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Gum Arabic Production and Population Status of *Senegalia senegal* (L.) Britton in Dryland Forests in South Omo Zone, Ethiopia

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Abstract: *Senegalia senegal* (L.) Britton is a multi-purpose dryland tree species that produces gum arabic, a commercially valuable product. However, this resource is underused in Ethiopian dryland areas. The aim of this study was to evaluate the population status and potential gum yield of *S. senegal* growing in natural stands in South Omo Zone, Ethiopia. Forty-five sample plots, each measuring 20 × 20 m, were established at 500 m intervals along transects, with 1 m^2 subplots located within the main plots to determine regeneration. *S. senegal* trees with a diameter at breast height of between 2 and 12 cm were most prevalent. Forty-two tree species were associated with *S. senegal*, of which 16 were gum- and resin-producing species. *S. senegal* was positively associated with *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *Commiphora edulis*, and *Dobera glabra*. *Senegalia senegal* comprised approximately 35% of regenerating trees. The maximum gum arabic yield obtained was 3948 g $tree^{-1}$. Linear models of dendrometric variables indicated that gum arabic yield is better predicted by tree diameter than by height. Despite the limitations of this pioneer survey, the population status and yield potential suggest that gum arabic could be sustainably produced and commercialized in natural stands of *S. senegal* in the studied dryland areas, providing local communities with supplementary seasonal incomes.

Keywords: commercialization; gum and resin; gum arabic; *Senegalia senegal*; stand; tapping

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1. Introduction

Forests in dryland areas are a crucial part of the livelihoods of the people that live in these areas worldwide [1,2], while supporting other economic activities through their ecological services and functions [3,4]. If managed properly, dryland forests have the capacity to provide a perpetual stream of non-timber forest products (NTFPs), such as gum and resin, edible plants, wild fruit, medicinal plants, fuelwood, and mushrooms, providing households with food and medicine [5,6]. In addition, sales from NTFPs can provide households with supplementary seasonal incomes [7], especially in times of dwindling economic activities, such as low crop productivity and drought [5,8].

Only 15.7% of Ethiopia is covered by forest [9]. Despite this, the county is rich in bio-diverse forest resources. Nine broad vegetation types are recognized based on climate, vegetation formation (physiognomic and habitat groupings), and associations (species composition/structure) [10]. Among these, dry forests cover some 55 million ha in Ethiopia, and are the largest vegetation resource in the country [10]. These forests are rich in *Acacia*, *Boswellia*, and *Commiphora* species [11,12], which provide important export commodities such as gum arabic, frankincense, and myrrh [11,12]. These products provide an important source of cash income for rural people and are the most important export commodities produced by the forestry sector in Ethiopia [13]. However, dryland forests are continuously shrinking due to the expansion of agricultural lands and human settlements and are suffering from severe degradation due to anthropogenic pressures [10]. Furthermore, despite their important socio-economic and ecological benefits, dry forests are poorly managed and receive no proper silvicultural treatment or attention and, hence, are highly fragmented, have little natural regeneration, and are degraded in terms of species composition and productivity [10]. Thus, the challenges and threat of biodiversity loss persist. Furthermore, the unmonitored exploitation of these dryland regions could have a long-lasting and potentially irreparable effect on the forest ecosystem, as well as on the livelihoods of rural communities [14].

Senegalia senegal (L.) Britton is a multipurpose tree species that is grown in dryland areas of Ethiopia, providing socioeconomic and ecological benefits [15]. Natural stands of this species are dominantly found in *Acacia*–*Commiphora* woodlands in the western and southern lowlands of Ethiopia [12,15]. The species is highly valued for its production of gum arabic from trunks, branches and twigs [16]. Gum arabic has a wide range of technological applications in the food, pharmaceutical, and cosmetic industries [16,17] and, hence, is considered a very important economic resource worldwide [18]. *Senegalia senegal* is also ecologically important because it improves soil fertility and is widely used to control desertification [19]. This species is therefore potentially suitable for future reforestation or restoration efforts in moisture-deficient arid and semi-arid areas [19,20]. Furthermore, *S. senegal* trees also provide wood for use as fuel and local construction materials, as well as leaves and pods, which are used as livestock fodder. In addition, the nitrogen-fixing ability of *S. senegal* trees makes them highly suitable for use in agroforestry systems, where they are grown in combination with agricultural crops [17].

