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Spatial distribution of tree species composition and carbon stock in Tozi tropical dry forest, Sinnar State, Sudan

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Abstract. *Yasin EHE, Mulyana B. 2022. Spatial distribution of tree species composition and carbon stock in Tozi tropical dry forest, Sinnar State, Sudan. Biodiversitas 23: 2359-2368.* Dryland forest ecosystem in Sudan plays an important role, either ecologically or economically, for the community around the forest areas. However, land-use change, illegal logging and grazing have caused dryland forests in the country to degrade. The research aimed to investigate the species composition and carbon stock in a Tozi tropical dry forest (TTDF), a typical dryland forest ecosystem in Sinnar state, Sudan. A total of 306 circular sample plots (1000 m2 for each) were established using a systematic sampling grid method. The distance between plots was 400 m and between survey lines 500 m. In each plot, all living trees were identified and counted, and their diameter at the breast height (DBH) was recorded. Research findings showed that there were 2,339 individual trees representing four species (*Acacia seyal, Balanites aegyptiaca, Acacia senegal* and *Acacia mellifera*) that belong to two families. The *B. aegyptiaca* and *A. seyal* were the dominant species widely distributed in the TTDF. The average tree density was 175 trees/ha and the Shannon-Weiner index for trees diversity was 0.264. For the seedlings stage, *A. mellifera* showed a high value of frequency and density, followed by *B. aegyptiaca* and *A. seyal*. The structure of seedlings, saplings, and adults trees formed a reverse J-shape in which the density of seedlings was the highest and followed by saplings and adult trees. Carbon stock of *A. seyal, B. aegyptiaca, A. senegal*, and *A. mellifera* were 990.95, 2602.78, 1085.82, and 249.20 kg C/ha, respectively. Spatial analysis showed that sites composed of three species resulted in the highest above ground carbon stock compared to single species, two species, and four species compositions.

Keywords: Carbon accounting, Geographic Information System, savanna woodland, species composition

INTRODUCTION

Dryland biomes in the world share around 40% of Earth's land surface, yet they are relatively less elaborated (Bastin et al. 2017). Based on the interpretation of very high temporal and spatial resolution of satellite imageries in 2015, Bastin et al. (2017) estimated that the extent of dryland forest in the world, was around 1,079 million hectares of which 286 million hectares were located in Africa. In Sudan, dryland forest plays an important role as the source of timber and non-timber forest products (NTFPs), and the habitat of biodiversity. For instance, *Adansonia digitata* and *Balanites aegyptiaca* fruits are the sources of household subsistence strategy (Adam et al. 2013), gum Arabic from acacia (*Acacia seyal* and *Acacia senegal*) are important NTFPs export commodities in Sudan. In terms of biodiversity, dryland forest and savanna woodland in Sudan are important habitats for flora (e.g., such as *Commiphora africana*, *Dablergia melanoxylon*, *Hyphaene thebaica*, *Salvadora persica*, *Sclerocarya birrea*, *Sterculia setigera*, *A. seyal*, *B. aegyptiaca*, *Faidherbia albida*, *Ziziphus spinachirsti*, and *Calotropis procera*) (Ahmed and Awad, 2008; Warrag et al. 2002; Hasoba et al. 2020) and fauna (e.g. *Capra ibexnubiana*, *Ammotragus tragelaphus*, *Canis mesomelas*, *Panthera pardus*) (Siddig et al. 2018).

Conservation of biodiversity is crucial in a country like Sudan, where ecosystems are fragile, and renewable natural resources are pressured by over-exploitation. The ecosystems in Sudan are deteriorating rapidly due to multiple interacting factors, mostly socio-economic changes, which result in excessive grazing, tree felling, soil erosion, desertification, over-hunting, and land degradation. There is evidence indicating that many aquatic and terrestrial species have either disappeared or been subjected to severe threats resulting from the destruction of their natural habitats (Higher Council for Environment and Natural Resources 2014; Siddig 2014).

