphic conditions, climate, elevation and barriers to gene flow, is helpful for managing genetic resources systematically (Graudal et al. 1997; St Clair et al. 2005). Then forest populations can be prioritized for conservation in each zone through the use of useful criteria (Rotach 2005; FAO 2000).

In Ethiopia, genecological knowledge remains limited even though there was an attempt to designate tree seed zones to guide tree seed collection and distribution (Aalbæk 1993). In addition, population selection through objectively measurable criteria and indicators has also been lacking.

The target species, *Boswellia papyrifera*, is a small deciduous tree that belongs to the family Burseraceae. In Ethiopia, the species is mainly found at altitudes from 950 to 1800 m a.s.l. in *Combretum–Terminalia* woodlands and wooded grasslands, one of the major natural vegetation types in Ethiopia mainly occurring along the western escarpments of the Ethiopian highlands (Friis et al. 2010). The species thrives best in warm, moist lowlands compared with moist or dry highlands (Ogbazghi et al. 2006). Although little has been known about its reproductive biology and genetic structure, a recent analysis of the genetic structure of the species employing microsatellite markers identified geographic structuring of the genetic variation of the species in Ethiopia (Addisalem et al. 2016).

The species is an important source of oleo-gum resin, called frankincense or olibanum, which in the Horn of Africa has numerous traditional, ceremonial and medicinal uses (Lemenih and Teketay 2003). Five-year data (2009–2013) from the Ethiopian Revenues and Customs Authority shows that the annual foreign exchange revenues generated from the export of gums and resins was 11.82 million (±1.24) USD. However, this revenue is very low compared with other commercial crops during the same period, such as sesame (368.57 ± 66.5 million USD/year). In addition, the net revenue from sesame production is higher when compared with the forest land-use that includes commercial nontimber forest products (Dejene et al. 2013).

The *B. papyrifera* dominated forest and woodlands of Ethiopia are under severe threat owing to the agricultural expansion, uncontrolled livestock grazing and recurrent droughts (Lemenih et al. 2014). The problem is exacerbated by high seedling mortality, poor recruitment (Negussie et al. 2008) and high adult mortality (Groenendijk et al. 2012). If the current trend continues unchecked, the country will lose the key environmental role played by the forest in protecting against desertification, conserving biodiversity and provisioning other products and services.

Amidst developments in the area, regional authorities have called for help in identifying forest areas that should be given priority for conservation. Thus, decision makers at various levels need specific information on which forest areas should be given priority for conservation while also maintaining the expansion of commercial agriculture for export. Then the questions are, what approach and methodology should be used to select viable populations for conservation, and what information on genetic structure on adaptive traits is lacking. Therefore, the present study was conducted to quickly collect information about the forest structure in one of the forests in the extensive *Combretum–Terminalia* woodland and reclassify the woodland into subunits with the main objective of selecting natural populations for conservation. By also engaging key stakeholders through a multi-criteria methodology, we aimed to incorporate their knowledge and concerns in the development of tools for guiding decisions based on scientific evidence.

Materials and methods

Designation of genecological zones

We hypothesized that species genetic variation correlates with environmental gradient, and since there is a marked rainfall gradient within the *Combretum–Terminalia* vegetation zone, reclassification of the vegetation into moisture zones would be a sound approach to identify genecological zones. Thus, map of the *Combretum–Terminalia* woodlands and wooded grasslands was obtained in a shapefile format from the project "Vegetation and climate change in eastern Africa (VECEA)", and annual rainfall surface data were obtained from World Clim (www.worldclim.org, version 1). Then the annual rainfall data were clipped using *Combretum–Terminalia* boundary, and the rainfall values were reclassified into three moisture zones (above 1400, 900–1400 mm, and below 900 mm). Finally, the moisture zones were designated as genecological zones.

Vegetation survey

Site description

Vegetation was surveyed in a selected forest area at Lemlem Terara in MetemaWoreda of North Gondar Zone in Amhara Regional State, northwestern Ethiopia (12°38.42′–12°41.46′N, 36°15.94′–36°20.42′E) from 769 to 889 m a.s.l. The mean annual rainfall at Metema is 924.2 mm, and the mean annual temperature is 32.98 °C (Wale et al. 2012).

