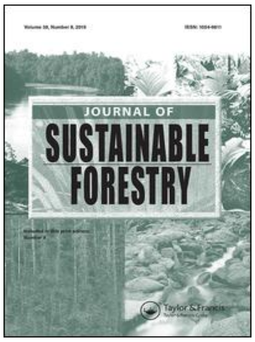

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Population Status and Resin Quality of Frankincense *Boswellia neglecta* (Burseraceae) Growing in South Omo, Southwestern Ethiopia

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ABSTRACT

A study was conducted in South Omo Zone, Ethiopia with the aim of assessing the population status of the frankincense tree *Boswellia neglecta* and investigating its resin essential oil chemical composition. The status of populations of *B. neglecta* was assessed by examining the density, abundance, frequency, dominance, importance value index, and population structure. Resin sample was analyzed for the physicochemical properties. The composition of the essential oil was analyzed with Gas Chromatography-Mass Spectrometry. The high values of density, abundance, frequency, dominance, and importance value index for *B. neglecta* showed the potential of the tree for bulk resin collection. *Boswellia neglecta* had a bell-shaped diameter distribution indicating a hampered regeneration. The *B. neglecta* resin had a moisture content of 2.68%, ash content of 0.99%, pH of 5.7, and oil yield of 5.92%. The resin possessed good quality as compared to resins in other reports. The essential oil was optically active (−31.6° at 23.2°C). The essential oil contained several compounds, but 71.1% of the composition were formed mainly from methyl oleate, methyl linoleate, methyl palmitate, which have not been reported from *B. neglecta*. Sustainable management must be enacted since the agro-pastoralist mode of life hinders regeneration of the species and its resin resources.

KEYWORDS

Abundance; essential oil; frankincense tree; importance value index; resin quality

Introduction

The dryland of Ethiopia accounts for about 75% of the country's total landmass and hosts woodlands that provide important resources for the people that inhabit these systems (Lemenih & Kassa, 2011). The woodlands are comprised of the major gum and resin producing genera of *Acacia*, *Boswellia* and *Commiphora* (Lemenih & Kassa, 2011). Studies demonstrate that 12 *Acacia*, 17 *Commiphora*, six *Boswellia* and three *Sterculia* species in the drylands are potential yielders of commercial gums and resins (Lemenih, Abebe, & Olsson, 2003). *Boswellia neglecta* is among the resin bearing species, and it is found in the dry *Acacia-Commiphora* woodlands of the South, Southwestern and Southeastern parts of the country (Lemenih & Kassa, 2011). *Boswellia neglecta* as a tree has benefits such as the production of resins, and these products are valuable non-wood forest products in arid

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and semi-arid drylands (Gitau, 2015; Lemenih & Teketay, 2003). The Borana type of resin/frankincense is produced from *B. neglecta* growing in the Southern and South-eastern part of the country (Tadesse, Desalegn, & Alia, 2007) and it is locally named as "tikuretan" (meaning: black incense) (Fikir, Tadesse, & Gure, 2016). Resins, in general, are important raw material used to produce essential oils (Lemenih & Teketay, 2003). Essential oils are highly concentrated volatile substances which are isolated from resins and different plant parts (Rav, Valizadeh, Noroozifar, & Motlagh, 2011) and are used for various purposes in cosmetics, medicinal value, fragrance and flavor application (Lemenih & Teketay, 2003; Santos et al., 2005). In addition to its commercial product, *B. neglecta* is valuable to the rural communities as a source of fuelwood, farm implements, construction material and fodder (Pretzsch, Mohmoud, & Adam, 2011). Other tree parts also have medicinal value, and woodlands composed of *Boswellia* spp. provide various environmental services such as soil and water conservation, carbon sequestration, provide plant cover and shade (Pretzsch et al., 2011; Yosef, Eshetu, Garedew, & Kassa, 2019).

Woodland resources in Ethiopia are important components of the livelihoods of pastoralists and agropastoralists (Worku, Lemenih, Fetene, & Teketay, 2011). In South Omo, *Boswellia negelecta* is a common dryland tree species often mixed with other species like *Acacia, Commiphora, Combretum, and Terminalia* (Admasu, Abule, & Tessema, 2010). The inhabitants of our study area are pastoralists or agropastoralists, whose livelihoods depend largely on raising livestock followed by honey production and subsistence farming (Admasu et al., 2010). The people that live close to towns may also depend on firewood collection and charcoal making to sell for additional income. Hence, these activities have likely led to decline in productivity and genetic diversity of *B. neglecta* and other resin bearing trees (Hundera et al., 2013). Despite the increasing ecological and socioeconomic importance of the woodland resources, limited research has been carried out to understand the ecological and population status of the woodland vegetation in Ethiopia (e.g., Worku et al., 2011). Detailed information on the diversity, population status and resin quality of gum and resin producing species is scant for South Omo zone, Southwestern Ethiopia. The quality, as well as quantity of product, is considered the basis for sustainable market of the product, which highlights the importance of an integrated and sustainable management of these resources. Therefore, this study aims to support the development of a management plan for *B. neglecta* by: (1) quantifying the species' population structure and regeneration status in Bena-Tsemay district and, (2) assessing its' importance using a value index; and (3) characterizing the quality and oil yield of resin and constituents of essential oil from the resin of *B. neglecta*.