Particularly dryland forest in Sudan is threatened by illegal logging for timber purposes, especially for fuelwood and building materials (Mohammed et al. 2021b). Forest and land degradation in Sudan significantly decrease soil fertility and threaten biodiversity (Ardiyaningrum et al. 2021). During the period 1973 to 2006, the bare land increased rapidly from 5.3% to 22.2% (Sulieman 2018). To overcome such problems, rehabilitation projects of dryland forests in Sudan have been conducted and showed a positive trend in increasing vegetation cover (Mohammed et al. 2016). Thus, providing current condition data of dryland forests and savannah woodlands, such as species composition and environmental services, will help in biodiversity restoration and sustainable forest management

(Hasoba et al. 2020). Less observational data on above-ground biomass in dryland, such as tree diameter, has made it difficult to estimate carbon stock accurately (Stringer et al. 2012).

Quantitative knowledge about basic stand diversity and structure, and stand health indicators such as canopy health and density of dead standing trees are required for these current efforts toward attaining proper management and use of gum Arabic producing trees stands to be successful (Bar-Ness 2005; Bauhus et al. 2017; Hasoba et al. 2020). Unfortunately, due to the absence of regular and long-term monitoring programs, Sudan currently lacks these vital forest condition indicators in most gum Arabic producing tree stands (Siddig 2019; Hasoba et al. 2020). Consequently, management and conservation planning are based on rough estimates. Baillie et al. (2008) stated that to create effective forest management plans, it is obligatory to know which species are present, their relative abundance and species-specific stages, and what factors control their future persistence and dynamics. Therefore, information about the current condition of Natural Reserved Forests, including species composition, diversity, density, stage structure, and species-rich communities is of primary importance in the planning and implementation of biodiversity conservation efforts (Eisawi et al. 2021).

Generally, the lack of awareness regarding the importance of biodiversity and inadequate institutional mechanisms for integrated biodiversity management have aggravated the situation of already degraded biodiversity in Sudan. In this respect, documentation of plant species abundance and diversity and their associated habitats are necessary. Therefore, this paper aims to study the spatial distribution of species composition, diversity, and carbon stock in the Tozi tropical dry forest, Sinnar State, Sudan. Such documentation provides the basis for taking appropriate steps in the conservation and maintenance of ecosystem functioning. It would also provide information to policymakers to facilitate resource management plans.

MATERIALS AND METHODS

Study area

This study was conducted in Tozi tropical dry forest, which is located in the southwestern part of Sinnar State, Sudan, and approximately 360 km southeast of the capital Khartoum (Ahmed et al. 2015). The forest covers an area of 6031.2 hectares. It lies between longitude 33°58′30″E - 34°40′30″E and latitude 12°27′0″N -12°33′0″N. It is bordered on the east and west side by Wad-Eneil and Tozi villages respectively (Gadallah 2019). Sinnar state is situated in central-eastern Sudan and shares borders with Gezira State to the north, Blue Nile State to the south, Gedaref State to the east, and White Nile State to the west (Figure 1).

The topography of the area is generally flat with some scattered mountains with an altitude ranging from 396.24-457.2 meters above mean sea level (Fahmi 2017). The soil characteristics of the area, in general, are clays, alkaline dark-colored, which swells and sticky when it is wet, while it becomes cracks when it is dry. An exception was found in the slope (Karab) of the narrow-eroded part of the Blue Nile River, where the soils are sandy loams and clays, as well as a permeable, fertile, sand-silt mixture (Gerif) in the nearest part along the banks of the Blue Nile valley (Fahmi 2017).