Like forest resources in other parts of Ethiopia, dryland forests in the South Nation, Nationalities and People Region (SNNPR) are subject to increasing pressure [4,10]. Deforestation in this area is driven by rapid population growth and the consequent clearance of forests for cropland expansion and by overgrazing [21], which seriously affects the population and regeneration of valuable tree species such as *S. senegal* [22]. Although some studies have investigated the growth performance, gum yield [17], and socioeconomics [4,11] of this species, *S. senegal* populations in different parts of Ethiopia are still inadequately characterized. Managing dry forests so that they can produce a range of NTFPs, such as gum and resin, even to a certain extent in combination with forest-compatible uses such as livestock grazing [11], is considered critical for their continued viability as a source of crucial resources in dryland areas of Ethiopia. Based on these considerations, the National Forests Sector Development Program of Ethiopia (NFSDPE) has devised a strategy to conserve and develop the country's forest resources, with the aim of increasing the proportion of Ethiopia covered by forest from 15% to 20% by 2028 [9]. This strategy also aims to enhance the production and utilization of various NTFPs, such as gum and resin, by undertaking surveying, mapping, and investigations of the resource base and assessing their potential for commercial utilization in dryland areas [9]. Thus, to conserve, manage and use the existing *S. senegal* stands in the South Omo Zone, it is crucial to understand the current population structure, density, and natural regeneration of this species. Furthermore, the conservation and sustained management of *S. senegal* stands appears to depend largely on the benefits that rural households receive from this species. Thus, an estimation of gum arabic yield potential and an understanding of important factors that influence gum production is imperative. Such information could be used to devise management strategies [23] and subsequently provide adequate information for setting appropriate harvest levels based on the status of the species [24,25]. With this goal in mind, the objectives of this study were: (1) to assess the species diversity associated with *S. senegal* trees and the current status and demography of *S. senegal* trees; (2) to evaluate the gum arabic yield potential of *S. senegal* trees; and (3) to evaluate the dendrometric variables associated with *S. senegal* gum production in South Omo Zone, SNNPR, Ethiopia. The information gathered in this research could help to safeguard the longevity and the proliferation of valuable

NTFP-producing tree species in lowland areas, as well as the livelihoods supported by these resources, both in the study area and country-wide.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in the Bena Tsemay district of the South Omo administrative zone in south-west Ethiopia in the SNNPR (Figure 1). The district is located between 5.11°–5.70° N and 36.20°–37.04° E [26], with average temperatures ranging from 10.1 °C to 27.5 °C and a mean annual rainfall ranging from 400 to 1600 mm. The study area is characterized by bimodal rainfall: the first rainy season occurs from mid-March to the end of April, which is important for crop production; a second short rainy season occurs from mid-October to the beginning of November, which is important for pasture production. The study area is 500–1500 m above sea level (m asl) [26]. The dominant vegetation types are mixed, the *Combretum*–*Terminalia* and *Acacia*–*Commiphora* woodlands, which are used as rangelands and common property resources of the whole community [27].

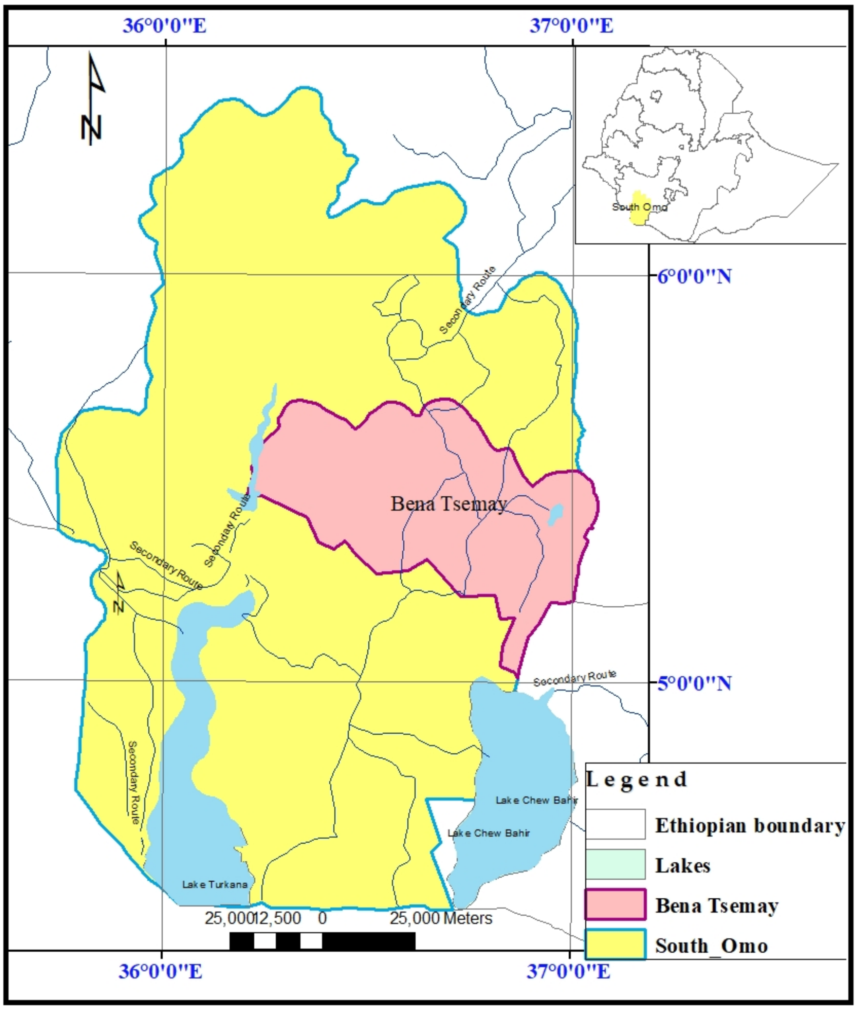

Figure 1. Map of the Bena Tsemay district showing the location of the study area, South Omo Zone, Southern Nations Nationalities and People's Region, south-west Ethiopia.