Materials and methods

Study area

This study was conducted in Bena-Tsemay district of South Omo Zone located in the Southwestern part of Ethiopia (Figure 1). The study area is located at 36°22′50″-36°59′58″E, 5°1′58″-5°44′10″N, and at about 670 km away from Addis Ababa. The elevation of the study area ranges between 567 and 1800m a.s.l. (Admasu et al., 2010). The district has a mean annual rainfall of 1400 mm (Hidosa & Gemiyo, 2017) and the average annual minimum and maximum temperatures are 16°C and 40°C, respectively

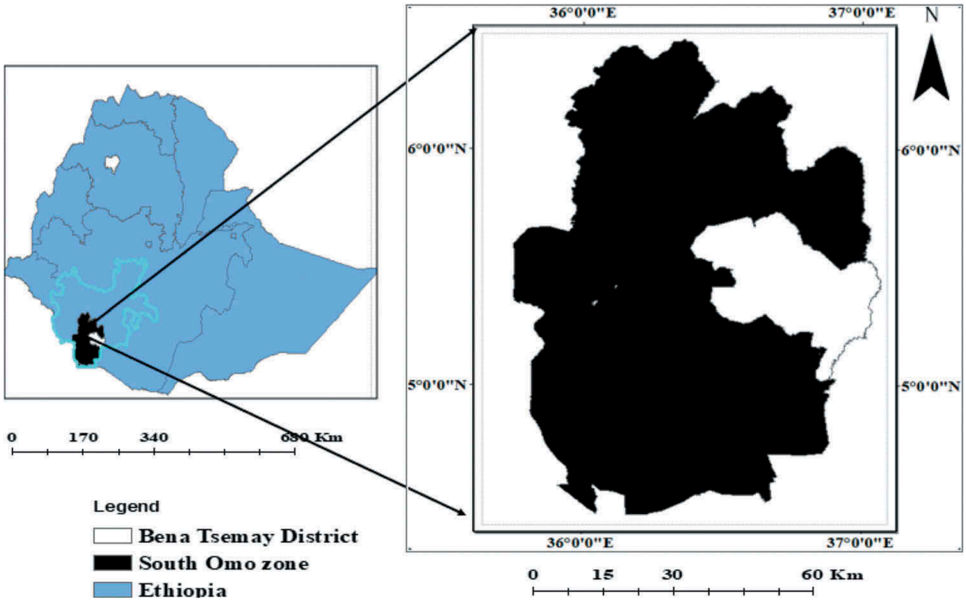

Figure 1. Location of the study area.

(Admasu et al., 2010). The district is endowed with substantial vegetation resources, particularly the *Combretum-Terminalia* and *Acacia-Commiphora* woodlands, which are also used as rangelands and common property resources of the community (Soromessa, Teketay, & Demissew, 2004). The dominant soil types of the area are Eutric Fluvisols in the plains and Eutric and Chromic Cambisols in the hills (Soromessa et al., 2004).

Field sampling

The data were collected using systematic sampling method where three transects lines (~5.4 km each) were established in a north-south direction and spaced at 500 m apart. Along each transect line, we established 40 m x 40 m plots at a distance of 300 m from each other. Accordingly, a total of 45 plots were used to sample trees from the study area. In each plot, we measured diameter at breast height (DBH; ≥2.5 cm) using caliper and height (≥1.5m) using clinometer of each tree (e.g., Eshete, Teketay, & Hulten, 2005). For assessing regeneration pattern of tree species, each plot was subdivided into four 10 m x 10 m sub-plots. In one random sub-plot of each plot, we recorded seedling and saplings (dbh < 2.5 cm and height < 1.5) by species. Most tree species were identified during sampling in the field, while specimens of trees, which were difficult to identify in the field, were collected and identified at the National Herbarium of Addis Ababa University (Hedberg, Kelbessa, Edwards, Demissew, & Persson, 2006). Resin sample was collected from 10 randomly identified mature *B. neglecta* trees, where one from randomly selected plot and the rest from every fourth plot established for tree sampling (e.g., Yebeyen, Lemenih, & Feleke, 2009). The resin samples from the 10 trees were then bulked into one composite sample. The vegetation data and resin samples were collected in drier season (January and February 2018).