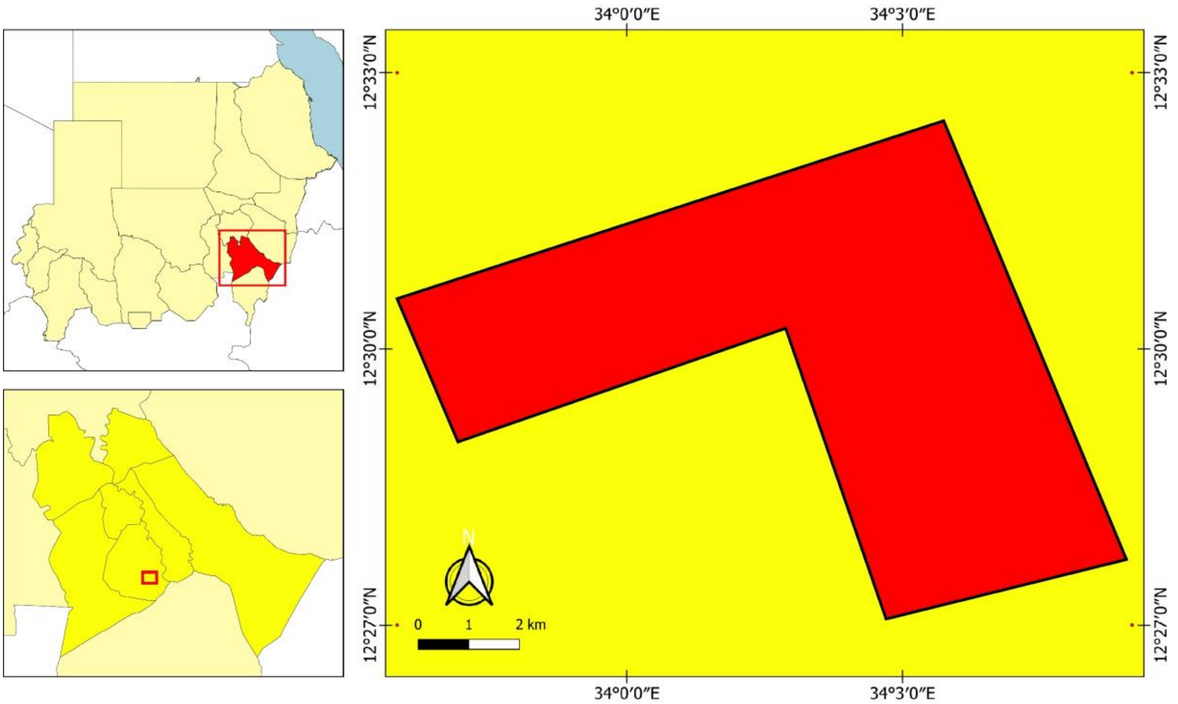

Figure 1. The map of Tozi tropical dry forest, Sudan

The region's climate is tropical with the year separated into very humid and rainy autumns, intensely dry winters, and hot summers. The winter months (December and January) are relatively cool, with temperatures ranging from 16.86°C to 33.5°C. From March to November, the climate is very hot (temperature range of 35°C-41°C).

The precipitation is motivated by South Atlantic and Congo air masses with little or no influence from the Indian Ocean. The precipitation increases in the southwest with the total annual precipitation between 300 and 700 mm. Most precipitation falls between June and October, with a peak in August (Gadallah 2019).

Investigation of the vegetation of the Sinnar State revealed that the state lies in the zone of a low rainfall woodland savannah. According to Gafaar (2011), the main vegetation community is bushland with the prominent presence of *A. mellifera* and *Cadaba rotundifolia* often mixed with *Boscia senegalensis*, *Acacia nubica*, and *Calotropis procera*. The woodland is light and open with *A. seyal*, *A. senegal*, *Acacia fistula*, and *B. aegyptiaca*, while forestland is predominated with *Acacia nilotica* forest. Single storey pure stands of *Acacia nilotica* of about 15-20 m high lie in the seasonally flooded basins along the bank of the river and are sometimes found on similar flooded areas, such as drainage channels (*Khours*) and shallow surface catchment areas (*Hafirs*), on the clay plain inland from the Blue Nile. These forests, many of which are managed or regulated by the Forest National Corporation (FNC) for conservation objectives, have considerable economic importance as they provide hardwood round logs and sawn timbers (Mustafa 2015).