2.2. Vegetation Inventory and Data Collection

Prior to the vegetation survey, a reconnaissance survey was undertaken in order to obtain an impression of the vegetation and topographic features in the study area. Vegetation data were collected in sample quadrants placed along transect lines, which were laid out systematically [28]. A total of 45 plots, 20 × 20 m in area, were laid out along

10 transect lines based on the concept of minimal area [29]. Plots were laid out every 500 m along transect lines, which were laid 400 m apart. All woody plant species, including trees and shrubs, were recorded in the 20 m × 20 m quadrants, whereas seedlings were counted in 1 m × 1 m subplots that were subjectively placed within the main plots [30,31]. All plant species were counted at an individual level within each main plot and subplot. Height and diameter at breast height (DBH) measurements were recorded for any woody plant species with a height ≥ 1.5 m and a DBH ≥ 2 cm. Individual plant with a height < 1.5 m and a DBH < 2 cm were counted [32]. Height and DBH measurements were obtained using a clinometer and a diameter tape, respectively. Plants < 1.5 m in height were measured using calibrated sticks [32]. Every plant species encountered in each plot was recorded using their scientific name. Vernacular names were also recorded whenever possible. For those species that were difficult to identify in the field, plant specimens were collected, pressed and then taken to the Ethiopian Environment and Forestry Research Institute for taxonomic identification. Published volumes of the Flora of Ethiopia and Eritrea [33,34] were used to identify plant specimens.

2.3. Gum arabic Yield Estimation

Gum production from *S. senegal* was evaluated on a per tree basis using the harvesting method [17,35]. Thirty-six individual *S. senegal* gum-producing trees growing in the study area were randomly selected. The selected trees had an almost uniform diameter. They were tagged and tapped with a "sunki" axe to yield strips of relatively similar depth, width, and length. Gum was harvested from each tree in January and February. The gum yield from each harvest was collected in a separate labeled paper bag and weighed using a high-precision balance after drying at room temperature. The total yield data for each tree was obtained by summation.

2.4. Data Analysis

The population structure of *S. senegal* was shown using frequency histograms to depict the diameter classes and the number of seedlings [32]. All individuals of each species encountered in the quadrants were arbitrarily grouped based on their diameter into 5-cm diameter classes (<2 cm, 2–7 cm, 7–12 cm, 12–17 cm, 17–22 cm and >22 cm) [36,37]. Frequency was determined based on the number of plots in which the species was recorded [29]. Density was calculated based on the number of individuals of each species per unit of area [32] using Equation (1).

$$\text{Density/ha} = \left(\sum_{i=1}^{n} \frac{d}{n}\right) \times 25 \quad (1)$$

where d is the number of stems/plot and n is the number of plots. Gum yield (kg) per hectare and year was calculated by multiplying the mean *S. senegal* stem density per hectare calculated above with the mean yield (kg/tree/year) (Equation (2)) following Dejene et al. [31]. Mean gum yield was obtained from previous studies of *S. senegal* [38].

$$\text{Gum yield/ha} = \left(\sum_{i=1}^{n} \left(\frac{d}{n}\right) \times 25\right) \times (\text{y (kg/tree} \times \text{year)}) \quad (2)$$

where d is the stem density/plot, n is the number of plots, and y = is gum yield per tree and year.

The association between the number of *S. senegal* trees and the number of other vascular tree species in the study area was assessed through matrices showing correlation coefficients and their significance levels using libraries "Hmisc" and "corrplot" in R [39]. The relationship between gum yield and individual tree attributes was determined through linear regression. The power of regression equations was seen by their R-values. Coefficients of each equation were used to estimate the gum yield of individual trees. Data were analyzed using R software [39].

3. Results

3.1. Species Composition and Size Structures

Forty-two tree species belonging to 26 genera and 13 families were recorded in woodland in the study area (Table 1). The majority of the species (83%) belonged to one of six families: the Fabaceae (14 species), Burseraceae (ten species), Malvaceae (four species), Combretaceae (three species), Anacardiaceae (two species), and Capparaceae (two species). The other seven families were represented by only a single species (Table 1). Sixteen tree species, including seven species of *Commiphora*, five species of *Acacia* (in the genus name of the *Vachellia* and *Senegalia*), and two species of *Combretum*, were identified as sources of either commercial gum and resins or adulterants. The genera *Sterculia* and *Boswellia* were each represented by one species. In terms of tree density, *S. senegal* had the fourth highest density (41 individual stems ha^{-1}), thus accounting for 7% of stems. The most prevalent species in the study area were *Boswellia neglecta* (91 individual stems ha^{-1}) and the gum- and resin-producing trees *Boscia coriacea* (70 individual stems ha^{-1}) and *Commiphora africana* (55 individual stems ha^{-1}) (Table 1).

