Heliyon 6 (2020) e05139

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Population status of *Boswellia papyrifera* woodland and prioritizing its conservation interventions using multi-criteria decision model in northern Ethiopia

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ARTICLE INFO

Keywords:
AHP model
Area exclosure
Conservation alternatives
Frankincense tree
Free grazing
Regeneration
Stakeholders
Over tapping
Agricultural science
Agronomy
Environmental science
Ecology

ABSTRACT

Boswellia papyrifera woodland provides considerable economic, ecological and socio-cultural benefits in the drylands of Ethiopia. However, its populations are in rapid decline due to human pressure and environmental degradation. As a consequence, the species is now considered being endangered, demanding an urgent conservation intervention to sustain its existence. This study was carried out in the Abergele district, northern Ethiopia, with objectives to characterize the current population structure of *B. papyrifera* and prioritize its potential conservation intervention alternatives using Analytical Hierarchy Process (AHP) modelling techniques. The woody species related data were collected from 33 sample plots randomly established in the study area. Data related to the potential intervention alternatives and their evaluating criteria were collected from experts, personal experiences and intensive literature reviews, and then validated using stakeholders' focus group discussion. Four candidate alternatives were then considered for the AHP: 1) free grazing with no tapping resting period (FGNTR), 2) free grazing with a rotational tapping (FGRT), 3) area exclosure with medium tapping resting period (AEMTR), and 4) area exclosure with long tapping resting period (AELTR). The results showed that the population structure of *B. papyrifera* is unstable and is characterized by low density (266 trees ha^{-1}), absence of regeneration and saplings (DBH<10 cm) due to different interrelated disturbances such as overgrazing, over tapping, pests, agricultural expansion and poor managements. The overall priority ranking value of all stakeholders using the AHP techniques also indicated that AEMTR (with overall rank value of 0.352) and AELTR (0.294) as the best alternatives strategies, respectively, for sustainable *B. papyrifera* woodland conservation. For the success of these strategies, their economic impacts at their early implementation stages (5–10 years) should be minimized by collecting different non-timber forest products from the woodland. Continuous capacity building training on sustainable utilizations and managements of *B. papyrifera* woodland should also be provided for all relevant stakeholders.

1. Introduction

In the dryland area of Sub-Saharan Africa, the genera *Boswellia, Commiphora* and *Acacia,* that comprise several indigenous woody species are known to yield economically valuable products of oleo-gum resins such as frankincense, myrrh, gum arabic and opopanax (Tadesse et al., 2007; Alemu et al., 2012; Yogi et al., 2017). The oleo-gum resins have diverse uses, mainly in food, pharmaceuticals, perfumery, adhesives, ink and dye industries (Lemenih and Kassa, 2011; Yogi et al., 2017). Oleo-gum resins are globally traded products that support the national

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https://doi.org/10.1016/j.heliyon.2020.e05139
Received 23 December 2019; Received in revised form 14 July 2020; Accepted 29 September 2020

economy of many Sub-Saharan African countries, including Ethiopia, Sudan and Eritrea (Ogbazghi et al., 2006; Lemenih and Kassa, 2011; Khamis et al., 2016). In 2014, their global trade was worth US$500 million (Yogi et al., 2017).

The genus *Boswellia* includes 20 tree species, of which only 5 produce oleo-gum resins of commercial value. The species *Boswellia papyrifera* (Del.) Hochst is one of them and it is known to produce an internationally tradable aromatic resin called frankincense (Gebrehiwot et al., 2003). *B. papyrifera* is a deciduous tree, reaching a height of 16 m with a rounded pole, thick branches and compound leaves that comprise sweet-scented flowers to attract honeybees for pollination. Its fruit is a drupe, about 2 cm long and usually contains three tapered seeds (Gebrehiwot et al., 2003). The seeds do not accumulate in the soil for a long period and germinate immediately after dispersal due to lack of dormancy. This implies that its major route of regeneration is through "seed rain" (Eshete et al., 2005). In Ethiopia, it is a native multipurpose tree that covers over 1.5 million ha and is mainly found on degraded drylands within an attitudinal range of 950–1800 m.a.s.l with average temperature of between 20-27 °C and annual rainfall less than 900 mm (Eshete et al., 2005; Tadesse et al., 2007).

In Ethiopia, *B. papyrifera* woodland provides several economic and ecological benefits (Gebrehiwot et al., 2003; Tilahun et al., 2011). For example, in 2014, Ethiopia exported about 7,900 tonnes of frankincense with a value of US$8.8 million. This makes the country one of the major frankincense suppliers to the world market (Tadesse et al., 2020). Frankincense collection and its associated trade activities also support the livelihoods of many residents in dryland areas where livelihood options are limited due to harsh environmental conditions (Mekonnen et al., 2013). Furthermore, the species is valuable for animal fodder, fences, medicines, apiculture, soil and water conservation, carbon sequestration and adaptation to climate change impacts (Abiyu et al., 2010; Tilahun et al., 2011; Mekonnen et al., 2013).