Sampling design and data collection

Information on vegetation was a basic input to identify realistic criteria and indicators for conservation. *B. papyrifera*, like many other species, is not uniformly distributed in the forest at Lemlem Terara. Hence, we targeted segments of the forest dominated by *B. papyrifera* and laid a total of 15 circular plots (each with a 15-m radius) on three 2-km-long transects. The consecutive plots were 500 m apart. In each plot, geographical location, altitude, tapping history, health and disturbance condition, dbh and height of all woody species were recorded. In each plot, two cohorts were identified, i.e., trees ($\text{dbh} \geq 2$ cm) and saplings ($\text{dbh} < 2$ cm, $\text{height} \geq 1$ m). Seedlings (individuals with $\text{height} < 1$ m) were counted in circular subplots with 7.5-cm radius.

In addition, three quadrats, each 50 m × 20 m, were laid along a randomly selected transect (with a bearing of 90°). The distance between two quadrats was 1 km. However, the second quadrat, where nomads kept their cattle, was heavily disturbed, and had only four adult trees. Since this disturbance does not reflect natural conditions, the quadrat was avoided for data collection and analysis. Data as similar to the types collected in the circular plots were collected in the two quadrats. Here seedlings were counted in subplots of 5 m × 5 m.

Identifying and weighting criteria and indicators

A multi-criteria decision analysis method (MCDA), a widely applied model in forest management (Mendoza and Martins 2006), with three steps was followed to identify and weight criteria and indicators to select viable populations for conservation.

Step 1 Identify criteria and indicators, based on globally agreed and widely employed criteria and indicators for sustainable forest management, to use in selecting a forest for conservation among several candidates (Castañeda 2000; FOREST EUROPE et al. 2011).

Step 2 Conduct a focus group discussion involving six research scientists and a gum and resin production expert to deliberate on the set of multiple criteria and indicators to fine-tune the list of criteria and indicators (C&I).

Step 3 Of the three multi-criteria decision-making (MCDM) methodologies described by Mendoza and Prabhu (2000), the "rating method" was used for C&I assessment. The rating method directly assigns weights explicitly to each decision element by distributing 100 points, which is the sum of all the weights. The relative weight,w_{ji}, for indicator i under criterion j, was computed following the method of Mendoza and Prabhu (2000),

$$0 \leq w_{ji} \leq 100 \text{ and } \sum w_{ji} = 100 \text{ for all } i. \tag{1}$$

The rating involved 43 respondents: professionally 28 were foresters and the remaining 15 were nonforesters, and in terms of responsibility, 22 were researchers and the remaining 21 were nonresearchers. Respondents were allowed to add a criterion and/or an indicator under each criterion whenever they believed that there was a need to do so. Those C&I seconded by at least five respondents were considered for inclusion. Corrections were made whenever weights did not add to 100 by adding equal points to each entry. The ratings by the 43 experts of the single qualitative criterion, the five quantitative criteria and 20 indicators were grouped into two (1) along the line of profession (from foresters and nonforesters) and (2) along the line of responsibility (from researchers and nonresearchers). The data on the ratings of criteria and indicators were then analyzed using descriptive statistics and a multivariate test in a generalized linear model. During the multivariate test, both profession and responsibility were considered as fixed effects. The results from this analysis were presented as multivariate tests by responsibility and profession and also as tests of between-subjects effects on each criterion and indicator.

Results and discussion

Genecological zones

We mapped three moisture zones within the *Combretum–Terminalia* woodland and designated them as genecological zones, which are referred to as (1) Dry *Combretum–Terminalia* Woodland Zone, (2) Moist *Combretum–Terminalia* Woodland Zone and (3) Wet *Combretum–Terminalia* Woodland Zone (Fig. 1). The altitude in the dry zone varied the most, from 380 to 2410 m (mean = 1110 ± 418 m). The altitude in the moist area ranged from 410 to 2270 m (mean = 1080 ± 403 m); the wet zone varied from 750 to 2100 m (mean = 1450 ± 248 m).