Table 1. Density (individual stems ha^{-1} with a DBH $\geq$ 2 cm) of trees and percentage of each tree species recorded in woodland in the study area, South Omo Zone, Ethiopia.

No.	Species	Family	Density (ha^{-1})	(%)	GR
1	*Acokanthera schimperi* (A.DC.) Oliv.	Fabaceae	1	0.17	
2	*Albizia schimperiana* Oliv.	Fabaceae	40	6.29	
3	*Annona senegalensis* Pers.	Annonaceae	3	0.42	
4	*Balanites aegyptiaca* (L.) Delile	Zygophyllaceae	14	2.27	
5	*Berchemia discolor* (Klotzsch) Hemsl.	Rhamnaceae	2	0.25	
6	*Boscia coriacea* Pax	Capparaceae	70	10.99	
7	*Boswellia neglecta* S.Moore	Burseraceae	91	14.35	x
8	*Combretum aculeatum* Vent.	Combretaceae	4	0.67	x
9	*Combretum molle* R.Br. ex G.Don	Combretaceae	2	0.25	x
10	*Commiphora africana* (A.Rich.) Endl.	Burseraceae	55	8.64	x
11	*Commiphora boranensis* Vollesen	Burseraceae	26	4.03	x
12	*Commiphora bruceae* Chiov.	Burseraceae	14	2.27	x
13	*Commiphora cyclophylla* Chiov.	Burseraceae	5	0.84	x
14	*Commiphora edulis* (Klotzsch) Engl.	Burseraceae	24	3.78	x
15	*Commiphora erythraea* (Ehrenb.) Engl.	Burseraceae	3	0.50	
16	*Commiphora myrrha* (Nees) Engl.	Burseraceae	15	2.35	x
17	*Commiphora schimperi* (O.Berg) Engl.	Burseraceae	31	4.95	
18	*Commiphora terebinthina* Vollesen	Burseraceae	16	2.52	x
19	*Dalbergia melanoxylon* Guill. & Perr.	Fabaceae	2	0.34	
20	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	3	0.42	
21	*Dobera glabra* (Forssk.) Juss. ex Poir.	Salvadoraceae	5	0.76	
22	*Euphorbia tirucalli* L.	Euphorbiaceae	4	0.59	
23	*Faidherbia albida* (Delile) A.Chev.	Fabaceae	3	0.42	
24	*Grewia bicolor* Juss.	Malvaceae	23	3.69	
25	*Grewia tenax* (Forssk.) Fiori	Malvaceae	21	3.27	
26	*Grewia villosa* Willd.	Malvaceae	36	5.71	
27	*Lannea schimperi* (Hochst. ex. A. Rich.) Engl.	Anacardiaceae	24	3.78	
28	*Maerua angolensis* DC	Capparaceae	3	0.50	
29	*Morus mesozygia* Stapf	Moraceae	3	0.42	
30	*Piliostigma thonningii* (Schum.) Milne-Redh.	Fabaceae	3	0.42	
31	*Sarcocephalus latifolius* (Sm.) E.A.Bruce.	Rubiaceae	2	0.25	
32	*Sclerocarya birrea* (A.Rich.) Hochst.	Anacardiaceae	3	0.42	
33	*Senegalia brevispica* (Harms) Seigler & Ebinger	Fabaceae	3	0.42	
34	*Senegalia mellifera* (M. Vahl) Seigler & Ebinger	Fabaceae	10	1.51	x
35	*Senegalia senegal* (L.) Britton	Fabaceae	41	6.54	x
36	*Sterculia africana* (Lour.) Fiori	Malvaceae	7	1.17	x
37	*Terminalia brownii* Fresen.	Combretaceae	3	0.42	
38	*Vachellia oerfota* (Forssk.) Kyal. & Boatwr.	Fabaceae	2	0.25	
39	*Vachellia nilotica* (L.) P.J.H.Hurter & Mabb.	Fabaceae	8	1.26	x
40	*Vachellia seyal* (Delile) P.J.H.Hurter	Fabaceae	2	0.34	x
41	*Vachellia sieberiana* (DC.) Kyal. & Boatwr.	Fabaceae	2	0.34	
42	*Vachellia tortilis* (Forssk.) Galasso & Banfi	Fabaceae	7	1.17	x

Note: Abbreviation: GR, gum- and resin-producing tree species. The genus names of *Vachellia* and *Senegalia* are also known as *Acacia*.