Despite the wide benefits of the species in Ethiopia, its populations are declining at an alarming rate mainly due to overgrazing, over tapping for frankincense production, poor policy and other interrelated factors (Gebrehiwot et al., 2003; Negussie et al., 2008; Abiyu et al., 2010; Derero et al., 2018). As a consequence, it has been included by TRAFFIC (the Wildlife Trade Monitoring Network) in the list of endangered species of Eastern Africa that need immediate conservation interventions (Marshall, 1998). It has also recently been suggested to be considered for a vulnerable category in the IUCN Red List, based on the criteria that >30% populations reduction over the past three generations (Bongers et al., 2019). Besides, the species is being attacked by different pests and diseases: the *Idactus spinipennis Gahan* insect, the *Lasiodiplodia* fungal disease and *Tapinanthus globiferus* parasitic plant (Yirgu et al., 2014; Gezahgne et al., 2017; Negussie et al., 2018).

In addition, *B. papyrifera* woodland is found in areas where there is no clear land ownership systems for implementing conservation strategies and involving the participation of relevant stakeholders (Abiyu et al., 2006; Lemenih and Kassa, 2011). Also, multiple stakeholders with competing interests are present in the utilization of the woodland, promoting its deforestation (Dejene et al., 2013; Derero et al., 2018). For example, local community needs to use the woodland as additional lands for agricultural activities whereas the frankincense enterprises want to conserve it for frankincense production (Dejene et al., 2013; Derero et al., 2018). To ensure sustainable conservation of the woodland, these diverse stakeholders with competing interests need to be accommodated (Derero et al., 2018). The Analytical Hierarchy Process (AHP) model is a multi-criteria decision model that offers an analytical framework to accommodate these conflicting interests through a pairwise comparison method (Saaty, 2010). To do this, it decomposes the overall goal of sustainable conservation of the woodland into objective, criteria and alternative options. The overall goal/objective is placed at the top level in the hierarchical structure of the decision tree, followed by criteria at the second level helping with the definition of the alternatives that are placed at the bottom of the structure (Mendoza and Martins, 2006). Selected individual stakeholders are then asked to compare among all the elements at a particular level and considering the elements located in a level above by using the pairwise comparison matrices of AHP model (Saaty, 2010). The comparisons made by individuals at different levels are finally combined to produce a final priority value for the alternatives at the bottom level of the hierarchy, according to their importance to the overall objective (Saaty, 2010). The model has already been widely used in prioritization of conservation alternatives for species under endangered conditions (Abiyu et al., 2006; Dhar et al., 2008; Derero et al., 2018) and biodiversity conservation (Masozera et al., 2006; Mendoza and Martins, 2006; Dhar et al., 2008; Balana et al., 2010; Lepetu, 2012).

It is therefore essential to determine the current population status of *B. papyrifera* and its potential conservation alternatives for sustainable conservation and management of the prevailing woodlands in northern Ethiopia. The specific objectives of the present study thus were to: (1) characterize density and the population structure of *B. papyrifera*; and (2) prioritize potential conservation intervention alternatives for the *B. papyrifera* woodland using AHP techniques by involving all relevant stakeholders.

2. Materials and methods

2.1. Study site

The study was conducted at the Gera site located in Abergele district within the Central zone of Tigray National Regional State (TNRS) in northern part of Ethiopia. The site is geographically located at 13°32′ N and 38°48' E and is distanced 150 km east-ward of Mekelle city, the capital city of TNRS (Figure 1). Within the study site, the altitude varies from 1500 to 1600 m.a.s.l, with a monthly average temperature of 25.3 °C and an average total annual rainfall of 445 mm mainly concentrated between mid-June and August. The dominant soil type of the site is Leptosols, characterized as being of low fertility levels and erosion problems. The natural vegetation of the site is dry woodland, occupying over 806 ha, being dominated by *B. papyrifera.* The total population of the site in 2018 was of around 6552 inhabitants (Negussie et al., 2018; Personal communication).