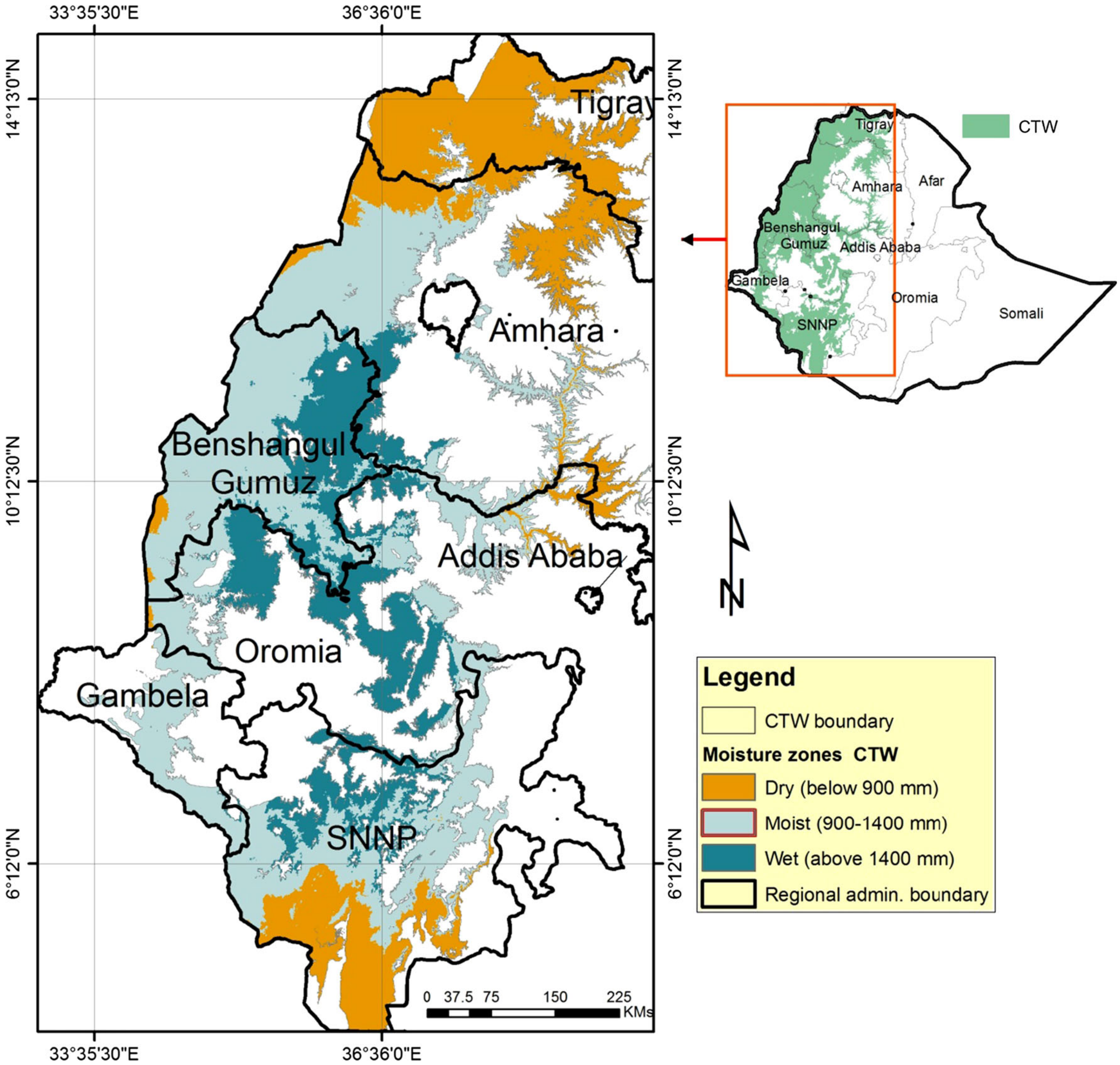

Fig. 1 Moisture zones in the *Combretum–Terminalia* woodlands and wooded grasslands (CTW) in Ethiopia

The zones can serve as sampling frames for provenance research and identifying and selecting viable natural populations of *Boswellia papyrifera* and other species for conservation. One of the environmental variables with high correlations with adaptive traits elsewhere is rainfall, and according to Wright (1976), trees from moister regions grow faster, have smaller seeds, are less deeply rooted and have greener foliage. The zonation approach based on environmental gradients such as in rainfall and elevation will be very instrumental in light of the absence of mapped genetic variation of adaptive traits (St Clair et al. 2005), and adaptive variation is generally manifested by the relationship between measured traits and environmental gradients (White et al. 2007). Because techniques based on DNA and isozymes developed to understand species genetic structure are insufficient for providing information regarding adaptive traits (König 2005), we need to work with a zonation system based on environmental differences.