Data collection

Data collection was conducted in February - March 2020. Data was collected by establishing 306 circular sampling plots (0.1 ha) which were determined in the systematic sampling grid using ArcGIS software (Figure 2). The grid consisted of several parallel survey lines spaced 500 m apart and the distance between each sample plot 400 m. A survey method to assess the species composition that used 0.1 ha sampling plot with systematic distribution sampling has been conducted in the Caspian forest of Iran (Tavankar and Bonyad 2015), nature forest of Tanzania (Mwendwa et al. 2020), Nuara reserved forest, Sudan (Hasoba et al. 2020), and Abu Gadaf natural reserved forest in Sudan (Mohammed et al. 2021b). Furthermore, (Mohammed et al. 2021b) have classified the trees into seedlings (total height ≤ 1.3 m), saplings (total height ≥ 1.3 m and dbh < 7 cm) and adults (dbh ≥ 7 cm). In each plot, the recorded data were the name of species, the number of individuals for each species, diameter at breast height and height using caliper and altimeters, respectively, and coordinate using GPS.

Data analysis

Important Value Index (IVI) was calculated based on the sum of ecological parameters, namely relative frequency, relative density, and relative dominance. Frequency was the occurrence of species in the sampling plot. Density was the total number of individuals for each species in the sampling plot. Dominance was the total basal area for each species in the sampling plot (Mohammed et al. 2021a; Ibrahim and Hassan 2015; Ibrahim et al. 2014; Idrissa et al. 2018; Assogbadjo et al. 2010). Because the growth stage of seedlings did not measure the diameter, the IVI was calculated from relative frequency and relative density.

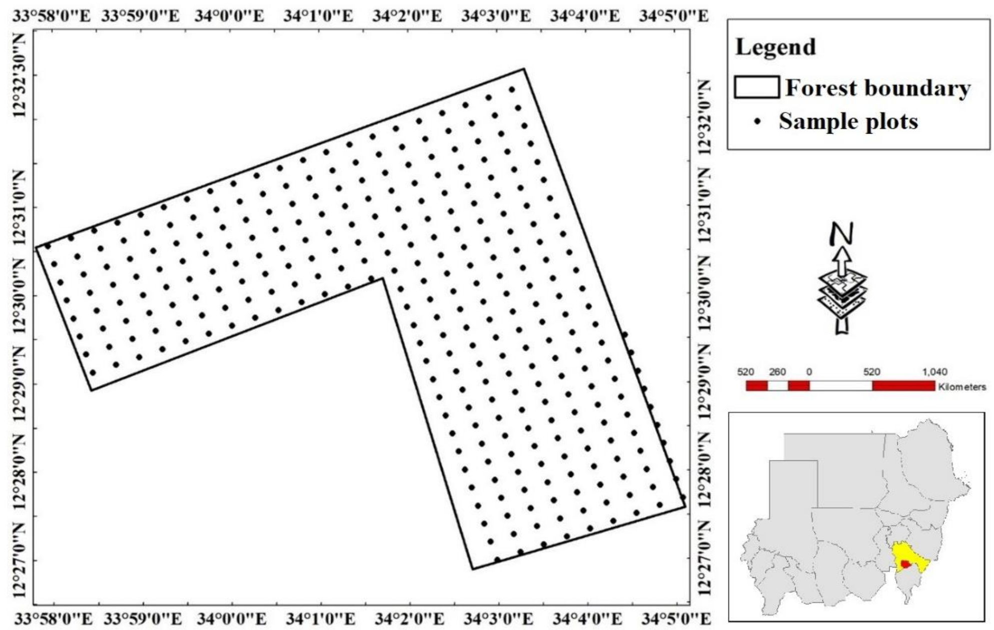

Figure 2. Distribution of sample plots in Tozi tropical dry forest, Sinnar State, Sudan

Furthermore, to assess the tree species diversity in the Tozi tropical dry forest, Simpson's Diversity Index was computed using Eqs. (1) (Assogbadjo et al. 2010; Idrissa et al. 2018; Listopad et al. 2018). We also calculated the species richness as the total number of species counted in the stand (Asbeck et al. 2021; Ghanbari et al. 2021; Mohammed et al. 2021).

$$H = \sum_{i=1}^{n} Pi * log(Pi) \quad \text{.. (1)}$$

Where H' is the Shannon-Wiener diversity index; i is the proportion of individuals belonging to species i; s is the number of tree species; and pi is the importance value of a species as a proportion of all species i in each sample plot.