2.2. Data collection and analysis

2.2.1. Vegetation data

Woody species related data were collected from a total of 33 representative sample plots along three parallel transects, 500 m apart, in May 2018 following the suggested vegetation survey time of the area (Negussie et al., 2008). Each plot measured 20 m × 20 m and was separated by 200 m from each other. The plots were established within the study site occupied by *B. papyrifera* and following a systematic random sampling method. The first sample plot was randomly laid out and the others systematically at the above-mentioned interval (Alemu et al., 2012; Negussie et al., 2018). In each plot, the following data were recorded: identification of all woody species, number of each woody species, Diameter at Breast Height (DBH) and height of each woody species. DBH of the species with 1.5 m height or more was measured using diameter tape and those individuals having less than 1.5 m height were measured using a calliper. Graduated measuring stick was used to measure the heights of the woody species (Groenendijk et al., 2012). Besides, tapping status, damage types and possible causes of damage on *B. papyrifera* trees were recorded based on visual observation.

The collected data were then analysed using different ecological indices to indicate species composition, diversity and dominance. Floristic composition and species richness of the area were determined following the simple procedures of Magurran (2004). Based on the richness values, species diversity and evenness were then computed using the Shannon Diversity index. Procedures of Kent and Coker (1992) were also followed to determine mean density, relative density, frequency and relative frequency of each woody species. Furthermore,

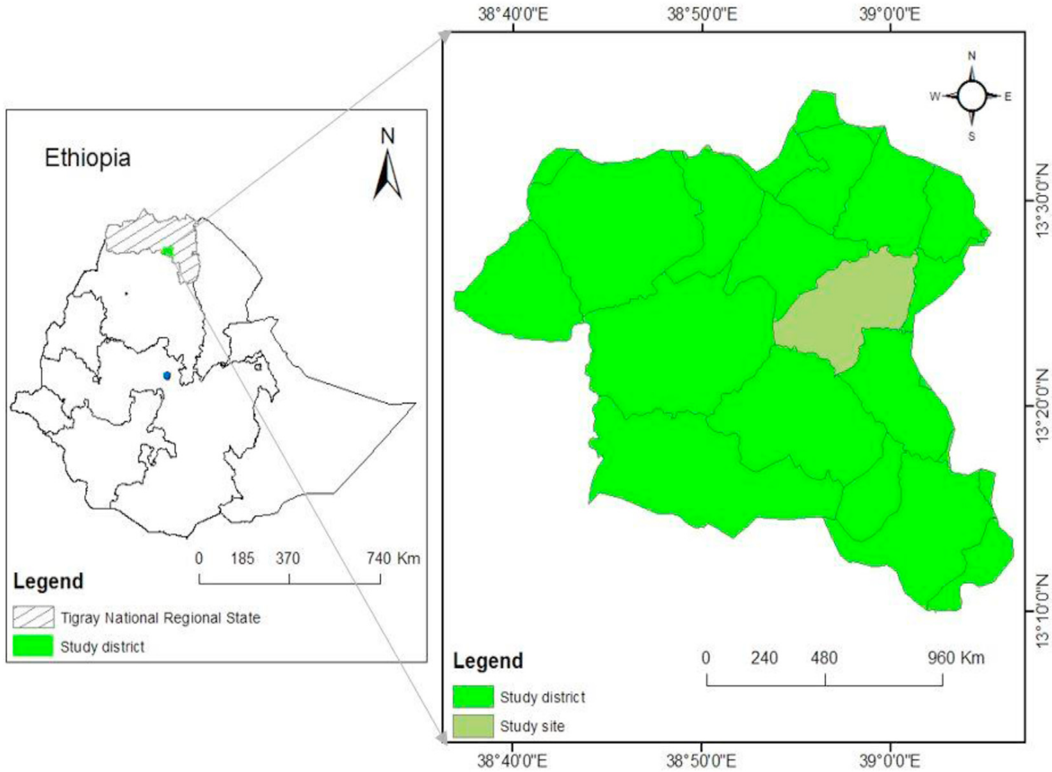

Figure 1. Geographical location of the study site.

dominance of each woody species was determined from its occupied space, usually expressed in basal area. Its relative dominance was then calculated as the percentage of its basal area out of the total basal areas of all woody species. The important value index (IVI) of each woody species was determined by summation of its relative values of density, frequency and dominance (Kent and Coker, 1992). The population structure of *B. papyrifera* was also depicted through histogram, constructed by using its density (Y-axis) and diameter classes (X-axis) (Peters, 1996).