Most of the *S. senegal* trees were found in the 2–7 cm and 7–12 cm diameter classes than in the larger diameter classes. However, the number of *S. senegal* trees in all diameter classes was significantly lower than that of the total vegetation. The total population status of *S. senegal* and of all the trees recorded is shown in Figure 2A. A comparison of the diameter classes of the three most common gum- and resin-producing tree species indicated that there was a significantly greater number of *B. neglecta* trees in the 2–7 cm diameter class than of *S. senegal* ($p < 0.0001$) or *C. africana* ($p = 0.009$) (Figure 2B), whereas the number of *S. senegal* and *C. africana* trees was not significantly different ($p = 0.661$). Furthermore, in the 7–12 cm diameter class, there were significantly fewer *S. senegal* trees than there were of the other two species ($p < 0.05$). However, in diameter classes with a DBH > 12 cm, the number of trees of each species did not differ significantly ($p > 0.05$) (Figure 2B).

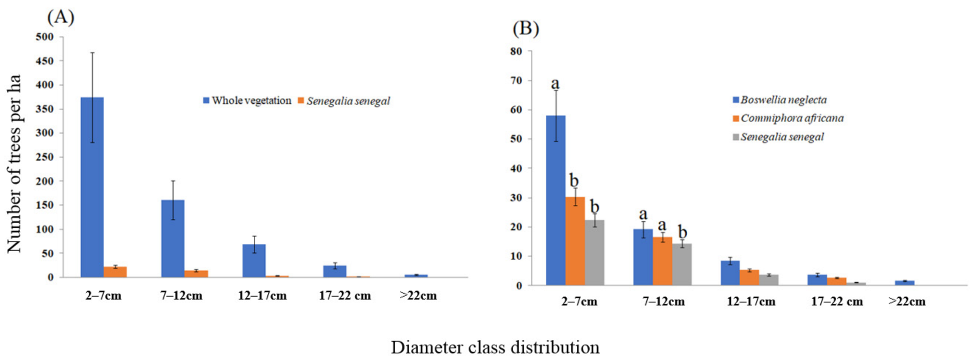

Figure 2. Diameter class distribution of the whole vegetation (**A**) and of *Senegalia senegal* trees (**B**) and of the three most prevalent gum- and resin-producing tree species in the study area (South Omo Zone, Ethiopia). Bars represent the standard deviations of the mean. Values with a different letter within a diameter class are significantly different ($p < 0.05$).

In the vegetation composition of the study area, *Senegalia senegal* was positively associated and coexisted mainly with *Vachellia tortilis* (cor = 18%; $p = 0.02$), *Senegalia mellifera* (cor = 17%; $p = 0.025$), *Vachellia nilotica* (cor = 14%; $p = 0.03$), *Commiphora edulis* (cor = 18%; $p = 0.02$), and *Dobera glabra* (cor = 21%; $p = 0.01$) tree species. The associational relationships of the *S. senegal* with other vascular tree species is provided (Figure 3).

3.2. Regeneration Status

We assessed the natural regeneration of the 42 vascular tree species growing in the study area; however, seedlings of only ten species were found (Figure 4), indicating that the regeneration of the other 32 species was hampered by various factors. Among the 10 regenerating tree species, *S. senegal* seedlings were the most abundant (35.15% of seedlings), followed by *Grewia bicolor* (22.65%), and *Commiphora edulis* (18.75%), with the other seven regenerating tree species making up 23.44% of the seedlings (Figure 4).

Among the five gum- and resin-producing tree species showing natural regeneration, *S. senegal* seedlings were the most abundant, followed by *Commiphora edulis*. Together, these two species accounted for approximately 75% of the natural regeneration of gum- and resin-producing tree species, with the other three species making up approximately 25% of the seedlings.