Data analyses

Density, abundance, and frequency

We calculated density, abundance, frequency, basal area, and importance value indices as described in Silvertown (1993), Gebrehiwot (2003) and Eshete et al. (2005). The importance value index (IVI) is based on the sum of relative abundance (equation 1), relative dominance (equation 2) and relative frequency (equation 3) (Kent & Coker, 1994). The IVI evaluates the relative ecological importance of tree species, and it has been shown to be a good index for ranking species for management and conservation practices (Kent & Coker, 1994).

$$\text{Relative abundance} = \frac{\text{Number of individuals of species}}{\text{Total number of individuals}} * 100 \quad (1)$$

$$\text{Relative dominance} = \frac{\text{Dominance of aspecies}}{\text{Total dominance of all species}} * 100 \quad (2)$$

$$\text{Relative frequency} = \frac{\text{Frequency of aspecies}}{\text{frequency of all species}} * 100 \quad (3)$$

Population structure

Population structure of a species may provide insight into past disturbances to the environment and hence, used to forecast future trends in the species' population and composition of the ecosystem it inhabits (Gebrehiwot, 2003; Young, Romme, Evangelista, Mengistu, & Worede, 2017). To determine the population structure of *B. neglecta*, diameter size frequency distribution of the tree was represented by categorizing plants in diameter size classes (<2.5 cm, 2.5–7.5 cm, 7.51–12.5 cm, 12.51–17.5 cm, 17.51–22.5 cm, ≥22.51 cm) (Eshete et al., 2005). Similarly, height frequency distribution of the tree was made by categorizing plants in height size classes (<1.5 m, 1.5–3.5 m, 3.51–5.5 m, 5.51–7.5 m, 7.51–9.5 m, 9.51–11.5 m, ≥11.51 m) (Eshete et al., 2005). Further, the frequency distributions were categorized into three types Type I, II, and III (Eshete et al., 2005; Gebrehiwot, 2003; Peters, 1996; Shibru & Balcha, 2004). Type I shows the case in which a greater number of smaller trees than big trees (Eshete et al., 2005; Shibru & Balcha, 2004) and such type of a pattern is skewed to a reversed J-shape distribution. Type II is characteristic of species that show discontinuous, irregular, and/or periodic recruitment while Type III reflects a species whose regeneration is severely limited for some reasons (Peters, 1996). Lastly, the regeneration status of the study trees was summarized based on the total count of seedling and sapling of each species across all plots and presented in tables and frequency histograms (Argaw, Teketay, & Olsson, 1999).

Analysis of physicochemical characteristic of resins

The physicochemical properties were analyzed in triplicates at the School of Chemical and Bio Engineering, Food and Chemical Engineering Laboratories, Addis Ababa University. The percentage moisture content (%MC) was determined by dividing the oven dry (105° C) weight (g) of resin by initial weight (g) and multiplying by 100 (FAO (Food &Agriculture Organization), 1999). Ash Content was determined after heating the sample at 550°C on platinum crucibles in a furnace (Nabertherm, LH15/14) until the variation between two successive weights becomes less than 1 mg. The percentage of ash content (% AC) was calculated by dividing the weight of ash (g) by the initial weight of the sample (g) and multiplying by100 (Gitau, 2015). The pH of a 1:4 (resin: water) solution was measured by a glass electrode microprocessor pH meter (HANNA 240) after calibrating the meter with buffer solutions (Gitau, 2015). Nitrogen content was determined by Kjeldahl method according to AOAC (Association of Official Analytical Chemistry) (2000). The resin quality was assessed by comparing its physicochemical properties with resins reported in literatures.

The ground sample of *B. neglecta's* resin (200 g) was placed in a round bottom flask (1000 ml) and enough quantity (above sample level) of water was added and boiled. The vapor mixture of water and oil was condensed, and the oil in the distillate was separated by a separatory flask. The extracted oil was dried (by Na_2SO_4), and the percentage of essential oil content was calculated by dividing the weight of oil (g) by the weight of resin sample (g) used for extraction multiplied by 100 (Zheljazkov, Cantrell, Astatkie, & Ebelhar, 2010). Optical Rotation was determined after 10 ml Polarimeter tube containing the essential oil was placed in the trough of the instrument between polarizer and analyzer. Analyzer was slowly turned until both the halves of the field were viewed through the telescope and then the direction of rotation was determined from the initial zero position to the final reading (Juliani, Zygadlo, Scrivanti, de la Sota, & Simon, 2004).

Analysis of essential oil

The components of essential oil were analyzed by GC–MS (MS-AGELANT Technologies); a Hewlett-Packard GCD system as described in Baser, Demirci, Dekebo, and Dagne (2003). A sample volume of 1.0 μl was injected, applying split mode (split ratio 100:1), into HP-5 MS capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness) was used with helium as carrier gas at a flow rate of 1 ml/min. Gas Chromatography oven temperature was kept at 60°C for 10 min and raised to 220°C at a rate of 4°C/min, and then kept constant at 220°C for 10 min and raised to 240°C at a rate of 1°C/min. The injector temperature was at 250°C. MS system, with ionization energy (70 eV), was used for GC/MS detection. Mass scanning range was *m/z* 41.1–328.4. Identification of components of essential oil was supported by using Wiley GC–MS Library and TBAM Library of Essential Oil Constituents. The components of essential oils were also supported by Pubchem open chemistry database. Relative percentage was calculated from total ion chromatogram by the computer.

Results

Density, frequency, dominance, and importance value index of tree species

The total density of all tree species was found to be 960 stems ha^{-1} (Table 1). The density values of all the tree species ranged between 3 for *C. aculeatum* to 142 for *B. neglecta. Boswellia neglecta, Boscia coriacea, Commiphora africana, Albizia schimperiana*, and *Ocimum americanum* contributed to 59.3% of the total density at the study site.