2.2.2. Development of conservation alternatives and comparisons

For this study, we followed the AHP techniques to select the best intervention alternative (the overall objective) for sustainable *B. papyrifera* woodland conservation in terms of ecological, economical and biological criteria by involving multiple stakeholders with their competing interests. To do this, candidate intervention alternatives for the woodland conservation were first developed based on the consultation of experts, personal field experiences and literature reviews (Abiyu et al., 2010; Lemenih and Kassa, 2011; Tilahun et al., 2011; Mekonnen et al., 2013; Derero et al., 2018; Negussie et al., 2018; Bongers et al., 2019). These activities also helped to consider free grazing and over tapping (without resting time for frankincense production) as the most important threats for the development of the alternatives. Furthermore, similar procedures were followed for the development of the criteria to evaluate the alternatives. The alternatives and their evaluating criteria were then critically evaluated and validated using focus group discussion comprised by 12 representative stakeholders from the study area. The representatives included four key informants from the local community, four from frankincense enterprises and four forest experts. These are the main groups of stakeholders in the study area that have different interests on the woodland. For example, the local community needs to use the woodland as additional lands for livestock grazing whereas the frankincense enterprises want to conserve it for frankincense production (Personal observation). The development of the alternatives, stakeholders' representations and democratically selection of their representatives were done following literature suggestions (Masozera et al., 2006; Balana et al., 2010; Lepetu, 2012). The representatives were then well informed about the study before the actual workshop in order to have similar understanding. The representatives next met in a two-day workshop at the Yechila town, located at around 20 km from the study site in June 2018. In the workshop, the representatives freely exchanged their opinions on the proposed alternatives of the study, and finally reached an agreement on the conceptual hierarchical structure and on four alternatives for sustainable *B. papyrifera* woodland conservation with their three evaluating criteria Figure 2.

As illustrated in Figure 2, the first alternative was the introduction of free grazing in combination with "no tapping resting period" (FGNTR) into the woodland. This alternative represents the current practice in the study area: free grazing in the woodland and tap it for frankincense production with no resting period. The second alternative was the introduction of a "rotational tapping" combined with free grazing (FGRT). The features of this alternative are: allow free grazing in the woodland, but divide it into 4 segments, and then tap each segment yearly in a rotational order. Each segment then visits in each four years for frankincense production. The other alternatives, area exclosure with "medium tapping resting period" (AEMTR) and area exclosure with "long tapping resting period" (AELTR) consider there is a complete restriction of free grazing in the woodland combined with a tapping resting period: 5 years for the AEMTR and 10 years for the AELTR. The AEMTR allows the woodland to tap for frankincense production in each 5 years whereas the AELTR allows in each 10 years. The alternatives were then evaluated against the three developed criteria: ecological, economical and biological (Figure 2). The ecological criteria considered the roles of the candidate alternatives for improving restoration process (e.g. regeneration and saplings growth) of the woodland. The economical criteria looked on their roles for maximization of livelihoods through frankincense production in a sustainable ways. The biological criteria also considered roles of the alternatives for minimization pests attack on the woodland.

Data on prioritization of the four alternatives for *B. papyrifera* woodland conservation using the three criteria were then collected using a structured questionnaire. The questionnaire was developed using the

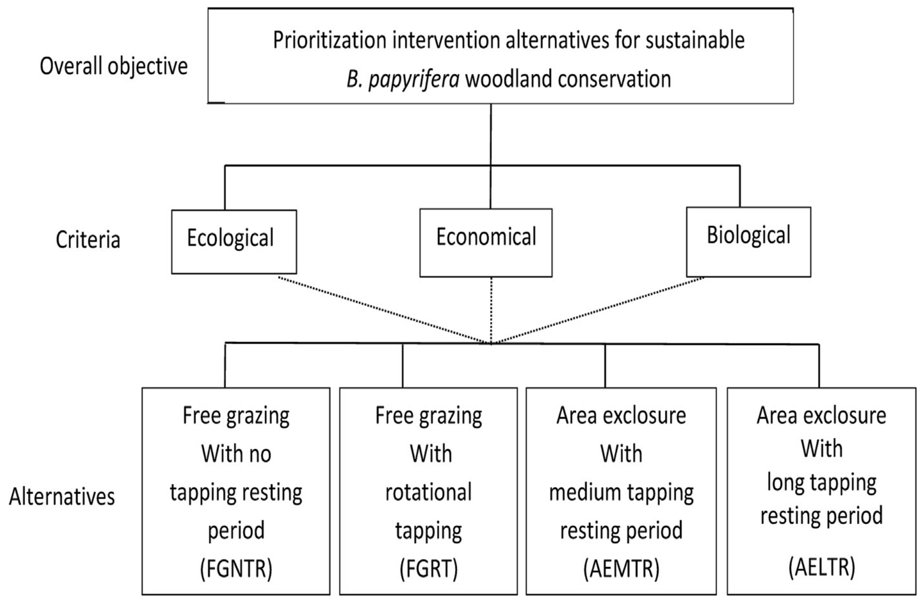

Figure 2. Hierarchical structure of the AHP model for the study.