Vegetation status at Lemlem Terara

Species diversity and population structure

The total area of the sampled plots was 1.26 ha, and mean altitude was 847 ± 36 m (769–889 m). Most of the plots had moderate slope (5–20%), 29% of the plots were flat (0–3%), and the remaining 21% were steep (30–48%). There were 405 trees per ha and 35 woody species in the forest: 30 species were recorded within the 1.26 ha sampled plots (Fig. 2); five tree species (*Adansonia digitata*, *Combretum collinum*, *Ficus thoningi*, *Lonchocarpus laxiflorus* and *Ziziphus spina-christi*) were found outside the sample plots. The Shannon diversity index was 2.01, and

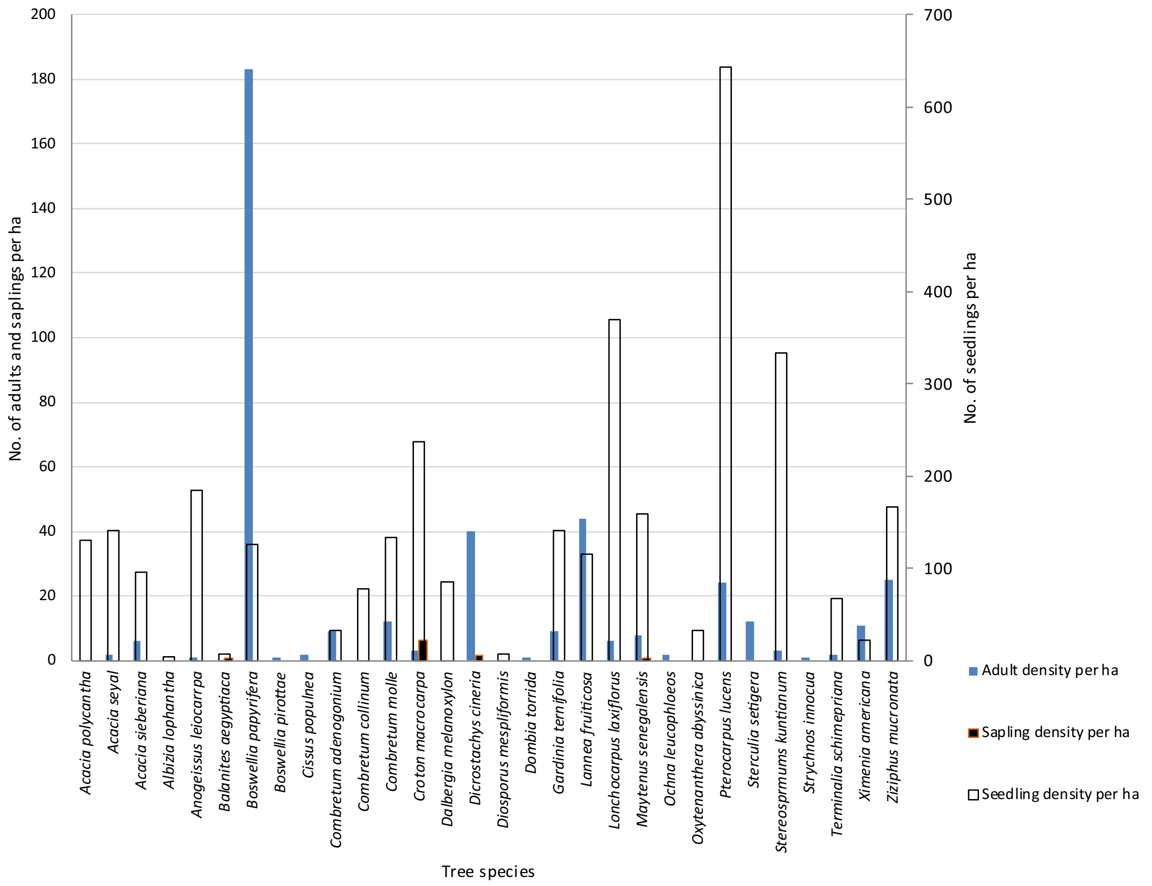

Fig. 2 Adult, sapling and seedling populations of woody species at Lemlem Terara, North Gonder Zone, Amhara Regional State

the evenness value was 0.62, indicating a moderate level of diversity. Another survey in the same area identified 87 vascular plants, of which 40 were woody species (Wale et al. 2012). In the *Combretum–Terminalia* woodland and wooded grassland, 199 species, subspecies and varieties of woody species were reported previously, of which 81 are specific to this vegetation type and do not occur in the remaining vegetation types of the country (Friis et al. 2010).