Boswellia neglecta, B. coriacea, and *C. africana* were the three-top abundant species with 142, 138 and 137 individual ha^{-1} respectively. *Boswellia neglecta* and *C. africana* were also the two most frequently encountered species and found in 44 and 42, respectively, of our 45 sample plots. The result of the analyses of dominance revealed that *B. neglecta, B. coriacea,*

Table 1. List of the top twelve abundant species encountered in the study quadrats at studied district in abundance order.

Species	Family	*D*	*N*	*N*(%)	*F*	RF(%)	DO	RDO	IVI
Boswellia neglecta	Burseraceae	142	3.16	14.8	44	12.2	0.94	17.53	44.51
Boscia coriacea	Capparidaceae	138	3.07	14.4	28	7.8	0.94	17.46	39.59
Commiphor aafricana	Burseraceae	137	3.04	14.3	42	11.6	0.89	16.55	42.46
Albizia schimperiana	Fabaceae	86	1.91	9.0	39	10.8	0.64	12.00	31.76
Ocimum americanum	Lamiaceae	66	1.47	6.9	23	6.4	0.61	11.29	24.53
Lannea schimperi	Anacardiaceae	42	0.93	4.4	26	7.2	0.27	4.94	16.52
Commiphora schimperi	Burseraceae	37	0.82	3.9	6	1.7	0.24	4.52	10.04
Grewia villosa	Tilaceae	33	0.73	3.4	7	1.9	0.05	0.84	6.22
Commiphora boiviniana	Burseraceae	32	0.71	3.3	13	3.6	0.04	0.81	7.75
Grewia tenax	Tilaceae	31	0.69	3.2	6	1.7	0.06	1.14	6.04
Commiphora myrrh	Burseraceae	28	0.62	2.9	5	1.4	0.04	0.66	4.96
Commiphora bruceae	Burseraceae	27	0.60	2.8	8	2.2	0.13	2.34	7.37

*Arranged in descending order of the average abundance of species (N) per quadrats; D = density/ha; N = average abundance per plot; %N = relative abundance of the species; F = absolute frequency; %RF = relative frequency; DO = Dominance; RDO = relative dominance; %IVI = percent IVI).

C. africana, *A. schimperiana*, and *O. americanum* were the five top dominant species (Table 1). The total basal area ha^{-1} of *B. neglecta* was found to be 0.94 m^2 ha^{-1}. The IVI of all tree species ranged between 1.53 for *C. aculeatum* and 44.51 for *B. neglecta* (Table 1). Based on the result of the comparison of individual species in terms of their IVI, *B. neglecta* was the first most important species comprised 44.5% (Table 1).

Population structure and regeneration status

Population structure of *B. neglecta* exhibited bell-shape or unimodal distribution, where there was a small number of individuals in the lower and higher diameter classes (Figure 2). Analysis of diameter size class distribution showed that abundance of stems was very high at second diameter classes (2.5–7.5 cm). The regeneration status of *B. neglecta* was grouped in type-II categories, because the characteristic of species shows discontinuous and irregular distribution pattern in the district (Figure 2).

At height class distribution exhibited a sort of bimodal distribution for the height classes with few individuals in the < 1.5 m class, followed by the highest number of individuals in the 1.5–3.5 m class, a sharp decline at the 3.51–5.5 m class, followed by a progressive increase at the 5.51–7.5 m class and a sharp decline again toward the upper height classes (Figure 3).

The density/ha of seedlings and/or saplings were found to be different depending on species in the study area (Figure 4). *Boswellia neglecta* had somewhat intermediate density of seedlings and saplings.

Physicochemical characteristics of the resin and essential oil

The moisture content, ash content, nitrogen content, oil yield and pH of the resin from *B. neglecta* were 2.68%, 0.99%, 0.27%, 5.92%, and 5.73, respectively (Table 2). The essential oil was optically active and levorotatory (Table 2).

The essential oil for this study had an oil-like in appearance, dark yellow in color, while it had a distinct aroma odor and volatilized at room temperature.