hierarchical structure of the study (Figure 2), for pairwise comparisons using the AHP matrices (Table 1) (Saaty, 2010) by selected individual stakeholders. For this, 24 representative individuals were selected from the three stakeholder groups who participiated in the focus group discussion. From each group of stakeholders, eight representative individuals were taken in order to ensure each group had equal representation. Following literature, to minimize biases, individuals who had participated in the group discussion were not re-selected (Balana et al., 2010). Ahead of the comparison activities, the selected individuals were well briefed about the study, its alternatives and their evaluating criteria, and comparisons using the AHP techniques in a one-day workshop held in July 2018 at the Yechila town. Following this, in the second day, each individual was allowed to administer his/her questionnaire to make pairwise comparisons for all possible pairs of elements: the alternatives are compared to each other with respect to each criterion above it, and the criteria are compared to each other with respect to the overall objective (Figure 2). A scale rated from 1 (the two elements are equally important) to 9 (the absolute importance of one element over the other), with different intermediate values, was used to make the comparisons (Table 1) (Saaty, 2010). The relative weight of each element within each category (e.g. the alternatives within each criterion) then computed using the eigenvalue method. This method needs the construction of a reciprocal matrix and the computation of the eigenvalue and the relative weight of each element. For this, we derived the following explanations and formulas from Saaty (2010).

The pairwise comparisons are used to construct a reciprocal matrix of weights. If w_n is an assigned weight to an item, and n is the number of items compared through pairwise comparisons, the reciprocal matrix A is constructed by assigning to any a_{ij} element the corresponding relative weight, and placing on opposite side of the main diagonal the reciprocal relative weight $a_{ji} = 1/a_{ij}$ as showed in Eq. (1).

Table 1. The AHP pairwise comparison scales.

Intensity of relative importance	Definitions
1	Equal importance
3	Weak importance of one over the other
5	Strong importance of one over the other
7	Very strong importance one over the other
9	Absolute importance of one over the other
2,4,6, and 8	Intermediate values between two adjacent judgements

$$A = a_{ij} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

In the matrix, when $i = j$, then $a_{ji} = 1$. When matrix A is multiplied by the transpose of the vector of weights w, we get the resulting vector in nw,

$$Aw = nw \quad (2)$$

Where $w = (w_1, w_2, \ldots, w_n)^T$ and n is the number of rows or columns. Eq. (2) can be rewritten as:

$$(A - nI)w = 0 \quad (3)$$

where n is also the largest eigenvalue, λ_{max}, or trace of matrix A and I, is the identity matrix of size n. Saaty (2010) suggested that $\lambda_{max} = n$ is a necessary and sufficient condition for consistency. However, when the pairwise comparisons are based on human responses, inconsistency may occur, leading λ_{max} to deviate from n. Therefore, the matrix A has to be tested for consistency using the equations:

$$CI = (\lambda max - n)/(n - 1), \quad (4)$$

$$CR = CI/RI \quad (5)$$

where CI is the consistency index, RI is the random index *(RI)* generated for a random matrix of order n, and CR is the consistency ratio (Saaty, 2010). A high CR means high inconsistency within the matrix of pairwise comparisons. As a rule-of-thumb, CR value should be lower than 0.1 to maintain consistency of the matrix (Masozera et al., 2006; Saaty, 2010).

Once all the elements were compared and weighted using the eigenvalue method by each individual representative, the geometric mean (Saaty, 2010) was then used to aggregate and average results of the 24 individual representatives in order to produce the overall relative priority ranks for each alternative or criteria. The Expert Choice computer software (Expert Choice, 2009) was used to analyse the pairwise comparisons (weights), the overall relative priority ranking values and the CR values.

3. Results and discussion

3.1. Species composition, diversity and dominance

A total of 11 woody species representing seven families were recorded in the study area. The Fabaceae family exhibited the highest richness of the woody species followed by the Anacardiaceae. The other families were represented by one woody species. The genera represented by the highest richness of the woody species were *Acacia* and *Lannea* (Table 2). The Shannon diversity and the Evenness values were 1.33 and 0.56, respectively, revealing a moderate level of diversity of the area (Table 2). On average about 569 individuals ha^{-1} of woody species were found in the area (Table 2), proximate to the average density of the nearby woodland (611 individuals ha^{-1}) (Eshete et al., 2011). Furthermore, dominance of the woody species ranged between 0.01 and 7.1 m^2 ha^{-1}, showing *B. papyrifera* the highest relative dominance value. The IVI of woody species ranged between 1 and 154% with the highest value belonging to *B. papyrifera, S. singueana* and *D. viscosa var.* angustifolia, respectively (Table 2). These results revealed that *B. papyrifera* was ecologically the most important species in the area, similarly to other studies in Ethiopia (Negussie et al., 2008; Eshete et al., 2011; Tolera et al., 2013). However, the current *B. papyrifera* dominance will gradually be replaced by other species due to its on-going selective threats such as over tapping (Eshete et al., 2011; Tolera et al., 2013; Bongers et al., 2019). Such changes in species composition and dominance have also been observed in *Boswellia sacra*, particular in relation to over tapping (Farah, 2008).