The overall mean dbh of the species was 16.9 ± 9.5 cm, ranging from 2.5 cm for *Combretum adenogonium* to 63.5 cm for *Sterculia setigera*. The majority (58.5%) of the trees measured had a mean dbh of 10–25 cm, 25.1% had dbh less than 10 cm and the remaining 16.4% had dbh above 25 cm.

Specifically, the measured dbh of *Boswellia papyrifera* ranged from 8 to 49.5 cm. The majority of individuals (75.5%) were medium-sized (10–25 cm), 22.7% were larger trees (>25 cm), and only a few (1.9%) represented small trees (<10 cm). In addition, the *B. papyrifera* inventory data obtained from MetemaWoreda Office of Agriculture from 723 1-ha sample plots indicated that 87% of the individuals had a dbh of 10–30 cm, and only 8.7 and 4.3% had dbh less than 10 and above 30 cm, respectively. Studies at some populations of the species in Eritrea, Sudan and elsewhere in Ethiopia indicated that medium-sized trees dominate the populations, and small trees (dbh < 8 cm) were generally not found (Ogbazghi et al. 2006; Negussie et al. 2008; Lemenih et al. 2007).

Forest disturbance

In almost all the plots (93%), grazing and expansion for crop production happened to be one of the major anthropogenic threats for regeneration and healthy species population structure, and only one plot was not affected by either farming or grazing damages. Major forest land-use changes were mainly caused by the expansion of sesame and sorghum farms. The other major cause of forest disturbance and large-scale degradation was forest fire; 53% of the plots had at least one fire during the 1–3 years before the survey. The possible reasons for forest fires include farmland expansion, harvesting honey, aim to initiate grass growth and reduce livestock parasites such as ticks, ground preparation for first tapping of *Boswellia* trees by gum collectors, and facilitating free movement of people and livestock by chasing snakes and wild animals (Eshete et al. 2005).

Table 1 List of criteria and their relative mean weight, as rated by 43 experts and listed in decreasing order of rank

Criteria coder	Criteria name	Rating
C1	Forest ecosystem health and vitality	22.6
C2	Forest cover and population structure of *B. papyrifera*	22.4
C3	Productive function of the forest	19.0
C4	Biological diversity in the forest	18.5
C5	Socio-economic benefits	17.5

Table 2 List of indicators, their respective descriptions and mean relative weights under each criterion, as rated by 43 experts and listed in deceasing order of rank

Criteria code	Indicator	Description	Rating
C1	Forest damage by fire	Damages due to fire vary with frequency and intensity among various forest populations	37.3
	Forest damage by biotic agents	The degree of damages due to livestock grazing and browsing, fungi, insect and parasitic plants attack, improper tapping and harvesting vary among forest populations	37.1
	Defoliation (insect attacks, diseases)	Different population exhibit varying levels of defoliation due to insect attacks and diseases, and this may relate with inherent resistance. Population with less level of defoliation of the target species deserves high scores	25.7
C2	Forest area (ha)	Larger population size is important for capturing rare alleles whereas very small populations are threatened by genetic drift, founder effects and inbreeding	24.3
	Number of *B. papyrifera* trees/ha	Forests have natural variation in stocking and these variations reflect different levels of degradation; hence data on density complements the data on forest size	23.9
	Diameter distribution of adult *B. papyrifera* (dbh above 2 cm)	Tree species in different places may exhibit different population structures; uniform to inverted J-shape diameter distribution is desirable	18.5
	Growing stock of *B. papyrifera* (m^3)	Forests with high total volume of trees indicate high productivity of wood and non-wood products; this phenotypic superiority however needs to be checked in common garden experiment to relate it with genetic quality	17.1
	Sapling density	The cause for small sapling (individuals with dbh below 2 cm and with height above 0.5 m) population size can largely be anthropogenic, but it determines the succession of the forest	16.2
C3	Frankincense yield (potential)	Forests with high proportion of big trees and with high average productivity level can give high frankincense yield	83.8
	Other forest products	The *Boswellia* forests may have other important forest products that may be produced at large scale	10.7
	Frankincense yield quality	Forests may vary in their frankincense quality	5.5
C4	Level of genetic variation	Population with high level of genetic variation/heterozygosity of *B. papyrifera* has high conservation value	26.5
	Habitat diversity	Populations vary in their habitat diversity (e.g. riverine areas). Populations with high habitat diversity should get higher scores	25.4
	Tree species composition/diversity	The target speciesin some forest populationscoexists with over 35 other woody species	24.9
	No of threatened species	The distribution of some tree species is highly localized. Populations with high number of threatened species in them deserve high scores	23.2
C5	Wood consumption	Community benefits in terms of collection of construction wood and farm implements vary from forest to forest	38.4
	Food and feed	Community benefits in terms of collection of food and fodder species vary from forest to forest	31.7
	Medicinal plants	Community benefits in terms of collection of medicinal plants vary from forest to forest	21.7
	Gums and resins	Community benefits in terms of collection of gum and resin vary from forest to forest	4.8
	Other benefits	The benefits include job opportunity, option value, cultural value, bee forage and beverage making	3.4

