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Gum and resin bearing dryland forests of the Somali region, Southeastern Ethiopia: Diversity, structure and spatial distribution

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ABSTRACT

Despite their ecological and socio-economic contributions, the lowland dry forests of Ethiopia have largely been neglected and hence experience severe deforestation and degradation challenges. It is, therefore, crucial to assess the status of the dry forest resources to formulate appropriate management strategies that facilitate their sustainable utilization. This study was undertaken to determine spatial distribution, species composition, structure, and regeneration of gum and resin-producing species in the dry forests of the Somali Regional State of Ethiopia. The recent Sentinel-2A image was procured and used to classify the area, using a supervised Random Forest Algorithm, into different land covers and vegetation types. Inside the two key vegetation types (Acacia dominated woodland and Mixed woodland), forest inventory was conducted by establishing 30 m x 30 m size quadratic sample plots. The results revealed that the study area was divided into settlement (0.2%), bare land (6.0%), undifferentiated forest (0.5%), acacia woodland (36.3%), mixed woodland (54.1%) and scrubland (2.9%). Thirty-four woody species were identified and recorded with a Shannon diversity of 3.03. The population structure showed a lack of sufficient natural regeneration. This shows that the forest containing the gum and resin-bearing species is not replacing itself as well as it should. On the other hand, if managed properly, the forest has the potential to produce various types of oleo-gum resins. Thus, implementing appropriate restoration measures is urgent to enhance natural regeneration. Moreover, formulating sustainable utilization while creating a product market of gum and resins are important consideration to ensure the conservation and sustainable use of dry forests in the region.

Keywords: Somali, Horn of Africa, Gum and Resin

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Introduction

Dry forests in the tropics are important forest biomes that support the livelihood of millions of people around the globe (Djoudi *et al.*, 2015). In addition, it provides multiple ecosystem services (Cortés-Calderón *et al.*, 2021). The dry forest covers about 42% of tropical and subtropical forests (Hasnat and Hossain, 2019). Compared with other biomes, it is much more prone to loss of biodiversity and habitat fragmentation due to the high rate of deforestation and forest degradation (Maass, 2010; Rivas *et al.*, 2020). While it comprises extensive distribution, it receives less research attention as compared to the moist tropical forests (Sunderland *et al.*, 2015).

The *Combreterm – Terminalia* and the *Acacia - Commiphora* are the two widely distributed forest ecosystems in the dry lowlands of Ethiopia. The resources are significant in biodiversity as they are endowed with numerous endemic plants and animals (Bareke, 2018). The woodland is also a source of various gum and resin products such as frankincense, myrrh, opopanax, and gum. It plays an important role economically, from enhancing household income (Berhanu *et al.*, 2021; Walle and Nayak, 2021; Worku *et al.*, 2014) to improving the GDP of the country (Mekonnen *et al.*, 2013).

Somali Regional State of Ethiopia is one of the regional states in Ethiopia where dry forests are the dominant vegetation types. El – Weyni district of Somali, region is known to have much of its areas covered with dry forests comprising large number of gum and resin-bearing species. However, this economically important resource has not properly managed and effectively utilized due to lack of adequate information on biodiversity aspects as well as on the distribution and production potential of gums and resin producing species and under development of markets. Hence, evidence-based planning and implementation of sustainable utilization is constrained by lack of adequate information. Forest inventory, which can reveal the existing diversity and structure of the forest, is an important phase in forest management. Understanding the regeneration status of woody species in general, and gum and resin-bearing species in particular, is fundamental in formulating appropriate policy and strategy both at a national and regional level. In addition, knowledge and information in these areas are crucial for the sustainable utilization of the resources.

Previous studies on gum and resin-bearing dry forests in Ethiopia have emphasized on the western and northwestern dry lowlands, providing critical information on their proper utilization and ecological sustainability (Addisalem *et al.*, 2016; Bekele, 2016; Mokria *et al.*, 2017; Yilma *et al.*, 2016), and socio-economic aspects (Eshete *et al.*, 2005; Tilahun *et al.*, 2015). On the other hand, there is scarce information on the forest resources of the Somali region of the southeastern lowlands. Limited work has been conducted in Somali Region on the current forest composition structure and the spatial distribution of the dry woodlands in general and gum and resin-bearing species in particular. The objective of this study was, therefore, to fill in the gap of information and determine the species composition, structure, and regeneration of gum and resin species. At the same time, it quantifies the spatial distribution of gum and resin-bearing species in the El-Weyni district of the Somali Regional State of Ethiopia.