3.2. Density and structure of B. papyrifera

The counted mean density of *B. papyrifera* was 266 trees ha^{-1} in the study area (Table 2), with a DBH ranged between 10.1 to 31.4 cm. There were no trees with DBH below 10 cm, 264 trees ha^{-1} with DBH between 10 and 30 cm and only two trees ha^{-1} had a DBH above 30 cm (Figure 3). About 99% of the individuals were found in a medium-size diameter classes (10–30 cm) is consistent with other similar studies (Ogbazghi et al., 2006; Negussie et al., 2008; Eshete et al., 2011; Alemu et al., 2012; Derero et al., 2018). The lack of individuals at lower classes (DBH<10 cm) indicated the absence of new recruitments through regeneration, and therefore the prevailing population of the species is unstable. From the group discussion, the main causes for the absence of lower diameter classes were indicated as overgrazing, over tapping, pests, agricultural expansion and poor managements. Similar factors were also reported for limiting regeneration and recruitments of the species from different geographical regions such as Ethiopia (Abiyu et al., 2010; Eshete et al., 2011; Derero et al., 2018), Eritrea (Ogbazghi et al., 2006; Rijkers et al., 2006) and Sudan (Alemu et al., 2012; Khamis et al., 2016). In connection with the regeneration and sustainability problems of the species, its ecological and economical benefits are expected to decrease in the study area (Lemenih et al., 2014; Negussie et al., 2018) and elsewhere (Ogbazghi et al., 2006; Mekonnen et al., 2013; Khamis et al., 2016). These sustainability problems are also expected to accelerate replacement of *B. papyrifera* by other aggressive woody species such as *Acacia etbaica* and *Lannea fruticosa* (Eshete et al., 2011). The current results indicated that *B. papyrifera* woodland is really suffering in regeneration to sustain its existence.

3.3. Prioritization alternatives for sustainable B. papyrifera woodland conservation

Results in Table 3 showed that the most important criteria pertaining to the choice of the candidate alternatives for *B. papyrifera* woodlands conservation, with an acceptable CR value of 0.08. The ecological criterion, with overall priority rank value of 0.419, was ranked as the most important criteria, followed by economical (0.356) and biological (0.184) criteria for prioritization of the alternatives (Table 3). This indicates that the stakeholders preferred the alternatives based on their future ecological roles for *B. papyrifera* woodland conservation, followed by their economical and biological roles, respectively. In the group discussion, the stakeholders further explained that *B. papyrifera* has been shrinking in the area due to different interrelated factors. They have not also seen its small saplings for more than a decade. The stakeholders therefore first considered roles of the alternatives for sustainable

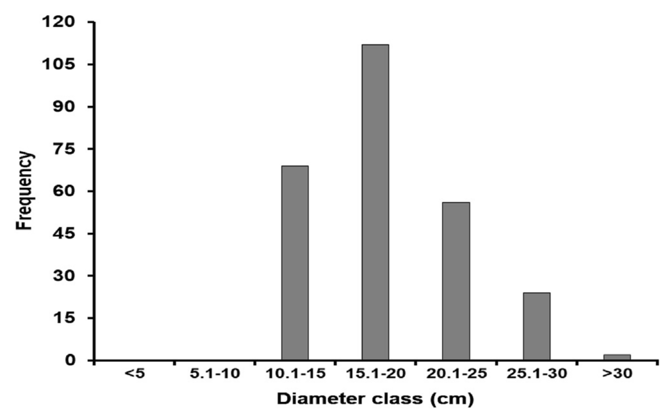

Figure 3. Diameter distribution of *B. papyrifera* species at the Gera site, Abergele district, northern Ethiopia.

Table 2. List of woody species recorded at the Gera site, Abergele district with their family names, mean densities (in decreasing order), relative densities (RD in %), frequencies and relative frequencies (RF in %), dominance, relative dominance (RDO in m^2 ha^{-1}) and important value index (IVI).