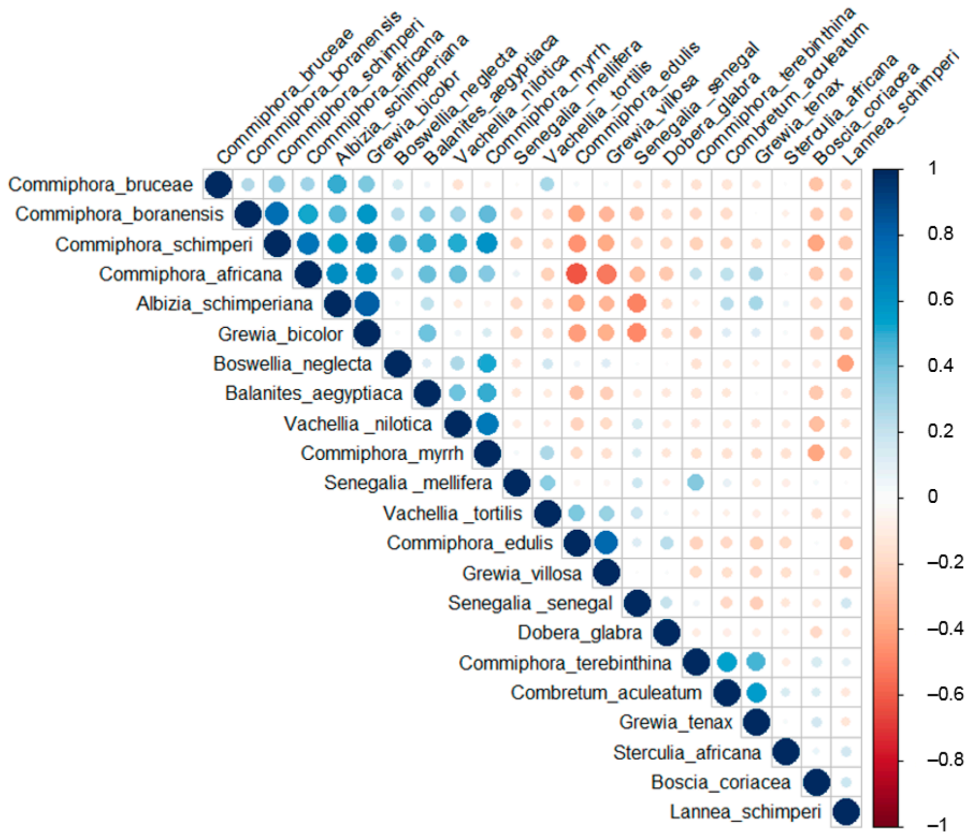

Figure 3. Correlation matrix visualizing relationships of the most prevalent vascular plants found in the study area and their relationship with the target tree species (*Senegalia senegal*). Positive correlations are displayed in blue and negative correlations in red. Color intensity and the size of the circle are proportional to the correlation coefficients. On the right-hand side of the correlogram, the legend color shows the correlation coefficients and the corresponding colors. The size of the circle indicates the magnitude of the relationship.

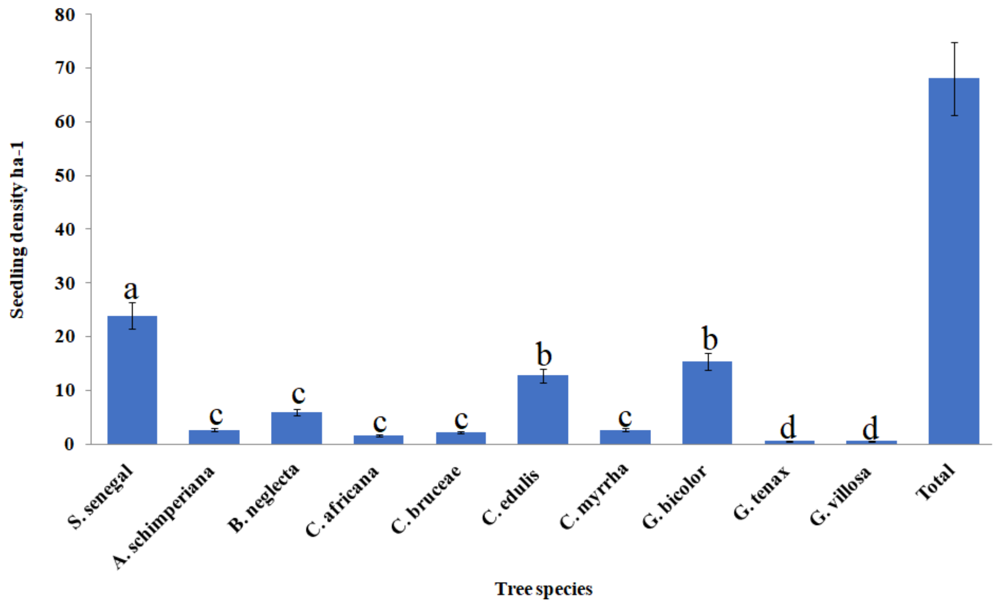

Figure 4. Seedling density (individuals ha^{-1}) of regenerating tree species in the woodland in the study area, South Omo Zone, Ethiopia. Bars represent the standard deviation of the mean. Values with a different letter are significantly different ($p < 0.05$).

3.3. Gum Arabic Yields and Prediction Models

Among the gum-producing *S. senegal* trees, the highest yield obtained from harvests in January and February was 3948 g tree^{-1} whereas the lowest was 266 g tree^{-1}. The mean gum yield per tree for the harvests in January and February differed significantly (F = 12.62; p = 0.001), with a higher yield obtained in January (1496 g trees^{-1}). The mean stem density of *S. senegal* trees with a diameter $\geq$ 2 cm was 41 stems ha^{-1} (Table 1) and the mean gum yield was 2063 g trees^{-1} year^{-1}. Based on these findings, we estimate that a mean gum arabic yield of approximately 190 to 84,578 g ha^{-1} year^{-1} could be expected from two harvests (January and February).

A linear model of the dendrometric variables indicated that gum arabic yield per *S. senegal* tree could be predicted by diameter ($p < 0.05$) rather than by height. Regressing gum yield against the diameter and height yielded the equations in Figure 5. The R2 value of the diameter indicated that the model fits the data well and that tree diameter could explain 21.48% of the variation in gum arabic yield. The sign of the coefficient for the diameter was positive, which indicates that as tree diameter increases, gum yield also increases. Thus, the average gum yield would increase for every one unit increase in the diameter of *S. senegal* trees.