Materials and Methods

The study area

The study was conducted in the El-Weyni district in the Somali Regional State of Ethiopia. It is located between 42° 45' to 43° 25' East and 6° 20' to 6° 45' north. El–Weyni was selected for the study because its resource endowment in terms of gum and resin bearing species in the region. The total area of the district is estimated at 242,030 hectares. The altitude ranges from 331 to 1035 m.a.s.l through an average value of 482 m.a.sl. The landform of the study area is mainly characterized by a smooth plain with some rugged topography in the northeastern section of the district. The climatic condition of the district is described as dryland affected by recurrent drought. The site has an annual average precipitation of 200 mm, and the mean maximum and minimum temperature is 28°C and 40°C, respectively (Hussein *et al.*, 2021).

The vegetation types of the study area are the dry woodland ecosystem types of *Acacia-Commiphora* woodland and scrubland (Friis *et al.*, 2010). In this ecosystem, gum and resin-bearing tree species are widely distributed. The woodland usually coexists with grasslands and pastureland. The pastoral system is the common livelihood means of the community in the area.

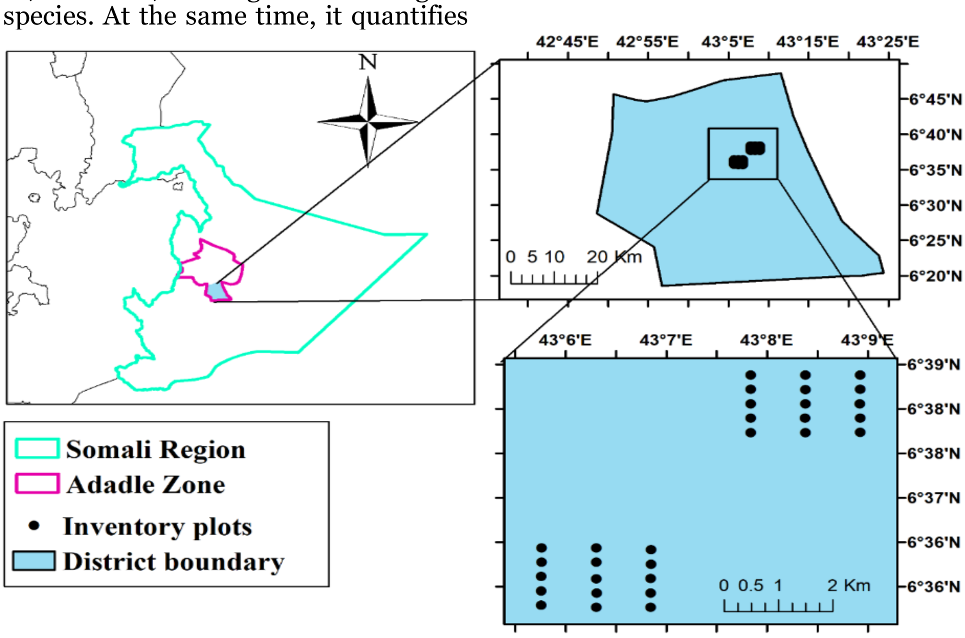

Figure 1. Location map of the study area and forest inventory plots.

Vegetation data collection and analysis

A reconnaissance survey was conducted before undertaking the forest inventory. A systematic random sampling technique was employed to lay sampling plots. Thirty quadratic plots of 30 x 30 meters were established to record the seedlings, saplings, and adults of all woody species. For the adult, the diameter at breast height (DBH) and height were measured using standard diameter tape and a True-pulse height meter, respectively. The total number of seedlings and saplings was counted and recorded within each plot. Environmental data such as location (latitude and longitude), altitude, slope and aspect were recorded from the center of each sample plot. For the present study, different growth stages were pre-defined as an adult (height greater than 1.5 meters), sapling (height between 0.5 and 1.5 meters), and seedling (height less than 0.5 meters).

In order to describe the woody species diversity, the Shannon-Wiener Diversity Index (H) and Evenness (E) were employed using the following equations:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Where: H = Shannon–Wiener diversity index and Pi = the proportion of individuals found in the i^{th} species.

$$E = \frac{H}{H_{max}} = \frac{H}{\ln S'}$$

Where: E = Evenness, H_{max}= the maximum level of diversity possible within a given population, which equals ln (number of species).