Other disturbances recorded were small-scale; among 29 small-scale disturbances, 52% were tree falls due to cuts and the other 48% were mainly windfalls (two cases were falls assisted by insect attack and one tree was over-topped). While such small-scale disturbances, or canopy gaps, in closed high forests may favor the growth of some tree species (Tesfaye et al. 2010), their effect on regeneration cannot be overemphasized in *Combretum–Terminalia* woodlands, which are open forests.

Regeneration and recruitment

Of the very few saplings (10 ind.·ha^{-1}) in the forest, 75% belonged to a *Croton* species, and the rest were *Balanites aegyptiaca*, *Dichrostachys cinerea* and *Maytenus* sp. In addition, there were 3314 seedlings/ha belonging to 24 different woody species, and *B. papyrifera* ranked 12th in seedling density. *Pterocarpus lucens*, *Lonchocarpus laxiflorus* and *Stereospermums cuntianum* were the three most-abundant seedlings in the forest floor (Fig. 2). Though some studies reported evidence that tapping of *B. papyrifera* trees for frankincense production reduces fruit and seed production significantly (Rijkers et al. 2006; Eshete et al. 2012), our data did not reveal any regeneration problem for the species, which might be due to the stand having been at a resting stage for consecutive years and thus helped the trees to recuperate. Our data showed that there was no apparent natural regeneration problem in general, but recruitment of seedlings to sapling and tree cohorts was seriously hampered by disturbances from grazing and fire. Similarly, a study on several forest populations in northern Ethiopia indicated that seedlings of *B. papyrifera* were abundant on forest floors, but saplings failed to recruit owing to damage from fire and grazing (Negussie et al. 2008; Groenendijk et al. 2012). In stark contrast, a high density of seedlings and saplings of *B. papyrifera*in less-disturbed forests was reported recently (Addisalem et al. 2016).

Population selection criteria

Five rating criteria were listed by the 43 experts for selection of viable populations of *B. papyrifera* (Table 1). They were adapted from the list of the globally agreed and widely used criteria for sustainable forest management

Table 3 Analysis of C&I relative weights given by the respondents, n = 43

C&I*		Code of C&I	Min.	Max.	Range	Mean	SD
Criteria	Health	C1	5	50	45	22.6	1.85
	Forest cover	C2	8	52	44	22.4	1.43
	Productive	C3	7	50	43	19.0	1.27
	Biological	C4	5	33	28	18.5	1.11
	Socioeconomic	C5	5	50	45	17.5	1.34
Indicators	Fire	C1I1	0	80	80	37.3	2.88
	Biotic	C1I2	10	70	60	37.1	2.23
	Defoliation	C1I3	10	60	50	25.7	1.84
	Forest area	C2I1	5	50	45	24.3	1.57
	Boswellia trees	C2I2	10	40	30	23.9	1.10
	Diameter	C2I3	8	36	28	18.5	1.11
	Growing stock	C2I4	0	40	40	17.1	1.22
	Sapling	C2I5	0	40	40	16.2	1.42
	Yield	C3I1	20	100	80	83.8	3.64
	Other products	C3I2	0	80	80	10.7	3.23
	Quality	C3I3	0	55	55	5.5	2.37
	Genetic variation	C4I1	5	50	45	26.5	1.75
	Habitat	C4I2	10	45	35	25.4	1.48
	Composition	C4I3	0	75	75	24.9	1.93
	Threatened	C4I4	10	40	30	23.2	1.13
	Wood	C5I1	0	70	70	38.4	2.38
	Feed	C5I2	0	60	60	31.7	1.79
	Medicinal	C5I3	0	60	60	21.7	1.74
	Gums and resins	C5I4	0	100	100	4.8	2.57
	Other benefits	C5I5	0	40	40	3.4	1.39