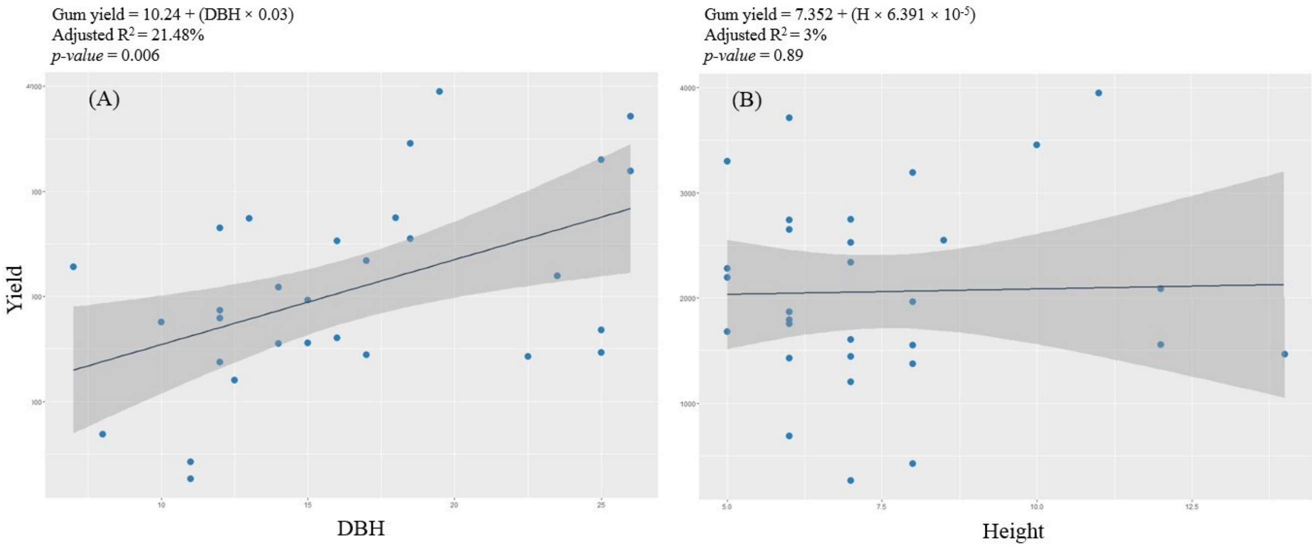

Figure 5. Linear regression models of observed and predicted values of gum arabic yield based on (**A**) diameter at breast height (DBH) and (**B**) height of *Senegalia senegal* trees growing in the study area, South Omo Zone, Ethiopia. Blue circles represent the observed gum yield, the black lines indicate the line fit plots and the dark-gray areas indicate the 95% confidence intervals.

4. Discussion

Forests in lowland areas in developing countries are important resources with the potential to provide services to rural communities [40]. In Ethiopia, dry forest is the largest remaining type of forest vegetation and more than half (52%) of the country is covered with dryland vegetation, including open canopy forests, wooded savannas, and scrub grasslands [41]. These forests are rich in *Acacia*, *Boswellia*, and *Commiphora* tree species that provide important commodities such as gum arabic, frankincense, and myrrh, respectively [10,42]. In this study, we identified 42 vascular plant species, of which 16 species (38%) were gum- and resin-producing tree species, which were considered the most useful trees. The number of gum- and resin-producing species recorded in this study appears to be higher than that reported to date from other dryland agro-ecologic zones in Ethiopia. For example, only *Senegalia senegal* and *Vachellia seyal* were reported as gum- and resin-producing tree species in a survey of the central Rift valley woodlands of Ethiopia [43]. Other studies of the northern part of Ethiopia have reported *Boswellia papyrifera*, *S. senegal*, *V. seyal*, and *Sterculia setigera* as the main sources of gum and resins [12]. In general, our findings suggest that the South Omo Zone supports more gum- and resin-bearing species than other parts of the country and, hence, there is a greater opportunity for the commercialization of different NTFPs in the form of gum, resin, and myrrh [4,42]. Apart from gum- and resin-bearing tree species, we also found some important wild tree species with edible fruit, such as *Dobera glabra*, which could play a vital role in food security in dryland areas because this fruit is generally collected for subsistence use by local communities [5]. Consistent with other studies, the presence of these valuable tree species among the vegetation of the study area suggests that this forest resource could enhance the livelihoods of local communities through income generated from the various NTFPs [11,32].