The absolute density (number of stems per hectare), frequency (number of plots with a species presence) and dominance (basal area of a species in m^2 per hectare) were calculated for all woody species in the study area using the standard methods. Then, relative density, relative frequency, and relative dominance were calculated using the following equations:

$$Relative\ density\ (RD) = \frac{Number\ of\ individuals\ of\ species}{Total\ number\ of\ individuals} x\ 100$$

$$Relative\ frequancy\ (RF) = \frac{Frequancy\ of\ a\ species}{Frequancy\ of\ all\ species} x\ 100$$

$$Relative\ dominance\ (RDO) = \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species} x\ 100$$

$$\boldsymbol{Important\ value\ index = RD + RF + RDO}$$

With the purpose of understanding the community and population structure, a population frequency diagram was generated based on different diameter sizes. The vegetation analysis was conducted on the R software program using the "vegan" and the "BiodiversityR" packages (Dixon, 2003; Kindt, 2018; Team, 2021).

Spatial data collection and analysis

Several spatial databases were collected to quantify the current distribution of different forest communities in the study area. The freely available Sentinel 2A satellite images with 10 - meter spatial resolution was downloaded. A better cloud-free image was selected from the available list of images. Two tiles (T38 NKN and T38 NLN) encompassed the entire study area. The selected satellite image was acquired in the late dry season (January – February 2022) to allow for clear separation of the different vegetation types. Only the spectral bands of the satellite images (Sentinel L2A) covering the Blue (Band - 2), Green (Band - 3), Red (Band - 4) and Near Infrared (Band - 8) were selected for the study.

Table 1. Description of different types of land cover classes.

No.	land cover classes	Description
1	Bare land	Areas with no vegetation cover consisting of exposed soil and/or bedrock
2	Settlement	Land covered by residences, road networks, buildings and small industrial areas in both rural and urban areas.
3	*Acacia* dominated woodland	Land covered by *Acacia-Commiphora* woodland but *Acacia* is a dominant species than *Boswellia* and *Commiphora*
4	*Commiphora* dominated woodland	Land covered by *Acacia-Commiphora woodland* but *Boswellia* and *Commiphora species* are dominant than *Acacia* species
5	Scrubland	Land covered by small trees, shrubs and herbs, which may be succulent, geophytic or annual.
6	Undifferentiated forest	Areas that were inaccessible for the team to differentiate physically and hence categorized as undifferentiated forest

The images were geometrically and radio-metrically (i.e., top of the atmosphere) corrected. Image pre-processing techniques such as sub-setting, layer stacking and image enhancement were conducted for the downloaded images. The Random Forest algorithm of the supervised classification technique was implemented to classify the image into the aforementioned classes (Table 1). The spatial analysis was conducted on R software and ArcGIS software programs.

Results and Discussion

Woody species distribution, diversity and composition

The vegetation distribution map of the study area (Figure 2) shows that the Acacia woodland (36.3%) and mixed woodland (54.1%) are the two dominant vegetation types. The proportion of the other land cover categories was bare land (5.9%), (14416.9 ha), scrubland (2.9%) (7193.7 ha), (2.9%), undifferentiated forest (0.5%) (1165.1 ha) and settlement (0.2%) (510.2 ha). The undifferentiated forest was found in remote and inaccessible areas where the altitude is relatively higher. This result gives clues to the need to reassess of the previously reported national spatial coverage of Gum arabic (399,700 ha) and Gum *Commiphora* (171,300 ha) (Fitwi, 2000).