Species	Family name	Density	RD	Frequency	RF	Dominance	RDO	IVI
Boswellia papyrifera (Del.) Hochst	Bruceraceae	266	46.6	100	26.0	7.1	81.6	154
Senna singueana (Del.) Lock	Caesalpiniaceae	132	23.2	87.8	22.8	0.35	4.0	50
Dodonaea viscosa var. angustifolia (L.f.) Benth.	Sapindaceae	111	19.5	51.5	13.4	0.38	4.4	37
Acacia etbaica Schweinf.	Fabaceae	20	3.4	51.5	13.4	0.26	3.0	20
Acacia oerfota (Forsskal) Schweinf	Fabaceae	11	1.9	27.3	7.1	0.21	2.4	11
Acacia abyssinica Hochst. ex Benth	Fabaceae	7	1.2	18.2	4.7	0.20	2.3	8
Terminalia brownii Fresen	Combretaceae	6	1.1	15.2	3.9	0.13	1.5	7
Stereospermum kunthianum (Cham, Sandrine. Petit)	Bignoniaceae	5	0.9	12.1	3.1	0.03	0.3	4
Acacia mellifera (Vahl) Benth.	Fabaceae	5	0.9	12.1	3.1	0.01	0.1	4
Lannea fruticosa (A.Rich.) Engl.	Anacardiaceae	3	0.5	6.1	1.6	0.02	0.2	2
Lannea triphylla (A.Rich.) Engl.	Anacardiaceae	3	0.5	3.0	0.8	0.01	0.1	1
Total		569						

Table 3. Stakeholders' relative priority ranking values for *B. papyrifera* woodland conservation alternatives with respect to main criteria, with a Consistency Ratio value of 0.08.

Criteria	Conservation Alternatives	Priority (All stakeholders)	Relative priority weight
Ecological	AEMTR	1	0.175
	AELTR	2	0.109
	FGRT	3	0.100
	FGNTR	4	0.035
			0.419
economical	AEMTR	2	0.100
	AELTR	3	0.061
	FGRT	1	0.160
	FGNTR	4	0.035
			0.356
Biological	AEMTR	2	0.013
	AELTR	1	0.150
	FGRT	3	0.011
	FGNTR	4	0.010
			0.184

AEMTR = area exclosure with medium tapping resting period; AELTR = area exclosure with long tapping resting period; FGRT = free grazing with rotational tapping; FGNTR = free grazing with no tapping resting period.

ecological restoration (e.g. regeneration and saplings growth) of the woodland. They also agreed that the positive ecological roles of the alternative to improve their livelihoods (frankincense production) from the woodland in a long term but in a sustainable ways. The stakeholders' preferences of the alternatives for the woodland conservation, respectively based on their ecological, economical and biological roles are consistent with previous studies (Abiyu et al., 2006; Derero et al., 2018). Accommodated diverse interests of stakeholders through mutual consensus were also mentioned as an effective approach for sustainable conservation of degraded woodlands elsewhere (Masozera et al., 2006; Balana et al., 2010; Lepetu, 2012). The results suggested that systematic inclusion of different relevant stakeholders with their competing interests on *B. papyrifera* woodland would help for its sustainable conservation.

Figure 4 illustrated the relative priority ranks of the candidate alternatives for sustainable *B. papyrifera* woodland conservation by all stakeholders and each stakeholder group. It also showed consistency of the relative priority ranks of the alternatives by each stakeholder group. All stakeholders preferred the AEMTR alternative (with overall priority rank value of 0.352) for the woodland conservation, followed by AELTR (0.294) and FGRT (0.212) alternatives. However, the least preferred alternative was FGNTR with overall priority rank value of 0.182 (Figure 4). These results indicate that the stakeholders perceived AEMTR and AELTR as suitable strategies for sustainable conservation of the woodland. In the group discussion, the stakeholders explained that free grazing restrictions and tapping resting period of AEMTR and AELTR alternatives would improve viable seed production, regeneration and saplings growth of the woodland through maximizing soil growth conditions and minimizing disturbances. The stakeholders also believed that the positive roles of these alternatives for ecological restoration would increase their livelihoods from the woodland in a long term but in a sustainable ways.

The choices of the AEMTR and the AELTR as top alternatives had already shown positive results for sustainable *B. papyrifera* woodlands conservation in different localities. For example, *B. papyrifera* woodlands under area exclosures along with some tapping resting period (5–10 years) provided more foliage, fruits and viable seeds, stable population structure, higher regeneration and frankincense yield, and lower attacks by pests and fire compared to the woodlands under non-exclosures with continuous tapping history (Gebrehiwot et al., 2003; Rijkers et al., 2006; Negussie et al. 2008, 2018; Tilahun et al., 2011; Alemu et al., 2012; Eshete et al., 2012). The stakeholders also expected that introduction of the AEMTR and the AELTR strategies will decrease their livelihoods from the woodland, particularly at their early implementation stages (5–10 years). For this, they suggested to introduce different alternative livelihood sources into the woodland, including collection of non-timber forest products (NTFP) such as dead woods, grass, medicinal plants and honey. Such alternative livelihood sources have been acknowledged for supporting conservation of dryland woodlands elsewhere (Lemenih and Kassa, 2011; Tadesse et al., 2020). On contrary, the stakeholders considered the FGRT and the FGNTR (current practices) alternative