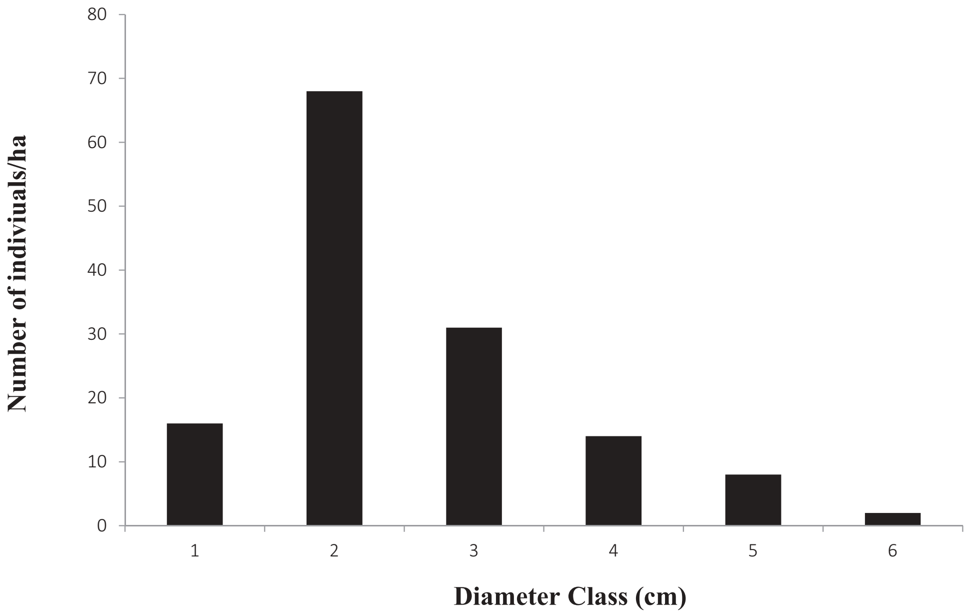

Figure 2. Population structure of *B. neglecta* at Bena-Tsemay district. (Diameter class (cm): 1 = <2.5, 2 = 2.5–7.5, 3 = 7.51–12.5, 4 = 12.51–17.5, 5 = 17.51–22.5, 6 = ≥22.51).

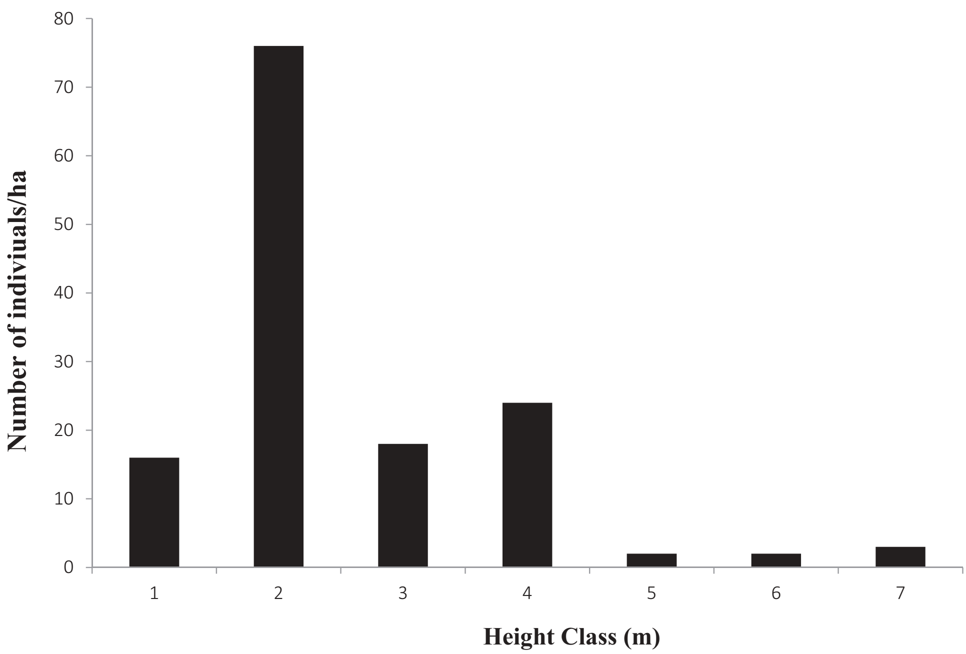

Figure 3. Height class distribution of the *B. neglecta* at Bena-Tsemay district. (height class (m): 1 = <1.5, 2 = 1.5–3.5, 3 = 3.51–5.5, 4 = 5.51–7.5, 5 = 7.51–9.5, 6 = 9.51–11.5, 7 = ≥11.51).

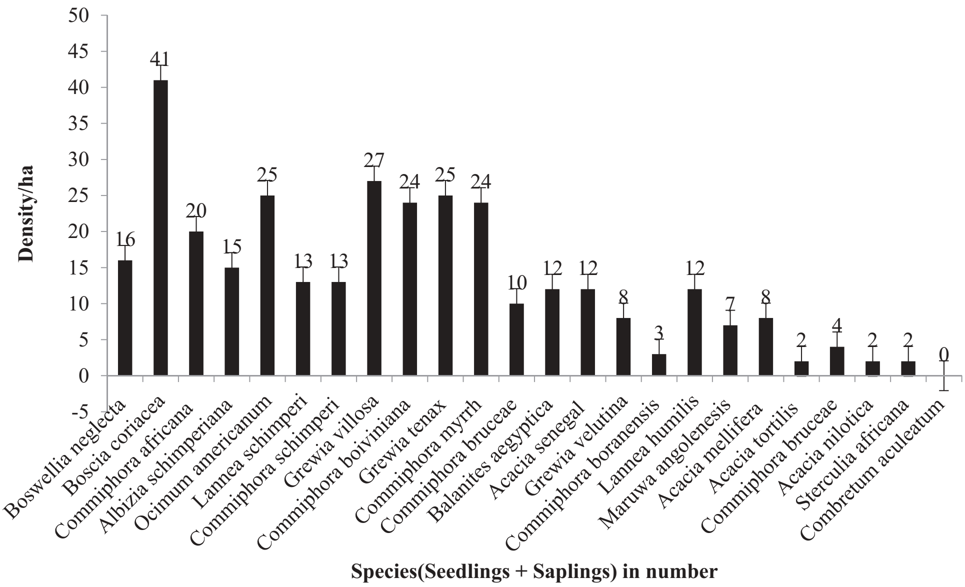

Figure 4. Regeneration status (seedling + sapling) of woody species Bena-Tsemay district.