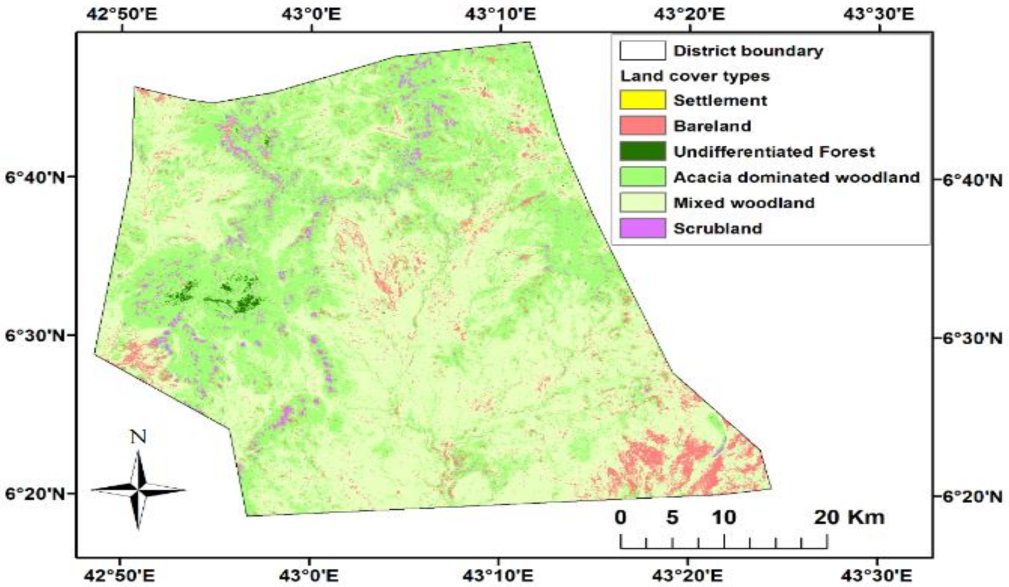

Figure 2. Spatial distribution map of vegetation types of the study area.

Table 2. The area coverage and density of predominant woody species in the study area.

No.	Land cover types	Area (ha)	Proportion (%)	Botanical name	Density of dominant tree species (stem/ha)
1	Settlement	510.24	0.21		-
2	Undifferentiated forest	1165.11	0.48		-
3	Scrubland	7193.71	2.97		-
4	Bare land	14416.89	5.96		-
5	Acacia dominated woodland (n = 15)	87864.94	36.30	*Acacia senegal*	49.6
				Commlphora gowlello	13.3
				Commiphora myrrha	12.6
				Commiphora truncata	6.7
				Commiphora erythraea	5.9
				Boswellia neglecta	5.2
				Boswellia rivae	5.2
6	Mixed woodland (n = 15)	130879.46	54.08	*Boswellia neglecta*	18.5
				Commlphora gowlello	14.8
				Acacia senegal	13.3
				Commiphora truncata	13.3
				Commipbora hodai	11.9
				Commiphora erythraea	11.1
				Commipbora samharensis	10.4
	Total	242,030.35	100.00		

A total of 34 woody species were recorded from the study area of which *Acacia, Boswellia,* and *Commiphora* are the three genera producing gums and resins. The mean pooled diversity of the study area is 3.03 and 0.93 for the Shannon and Simpson diversity indices, respectively (Table 3). *Acacia senegal, Commiphora erythraea, Commlphora gowlello, Acacia asak* and *Commiphora myrrha*, are the five most frequently found species in the study area. The most dominant gum and resin bearing species in the study area include *Commiphora guidotii, Commiphora erythraea, Commiphora myrrha, Boswellia rivae* and *Acacia senegal*.

Table 3. Woody species diversity of the study.

Diversity indices	Pooled values
Richness	34.00
Shannon diversity	3.03
Simpson diversity	0.93
Evenness	0.61

The spatial distribution, together with composition and density of the gum and resin species (Table 3) indicate that there is a huge potential in the study area to produce several types of oleo-gum resins such as gum arabic from *A. senegal*, frankincense from *B. neglecta* and *B. rivae*, myrrh from *C. myrrha* and *C. truncate*, opopanax from *C. guidotii*, Hager from *C. africana*.

Table 4. Estimated gum and resin production potential of the study area.

Product name	Density (stems/ha)		Mean production kg/tree/yr*	Estimated production gum/resins in kg/ha/yr	
	Acacia woodland	Mixed woodland		Acacia woodland	Mixed woodland
Gum arabic	49.6	13.3	2.0630[a]	102.32	27.44
Myrrh	34.1	48.9	0.5000[b]	17.05	24.45
Frankincense	10.4	24.4	0.2610[c]	2.71	6.37

a: (Zeleke *et al.*, 2021); b: (Lemeneh and Kassa., 2011); c: (Eshete *et al.*, 2012)

The estimated production (Table 4) shows variation between the two types of vegetation. In the *Acacia* woodland, higher production potential of gum Arabic is expected as compared to the mixed woodland. Myrrh and frankincense are expected to be produced more from the mixed woodland vegetation type. Thus, the resource potential of the study area is huge and is an indication of the need for a better utilization of the resource. With this estimation, the study area has an area-wise extrapolated total production potential of 18351.5 tons (58.5% from *Acacia* woodland and 41.5% from mixed woodland). Indeed, actual production may vary from the potential by several factors such as species, growth stage, weather conditions, implemented harvesting techniques and tools and many other related factors.