* Full C&I names are given in Table 1 and 2

Table 4 Multivariate tests on ratings of 5 criteria and 20 indicators by 43 respondents

Effect	Criteria				Indicators			
	F	Hypothesis df	Error df	Sig.	F	Hypothesis df	Error df	Sig.
Responsibility	3.679[a]	4	36	0.013	4.784[a]	18	22	0.000
Profession	0.326[a]	4	36	0.859	1.126[a]	18	22	0.391
Responsibility × Profession	2.409[a]	4	36	0.067	0.491[a]	18	22	0.935

[a] Exact statistic

Table 5 Tests of between-subjects effects on the ratings of the criteria and indicators

C&I		Code of C&I	Sources of variation					
			Between researchers and non-researchers			Between foresters and non-foresters		
			Mean Square	F	*P* value	Mean square	F	P-value
Criteria	Health	C1	1562.0	14.16	0.001	10.2	0.09	0.763
	Forest cover	C2	329.6	4.02	0.052	20.0	0.24	0.624
	Productive	C3	31.8	0.45	0.508	0.0	0.00	0.994
	Biological	C4	93.3	1.83	0.184	49.5	0.97	0.330
	Socioeconomic	C5	301.0	4.06	0.051	0.5	0.01	0.937
Indicator	Fire	C1I1	8366.0	52.68	0.000	493.7	3.11	0.086
	Biotic	C1I2	3337.7	23.79	0.000	249.3	1.78	0.190
	Defoliation	C1I3	1126.2	9.06	0.005	43.1	0.35	0.559
	Forest area	C2I1	6.1	0.06	0.810	94.6	0.90	0.349
	Boswellia trees	C2I2	36.9	0.67	0.417	8.1	0.15	0.703
	Diameter	C2I3	151.0	3.27	0.078	11.0	0.24	0.628
	Growing stock	C2I4	234.9	3.83	0.057	68.9	1.13	0.295
	Sapling	C2I5	44.0	0.48	0.494	0.9	0.01	0.922
	Yield	C3I1	60.9	0.11	0.743	2088.2	3.74	0.060
	Other products	C3I2	52.5	0.11	0.739	380.4	0.82	0.372
	Quality	C3I3	226.4	1.00	0.323	686.0	3.04	0.089
	Genetic variation	C4I1	393.1	3.11	0.086	33.7	0.27	0.609
	Habitat	C4I2	662.0	8.69	0.005	355.4	4.66	0.037
	Composition	C4I3	2.7	0.02	0.900	182.9	1.10	0.301
	Threatened	C4I4	18.6	0.32	0.573	0.3	0.00	0.946
	Wood	C5I1	41.7	0.20	0.653	1605.0	7.88	0.008
	Feed	C5I2	25.7	0.18	0.678	1.8	0.01	0.913
	Medicinal	C5I3	42.8	0.32	0.577	46.7	0.34	0.561
	Gums and resins	C5I4	272.1	1.00	0.323	537.4	1.98	0.168
	Other benefits	C5I5	2.1	0.02	0.875	131.8	1.57	0.218

(Castañeda 2000; FOREST EUROPE et al. 2011). The list of criteria and indicators with their relative weights are presented in Tables 1 and 2, respectively.

Ratings of criteria and indicators

The individuals engaged in rating varied greatly in their judgments of the C&I as depicted in Table 3. The lowest variability and hence the highest level of consistency among individual judgments was recorded for the criterion "Biological diversity" and for the indicators "Number of *B. papyrifera* trees/ha", "Diameter distribution of adult *B. papyrifera*" and "number of threatened species". The highest variability among the respondents was recorded for "Forest ecosystem health and vitality" from the list of the criteria and for "Frankincense yield" from the group of indicators.