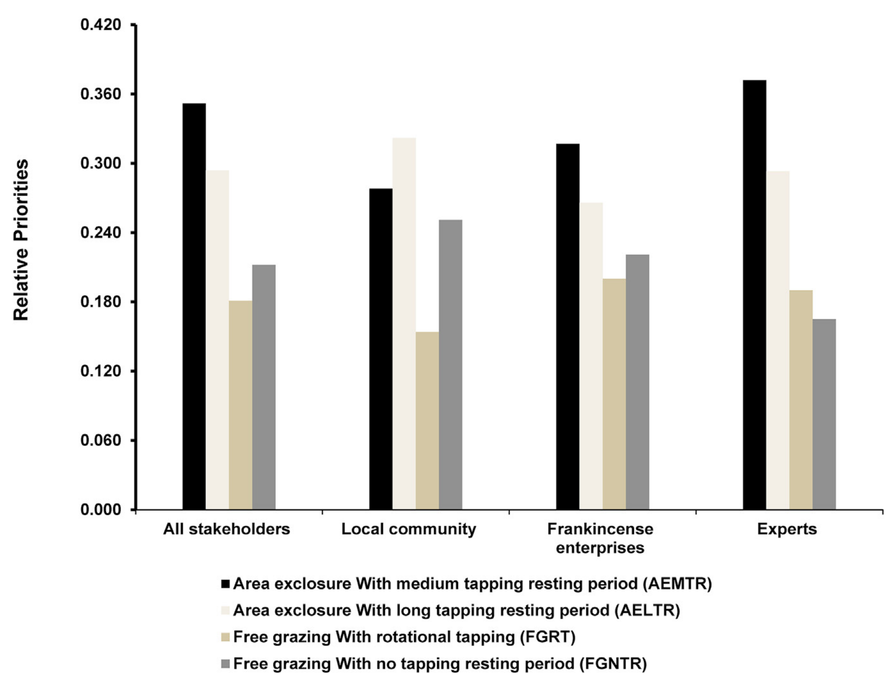

Figure 4. Relative priority values of the stakeholder groups for the *B. papyrifera* woodland conservation alternatives, with a Consistency Ratio value of 0.076.

strategies as less effective for sustainable *B. papyrifera* woodland conservation, and these in agreements with different previous studies (Abiyu et al., 2006; Ogbazghi et al., 2006; Eshete et al., 2011; Tolera et al., 2013; Lemenih et al., 2014; Negussie et al., 2018). The current results suggested that the AEMTR and the AELTR alternative strategies would be effective for sustainable *B. papyrifera* woodland conservation if combined with collection of different NTFP from the woodland, particularly at their early implementation stages.

4. Conclusions

The study evidenced that sustainability of *B. papyrifera* woodland is at risk (specifically, it suffers in regeneration, recruitment and saplings with a DBH<10 cm) because of different interrelated disturbances including overgrazing, over tapping, pests, agricultural expansion and poor managements. The study also evidenced that application of multi-criteria decision model can facilitate prioritization of intervention strategies for sustainable *B. papyrifera* woodland conservation, by involving diverse stakeholders with their competing interests through maximizing consensus and minimizing conflicts. Besides, the study suggested area exclosure with a medium and long tapping resting period (AEMTR and AELTR, respectively) as the best alternatives in terms of ecological, economical and biological aspects for sustainable *B. papyrifera* woodland conservation. Economic impacts of these alternatives at their early implementation stages (5–10 years) should be minimized by collection of different NTFP from the woodland. Continuous capacity building training on sustainable utilizations and managements of the woodland should also be provided for all relevant stakeholders. These collective actions may save the *B. papyrifera* woodland and promote succession to occur in the remaining dry *Boswellia* woodlands in northern Ethiopia and other locations.

Declarations

Author contribution statement

Tesfay Gidey, Daniel Hagos, Hagos Mehammedseid Juhar, Negasi Solomon, Aklilu Negussie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Josep Crous-Duran, Tania Sofia Oliveira, Abrham Abiyu and Joao HN Palma: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This study was supported by the Rufford Foundation, based in UK, with the grant numbers of 21680-1 and 26273-2. The study was also supported both in finance and equipment by the Adigrat University, Ethiopia.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors greatly thanked the IDEA WILD (grant number of BezaETHI0817) foundation based in USA for its equipment support. We also acknowledged all the stakeholders who participated either directly or indirectly in this study.

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