The results are also consistent with a study that claims the underutilization of gum and resin resources in Ethiopia (Tadesse *et al.*, 2007). It should be noted that these products are internationally demanded commodities for various applications such as food, beverages, pharmacology, adhesives and cosmetics industries and can be sources of much needed hard currencies (Başer *et al.*, 2003; Lemenih and Teketay, 2005; Sambawa *et al.*, 2016; Hamad *et al.*, 2017; Efferth and Oesch, 2022).

Structure and regeneration status

The diameter class distribution of the entire community showed “reverse J-shaped” which is regarded as a higher density of individuals found at the lower diameter classes and gradually decreasing their density with increasing diameter class (Figure 3). The first diameter class (< 5 cm DBH) shows a slight decrease that indicates insufficient regeneration of woody species at the community level. The regeneration status also indicates a “J-shape” which shows the unhealthy status of the regeneration of woody species (Figure 3).

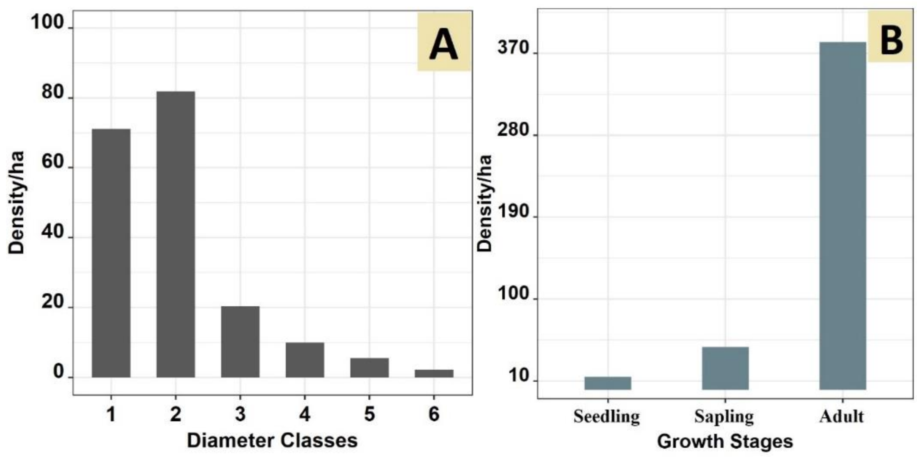

Figure 3. Diameter class distribution (diameter class in cm: class 1.5 ≤ 5 cm, 2 =5 – 10 cm, 3 = 10 – 15 cm, 4 = 15 – 20 cm, 5 = 20 – 25 cm, 6 ≥ 25 cm) of adults (A) and density of regenerates and adults of woody species (B) in the entire community.

The population structure of some of the species (most of them are gum and resin-bearing species) shows an irregular pattern and is bell-shaped (Figure 4). The bell-shaped pattern is described by the larger density of individuals in the middle diameter class (DBH = 5-20 cm). Except for *Acacia asak*, the population structure of the dominant and/or abundant woody species lacks the density of individuals at the lower diameter class (particularly in the first and second classes), which strongly suggests the problem of regeneration and recruitment. This pattern is consistent with previous studies in the lowland dry forest of Ethiopia (Adem *et al.*, 2014; Hido *et al.*, 2020).