Table 2. Physicochemical characteristics of the resin sample from *B. neglecta* species.

Characteristics	Mean ± SD
Moisture content (%)	2.68 ± 0.50
Ash content (%)	0.99 ± 0.01
pH	5.73 ± 0.01
Nitrogen content (%)	0.27
oil yield (%)	5.92 ± 1.06
Optical rotation (deg) at 23.2°C [a]	−31.61 ± 0.00

[a]only for essential oil.

Essential oil constituents

Relative abundance of oil with its retention time in terpenic range was: mono-: α-pinene (6.27%) to Cineole (3.89%); sesqui- Terpinen-4-o1 to Methyl myristate both of them were highly volatile compounds; di- (Methyl palmitate to Ethyl palmitate) and triterpenes (Butyl phthalate to Methyl icosanoate)- low and very low volatility, respectively (Table 3). In GC-MS chromatogram, out of three components per each retention time a peak quality was screened. Thus, a total of 25 compounds were identified in the essential oil, accounting for 97.8% of the total oil, which correspond to seventy-six (76) different compounds. The essential oil tested contained a high amount of methyl oleate (25.92%) and methyl linoleate (25.29%) followed by methyl palmitate (13.62%) and α-pinene (6.27%).

Discussion

Density, frequency, dominance, and importance value index

Boswellia neglecta had the highest density of 142 individual stems ha^{-1} thus accounting for 14.79% of the stem composition of the study woodland in terms of tree density. The values

Table 3. Relative compositions (%) of peak area of major volatile components from frankincense collected of *B. neglecta* (Bena-Tsemay) and Ethiopian *Boswellia.*

R.T.	Components	A* (%)	B (%)	A (%)	C (%)	D (%)
4.829	α -Thujene	0.48	-	-	-	-
4.919	α-Pinene	6.27	5.3	16.7[a]	5.2	2.6
5.788	Sabinene	1.55	1.2	2.9	6	-
6.614	Limonene	0.81	14.8	2.2	0.4	6.5
6.757	β-Terpinene	0.3	-	-	-	-
6.954	1,8-Cineole	3.89	-	-		-
9.881	4-Terpineo1	1.04	1.4	12.5	14.6	-
10.333	α-Terpineol	0.37	1.4	1.4	1.1	0.5
10.775	α-Cyanotoluene	1.03	-	-	-	-
11.554	Methyl decanoate	1.22	-	-	-	-
12.098	α-Terpinyl acetate	0.31	1	0.3	0.9	-
12.614	Caryophyllene	0.27	-	-	-	-
13.121	2,5-Dimethoxy-*p*-cymene	0.56	-	-		-
13.52	β-Bisabolene	0.5	-	-		-
14.09	Methyl Laurate	0.96	-	-		-
14.897	1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, (E)-	0.38	-	-	-	-
15.371	Elemicin	0.32	-	-	-	-
16.38	Methyl myristate	2.48	-	-	-	-
18.989	Methyl palmitate	13.62	-	-		-
19.957	Ethyl palmitate	1.54	-	-	-	-
22.067	Methyl oleate	25.92	-	-	-	-
22.168	Methyl linoleate	25.29	-	-		-
22.287	Methyl stearate	3.83	-	-	-	-
22.422	Methyl linolenate	1.55	-	-		-
26.222	Methyl icosanoate	3.29	-	-		-

A*, A, *B. neglecta*; **B**, *B. rivae*; **C**, *B. pirottae*; **D**, *B. papyrifera* (**A, B, C**&**D** from Dekebo et al. (1999); Baser et al. (2003)); R.T., Retention time for the present study tree **A***

observed from this study on tree density were comparable to values reported by the Worku (2006) which has shown that the stem densities ha^{-1} was ranging from 65 to 162 for *B. neglecta* at Borana Zone in Southern Ethiopia. It is also within the range of values (87 to 175 stems ha^{-1}) reported by the Eshete et al. (2005) for *B. papryifera* in Tigray Region, Northern, Ethiopia. *Boswellia neglecta* is one of the economically important tree species with its highest density and frequency. When evaluating basal area from our field sampling, *B. neglecta* was the first most dominant species recorded. As basal area provides the measure of the relative importance of the species than simple stem count, species with the largest contribution in dominance value could be considered as the most important species in the study vegetation (Shibru & Balcha, 2004). The highest dominance and density of *B. neglecta* species could indicate the potential of the tree for bulk collection of resins. *Boswellia neglecta* held the top largest value of IVI and it was relatively dense across the study area. This could show the relatively high ecological importance of the tree in the ecosystem (Akwee, Palapala, & Onyango, 2010).