Previous studies of gum production have involved stands of *S. senegal* trees with a diameter $\geq$ 4 cm [17]. In this study, we sampled trees with a diameter $\geq$ 2 cm because Yebeyen [43] reported that these trees are considered to be sufficiently mature for gum production purposes. The average density of *S. senegal* trees with a diameter $\geq$ 2 cm was 41 stems ha^{-1} (37% of *S. senegal* stems in the study woodland), which is lower than that reported in other areas of Ethiopia. For example, Yebeyen [43] reported 12–209 *S. senegal* trees ha^{-1} in the rift valley areas of Ethiopia. Similarly, Dejene et al. [31] reported 211 trees ha^{-1} in Abderafi district in north west Ethiopia. The higher density of *S. senegal* in both these areas might be because the vegetation is dominated by *S. senegal* trees in these areas. In our study, *S. senegal* was mainly found in association with *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *C. edulis*, and *D. glabra*. Most of these species have a wide, dense crown that is umbrella-like and flat-topped [15]. Tree dimensions and structure are of great importance in natural and managed forest ecosystems because they can influence the resource retention capacities of individual trees and, hence, affect their growth and survival [44]. Thus, trees with a dense umbrella-like crown, together with aspects such as the capacity of the forest soil to retain water or rainfall, might limit the number of individual plants per area that can grow under this type of tree and, hence, the overall composition of the vegetation in the ecosystem. Despite the comparatively low density of matured *S. senegal* trees in the study woodland, there is a sufficient number of *S. senegal* trees and associated gum- and resin-producing tree species to support the launch of a commercial gum arabic and resin-harvesting enterprise in the study area. In addition, the regeneration status of *S. senegal* is good compared with that of other species found in the study area, possibly reflecting the abundant seed production of *S. senegal* and their contribution of seeds to the soil seed bank [45]. The thorny nature of *S. senegal* might also help seedlings to escape the browsing effects of cattle [31], which might indicate that *S. senegal* trees are a sustainable resource in this study area.

The average gum arabic yield from tapped trees in this study was 2060 g tree^{-1}, with yields ranging from 266 g to 3948 g trees^{-1} in a two-month period, indicating a high level of variation in gum yields among individual trees. Although information on gum yield from different provinces is scarce, our findings agree with those of a similar study conducted in Ethiopia. Alemu et al. [17] showed that gum yield from a managed plantation of *S. senegal* trees could provide on average 96 g per two months of harvesting. Furthermore, a study performed in the Abderafi area, where the woodland is dominated by *S. senegal* trees (211 stems ha^{-1}), estimated that 190 to 422 kg ha^{-1} year^{-1} of gum arabic could be harvested, which could be worth approximately $US 950 to 2110 ha^{-1} year^{-1} [31]. The yield estimated in this study is based on two harvests in January and February, which may be a more intensive period of tapping compared with those of other studies, which may have resulted in a lower annual gum yield per hectare in our study area compared with that of other studies. However, taking the overall average gum arabic yield of 2060 g per individual tree and dividing it by 16 tapping seasons, the overall average yield/tree/season would be 129 g per season. Therefore, the predicted yield that could be obtained from the *S. senegal* trees in our study is greater than that predicted by Dejene et al. [31] and Alemu et al. [17] for natural and plantation forests, respectively.

The relationship between gum yield per tree and tree parameters was expressed using linear regression models. The model based on *S. senegal* DBH measurements enabled an accurate estimation of gum yield from the study area woodlands. However, previous studies have indicated that gum yield not only depends on stem diameter but also on the tapping intensity, number of tree branches, direction of tapping and season [16,17]. Furthermore, all these tree parameters are affected by environmental and geographical factors such as rainfall, temperature, latitude and longitude, and soil conditions [46,47], which might have a direct impact on the accuracy of the models. Our model based on DBH measurements provides new insights regarding the potential commercial development of gum arabic production in dryland areas as an off-farm activity to supplement the household economy of local communities together with the other associated gum- and resin-producing tree species. However, further models that include more ecological variables should be developed to extrapolate this potentiality to other understudied areas. Furthermore, the findings from this preliminary study could be used to estimate the gum arabic yield per tree and season in natural stands in the study area. Yield assessments should also be carried out for several seasons to determine the best tapping time/dates.

5. Conclusions

This study highlighted the population status of *Senegalia senegal* trees in a dryland area of South Omo Zone, SNNPR, Ethiopia. In addition, we have provided useful preliminary information on gum yield and a model based on *S. senegal* DBH measurements as a predictor for potential gum yield by this species. However, further modeling studies are needed to incorporate environmental and geographical factors that affect tree parameters to determine whether these factors influence the accuracy of the yield model. Further yield assessments should be carried out for several seasons to determine the best tapping time. Overall, there is a good level of regeneration and the diameter distribution of individual *S. senegal* trees indicates that most are mature enough to be tapped. This indicates that gum arabic harvesting could be started in this area if appropriate management activities are applied. Thus, this study provides baseline information that could be used for planning future economic development in the study area based on the use of NTFPs, mainly gum- and resin-production, through considering the multiple uses of gum- and resin-producing species. The findings from this study also provide baseline information about gum yield that could be used to promote the protection, conservation, planting, taping, or commercial use of the *S. senegal* trees in South Omo Zone, Ethiopia. The gum yield data could be used to estimate gum arabic yields per *S. senegal* tree per year in the study area at different density levels and could also be used to assist other developing countries with valuable but underutilized trees like *S. senegal* that produce NTFPs. However, before gum arabic production can begin, management plans need to be established for natural forests to ensure the continuity and sustainability of gum arabic production, either by limiting production levels or the number of stems in different DBH classes that can be tapped.

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