Multivariate tests on the five criteria revealed statistically significant differences among the researchers and the nonresearchers ($p < 0.05$) but not between foresters and nonforesters (Table 4). The tests of between-subjects effects showed that, among the criteria compared, only the criterion "Health and vitality", differed significantly different ($p < 0.05$) between the researchers and non-researchers (Table 5). Similarly, the multivariate test on the twenty indicators revealed statistically significant differences among the researchers and the nonresearchers ($p < 0.05$), but not between foresters and nonforesters (Table 4). The tests of between-subjects effects showed that, of the indicators compared, habitat diversity, defoliation, forest damage by biotic agents and forest damage by fire differed significantly among researchers and nonresearchers ($p < 0.05$), but not between foresters and nonforesters (Table 5). Foresters and nonforesters were thus consistent because there was no significant difference between the two groups in the multivariate tests. The results also indicate that involving researchers and no-researchers in MCDA can provide a more balanced view with respect to selecting populations for conservation because the two groups differed significantly in the multivariate tests.

Policy framework and implementation

The overwhelming majority of the respondents (98%) agreed that the surrounding land-use is the single most important factor to consider, as commercial farms and human settlement are expanding in the woodlands in recent years. This result implies that identifying conservation sites in areas designated for large-scale agricultural development would not be practical for *B. papyrifera* conservation. The lack of policy implementation tools and poor law enforcement were highlighted by 10 of the respondents as one of the underlying causes for the worsening forest conditions and lack of habitat protection in the area. Sidelining proper implementation of forest policy and law, wildlife policy and law, the environmental impact assessment and other relevant legal frameworks in favor of agricultural expansion especially undermines efforts toward sustainable resource management. In addition, the distribution of the gum and resin resources to communities without considering production capacity and lack of clear forest area demarcation are resulting in conflicts among user groups. Further, the following factors were also identified by respondents as important policy issues that need to be addressed: lack of proper institution for overseeing policy implementation, unclear property rights, low benefit to primary producers in the value chain, uncontrolled grazing systems, and limited experience in designating areas for conservation in the dry lowland areas.

Conclusion and recommendations

The categorization of the region into three genecological zones is a sensible approach for delineating conservation zones for all the tree species in the extensive *Combretum–Terminalia* woodland. Hence, conservation efforts for *B. papyrifera*and any other species in this dry forest can benefit from the current classification. And the analysis of the forest patch at Metema was instrumental in establishing candidate conservation criteria and indicators by determining the species composition, diversity and the forest structure and dynamics. Thus, population selection indices can be computed by giving priority to those high-rated indicators under the six criteria, namely health and vitality, cover and population structure, productive function, biological diversity, and socioeconomic benefits. The criteria and indicators can be applicable to more species with some modifications to context. The level of consistency of different groups in judging different C&I indicates that participatory MCDA is a powerful tool for sound decision-making by involving relevant professionals from various institutions at various capacities irrespective of professional differences because we did not observe professional biases in judgments.

We propose that the selected and weighed C&I be used to select populations within a given genecological zone by producing population selection indices based on biophysical and socioeconomic data for each forest. It will be prudent to evaluate carefully the policy environment especially with respect to land-use plans and related development programs of the government in this regard. Hence, we recommend that land-use and concerns related to development policy be discussed and addressed at a higher level which in most cases appears to be an absolute prerequisite before any exercise to select populations. Once decisions on site selections have been made, conservation of *B. papyrifera* populations should incorporate conservation principles into sustainably managing forests, establishing a network of conservation stands in the various genecological zones and promoting parkland agroforestry in areas where forest areas are being converted to agricultural fields.

Acknowledgements All scientists and experts who participated in the focus group discussion and in the refinement and weighing of the criteria and indicators are appreciated. This work was financed by CIFOR through its Community Forestry Project in Ethiopia funded by the Austrian Development Agency (Project No. 2008/03). The authors are thankful to the People and Government of Austria. They are also grateful to the Central Ethiopia Environment and Forestry Research Center, which supported the study by covering the staff time of the lead author.

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