Population structure and regeneration status

The diameter class distribution of the *B. neglecta* species of the study woodland falls under type-II which might be related to mortality or intensive use of matured trees and grazing. This type of diameter class distribution for *Boswellia Papyrifera* in Northern Ethiopia was ascribed to mature tree mortality, fire, and grazing (Groenendijk, Eshete, Sterck, Zuidema, & Bongers, 2012). In this group, though the recruitment was low, there is a reasonable number of seedlings and relatively large number of middle diameter class individual that could be managed for resin production. The findings obtained from this study on the population structure of *B. neglecta* agreed with what Worku (2006) and Adam and Osman (2008) reported from Arero district, Borana lowland, and *B. papyrifera* respectively from Jebel Mrarra, Darfur, Sudan. Several studies from Ethiopia and Eritrea by different authors (Alem, Eshetu, Garedew, & Kassa, 2011; Eshete et al., 2005; Lemenih, Feleke, & Tadesse, 2007) have also reported unstable populations of *B. papyrifera* in different sites. This is an indication that resin bearing species of the genus *Boswellia* are under threat in the study area similarly as in other parts of the country. The same authors also indicated that at tree level, sexual reproduction decreased with increasing tapping regime irrespective of tree size. Such relatively intermediate regeneration condition of the study species may be attributed to the agro-pastoralist mode of life at the area which leads to a continuous trampling and free grazing (Groenendijk et al., 2012). The result of the regeneration analyses further showed, even if there was variation in density, and horizontal distributions, all the study species at district was represented at the sapling stage. It was revealed by the key informants that most of the *B. neglecta* was palatable for livestock. Although, *B. neglecta* has an average regeneration; however, there is a possibility to start the resin or "tikur etan" (meaning: black incense) business in the area with the existing harvestable number of *B. neglecta* trees in the area. Integration of resin with livestock and agricultural sectors could be considered as an alternative source of livelihood in South Omo dry land. We suggest the possibility of future commercialization of this versatile resource in general and the sustainable production of resin with the implementation of sustainable management at the study area. Sustainably managing the woodland as oleo-gum resins source has a dual purpose helping to meet both the objectives of livelihoods and carbon sequestration (Lemenih et al., 2003; Yosef et al., 2019). However, the yield of resin per plant and the practice of resins tapping by the people were not investigated, which we consider are the limitations of the present study.

Physicochemical characteristics of the resin and essential oil

The resin sample had a moisture content of 2.68% in the present study and this moisture content of the resin was lower than the moisture content of gum resin (10.6%) reported from *Commiphora africana* (Gundidza et al., 2011). Similarly, as compared to the present study, higher moisture content was reported for oleo gum resin (10-11%) from *Boswellia serrata* (Alam, Khan, Samiullah, & Siddique, 2012) and resin (8.9–10.6%) of *Commiphora abyssinica* (Gitau, 2015). Moisture content may vary due to difference in age of trees, exudation time, season, storage type, and climate (Franco et al., 2012; Montenegro, Boiero, Valle, & Borsarell, 2012). The pH of the resin in the present study was relatively higher and less acidic as compared to those of gum resin of *Commiphora schimperi* which have pH 5.39 in Chesori (2008) and gum resin of *C. abyssinica* which have pH 5.20 to 5.31 (Gitau, 2015). The nitrogen content of the resin from *B. neglecta* in the present study is within the range reported for resins in FAO (Food & Agriculture Organization) (1990). The nitrogen content value of the resin, however, was higher than oleo-gum resin (0.16%) from *B. serrata* (Alam et al., 2012) and lower than gum resin (1.5–1.8%) of *Commiphora abyssinica* (Gitau, 2015). The ash content represents the quantity of inorganic matter, and the lower the value of the ash content, the higher the degree of purity (Glicksman, 1970). The ash content of the resin of *B. neglecta* was lower than the gum resin (2.2–3.0%) of

Commiphora abyssinica (Gitau, 2015). The variations in ash content of resins in different studies were attributed to factors such as the degree of verification, environmental conditions, and picking time (Franco et al., 2012; Montenegro et al., 2012). In general, the *B. neglecta* resin in the present study can be considered of good quality.

The oil yield in the present study was higher than the yield obtained for *B. neglecta* (5%), *B. pirottae* (5%) and *B. rivae* (4%) in the study of Baser et al. (2003). The yield from *B. neglecta* was also higher than the maximum of the range for essential oil yield (0.5–-0.8%) for *B. neglecta* growing in Konso, Southern Ethiopia (Fanta, Ede, & Dekebo, 2013) and more than specifications range of 1.5–2% from most oleo-resins producing species (Srivastava, Chowdhury, & Thombare, 2016). This could indicate the potential of the resins of *B. neglecta* for essential oil production in the study area. The differences among reins for oil contents with location and/or tree have been reported, and it was often attributed to the age of trees, exudation time, season, storage type, and climate (Montenegro et al., 2012). The color of the essential oil in this study had comparable description to that from *B. neglecta* and *B. rivae* from Ethiopia (Baser et al., 2003). The essential oil in the present study was optically active and was found to be levorotatory. The specific rotation value of the essential oil of *B. neglecta* resin was lower than *C. abyssinica* gum resin, whose optical rotation was between −44.5° to −51° (Gitau, 2015). The specific rotation of the essential oil of *B. serrata* resin was dextrorotatory with optical rotation of +24° (Alam et al., 2012). Similarly, the specific rotation of the essential oils of *B. sacra* resin was dextrorotatory and had optical rotation ranging between +0.176° and +0.462° (Saidia, Rameshkumarb, Hisham, Sivakumara, & Kindya, 2012).