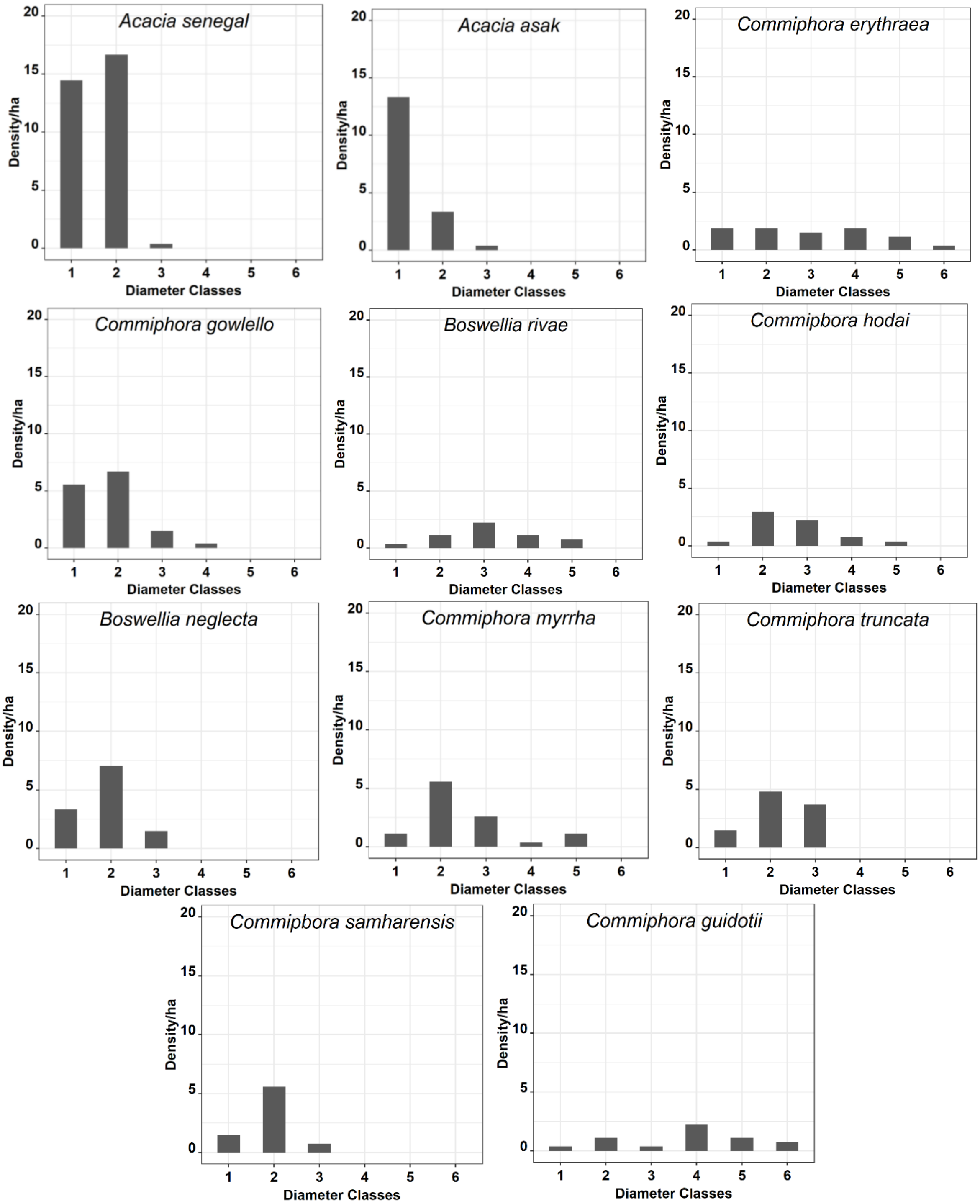

Figure 4. Diameter class distribution (diameter class in cm: class 1.5 < 5 cm, 2 =5 – 10 cm, 3 = 10 – 15 cm, 4 = 15 – 20 cm, 5 = 20 – 25 cm, 6 ≥ 25 cm) of dominant and/or abundant species.

The results also showed that the vegetation resources of the study area are relatively less affected by urbanization and agricultural expansion, unlike the western and Northwestern lowland forests of Ethiopia. Moreover, it was observed that there was relatively less charcoal production and marketing in the study area. However, the vegetation might be affected by over-grazing activities since the livelihood of the community depends primarily on livestock production. The free grazing practice in the dry forests of Ethiopia's lowlands has been reported as a major factor that hampers the natural regeneration of gum and resin species (Lemeneh and Kassa, 2011). Climate variability and frequent drought could also be another factor for the loss of regeneration of the woody plants in general and gum and resin-bearing species in particular.

The findings of the study highlight the potential contribution of dry forests to support livelihoods of local communities and to halt the decline of biodiversity, which are the two most challenging global sustainability issues (Wei *et al.*, 2018). However, little attention is given to research and development of dry forests in the lowlands of Ethiopia as compared to the montane forest. For instance, the quasi absence of nurseries that propagate and raise lowland tree species is one of the justifications to substantiate the low level of attention being paid to the lowland dry forests. Moreover, the soil is highly susceptible to erosion and degradation and hence forest restoration is crucial and cost-effective (Crouzeilles *et al.*, 2020). With a slight reduction in human pressures, the restoration of such areas may require little effort to achieve results that are more significant before the degradation reaches the stage of no return.

Finally, it is suggested that research and development in these ecologically and economically useful lowland dry forests would be very helpful to effectively restore the landscapes by selecting appropriate restoration techniques and available propagation mechanisms. Implementing appropriate restoration is urgent to enhance and aid natural regeneration while formulating sustainable utilization and marketing of gum and resin species, which would be crucial to the well-being of the surrounding community and the country at large.

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