The composition of essential oil

The presence of lower molecular weight mono and sesquiterpenes is of considerable interest as these highly volatile components are rapidly lost upon aging and heating. In addition, diterpenes exhibit low volatility and triterpenes very low volatility. The presence of α-pinene, limonene, α-terpineol, sabinene, 4-terpineno1, and α-terpinyl acetate is in the essential oil of *B. neglecta* agreed with previous reports for *B. neglecta, B. rivae, B. pirottae*, and *B. papyrifera* in Ethiopia (Baser et al., 2003; Dekebo, Zewdu, & Dagne, 1999). The essential oil of *B. neglecta* in the present study was composed mainly of methyl oleate (25.92%) and methyl linoleate (25.29%), methyl palmitate (13.62%) and α-pinene (6.27%) which differs from the previous studies on essential oils from resins of different *Boswellia* species (Baser et al., 2003; Dekebo et al., 1999; Fanta et al., 2013). In a previous study by Baser et al. (2003), hydrocarbon and oxygenated monoterpenes: thujene (19.2%), α-pinene (16.7%) and terpinen-4-ol (12.5%) were found to be the most abundant components of the essential oil of the resin of *B. neglecta*. Ester derivatives and diterpene derivatives: incensole acetate (39%), nerolidyl propionate (27%), n-octyl acetate (19%), neocembrene A (7%), verticillol (8%), and biformene (8%) were found to be the most abundant components of the essential oils of the resin of *B. neglecta* (Fanta et al., 2013). The variation in main constituents of the essential oils of the same species could be attributed to the climate, harvest conditions, and the geographical source (Hussain, Al-Harrasi, Al-Rawahi, & Hussain, 2013). Besides, the main constituents differed largely in the essential oils of *B. sacra* between reports (Al-Harrasi & Al-Saidi, 2008; Ammar, Founier, & El-Deeb, 1994), and this variation was attributed to the sample collection method (Al-Harrasi & Al-Saidi, 2008). Further, the main constituents of the essential oils varied within species of

B. serrata and *B. carteri*, and the variation was ascribed to a possible existence of different chemotypes (Hussain et al., 2013). Consistent to the dominance of ester derivatives in the present study, n-octyl acetate (63.5%) was the main compound in *B. papyrifera* resin essential oil besides minor amounts of n-octyl formate and n-decyl acetate (Camarda, Dayton, Stefano, Pitonzo, & Schillaci, 2007). In addition, a straight-chain alkyl-esters (e.g., methyl linoleate, methyl dodecenoate) and carboxylic acids (e.g., n-tetradecanoic acid, hexadecenoic acid) were found in the essential oils of the genus Boswellia (Hussain et al., 2013). Methyl oleate, methyl linoleate, and methyl palmitate (isolated from other plants), showed antioxidant, antibacterial, and antifungal properties (Pinto et al., 2017; Rahman, Ahmad, Mohamed, & Rahman, 2014). This may imply that the *B. neglecta* resin could have a medicinal value besides its use as incense. Thus, we recommend further study on medicinal value of the resin's essential oil and on factors causing the variation of main oil constituents of *B. neglecta*.

Conclusions

Boswellia neglecta had the highest density (142 individual ha $^{-1}$) and it accounted for 14.79% of the stem composition of the study woodland. The total basal area of *B. neglecta* was the highest (0.94 m^2 ha^{-1}), and hence *B. neglecta* was the most dominant species recorded. *Boswellia neglecta* had also the highest relative and absolute frequency. The highest dominance and frequency of *B. neglecta* species could indicate the potential of the tree for bulk collection of resins. *Boswellia neglecta* had the highest value of IVI (44.51) and it was relatively dense across the study area. The diameter class distribution of the *B. neglecta* species was of type-II and this might suggest mortality or intensive use of matured trees. Despite the average recruitment, there is a reasonable number of seedlings and relatively large number of middle diameter class individual that could be managed for resin production. Therefore, the status of tree species at the study district could show the opportunity of sustainable development of the woodland for resin production from *B. neglecta*. With improved management of the woodland as oleo-gum resins source, the woodland could contribute more to the livelihood of the inhabitants with possibly added benefits from carbon sequestration.

The physico-chemical properties of the resin from *B. neglecta* in the study area showed a good agreement except the ash content with similar studies and international standards. The major components of the essential oil of *B. neglecta* were α-pinene, methyl palmitate, methyl linoleate, and methyl oleate in increasing order of their compositions. Moreover, methyl palmitate, methyl linoleate, and methyl oleate were components, which were not reported in previous studies from the species. The presence of these compounds may indicate that the resin from *B. neglecta* can have a medicinal value. *Boswellia neglecta* resin also contains many other chemical constituents and we recommend further chemical and biological studies to identify its medicinal contribution. In addition, for sustainable production of resin, an immediate conservation and utilization of the woodland is needed.

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