The allometric equation to estimate dry weight biomass referred to Djomo et al. (2016) who have developed an allometric equation for the African tropical forest (equation 1). Furthermore, carbon stock per tree was calculated by multiplying the dry weight of biomass with the percentage carbon content (PCC) (equation 2).

$$\ln(M) = -0.841 + 2.082 \ln(D) + 1.248 \ln(\rho) \ldots (2)$$
$$C = M \times PCC \ldots\ldots\ldots\ldots (3)$$

Where M is dry weight biomass (kg), D is the diameter at breast height (cm), ρ is wood density (gr/cm^3), C is carbon stock (kg), and PCC is percentage carbon content. The value of wood density for *A. seyal*, *B. aegyptiaca*, *A. senegal*, and *A. mellifera* were 0.73, 0.73, 0.6, and 0.6 gr/cm^3 (World Agroforestry 2021). The percentage carbon content (PCC) in this research was 0.5 (Intergovernmental Panel on Climate Change 2006). The value of PCC 0.5 has been used to estimate carbon stock in African forests (Alam et al. 2013; Forkuor et al. 2020; Lung and Espira 2015). And we divided the carbon data into four groups, including a single tree, two trees, three trees and four trees, depending on the number of species per sample plot. Spatial analysis of species composition and total carbon stock used QGIS v. 3.22.

RESULTS AND DISCUSSION

Species richness and diversity

From surveys of 306 sample plots in Tozi tropical dry forest, we found 2,339 living trees representing four species (*A. seyal*, *B. aegyptiaca*, *A. senegal* and *A. mellifera*) which belong to two families: Mimosaceae (three species) and Balanitaceae (one species) (Table 1). *Balanites aegyptiaca* was the most abundant and dominant species, with 1,102 individuals. We also identified 665 trees for *A. seyal*, 377 trees for *A. senegal* and only 195 trees for *A. mellifera* in the entire forest. The average tree diversity in Tozi tropical dry forest was 0.264 as computed by the Shannon-Wiener diversity index, which was very low. While this number of species was similar to other forests in this transitional zone with precipitation between low and high, it was much lower compared to the species richness found in many dry forests in Africa. For instance, the average number of woody species was 28 in Neotropical continental forests, 48 in Beza Mahafaiy tropic dry forests in Madagascar and 110 in Bereku Forest Reserve, Tanzania (Sussman, 1994). The analysis of the trees in our study area revealed that Tozi tropical forest was dominated by one species (*B. aegyptiaca*), an indicator of change in the state of the ecosystem (Thompson, 2011). This dominance may suppress other tree species' natural regeneration in this area.

The tree species diversity in Tozi tropical dry forest of Sudan (H'=0.264) was similar to tree species diversity in Nuara Reserved Forest (H=0.204) in Sudan, as reported by (Hasoba et al. 2020) and also was lower than those in other forests of Africa (H' ranged from 0.380 in North-East Nigeria to 4.270 in Bereku Forest Reserve of Tanzania). The lower species diversity in the present study could be due to the size of the study area and environmental heterogeneity as well as deforestation activities (Suratman 2012). The low values of tree density and diversity compared to other locations may reflect dissimilarity in precipitation, soil characteristics and landscape, in addition to differences in sampling intensity (Wakawa et al. 2017).

Tree species composition and spatial distribution

Tree species recorded in Tozi tropical dry forest were *A. seyal*, *B. aegyptiaca*, *A. senegal*, and *A. mellifera*. All the species found in growth stages of seedling, sapling, and adult. Overall, *A. seyal* and *B. aegyptiaca* were the dominant species in the Tozi tropical dry forest (Figure 3).

Table 1. Estimates of trees species composition, relative frequency, and number of individuals in Tozi tropical dry forest

Species	Number of plots	Relative frequency (%)	Number of individu
A. seyal	154	27.4	665
B. aegyptiaca	230	40.9	1,102
A. senegal	102	18.1	377
A. mellifera	77	13.7	195

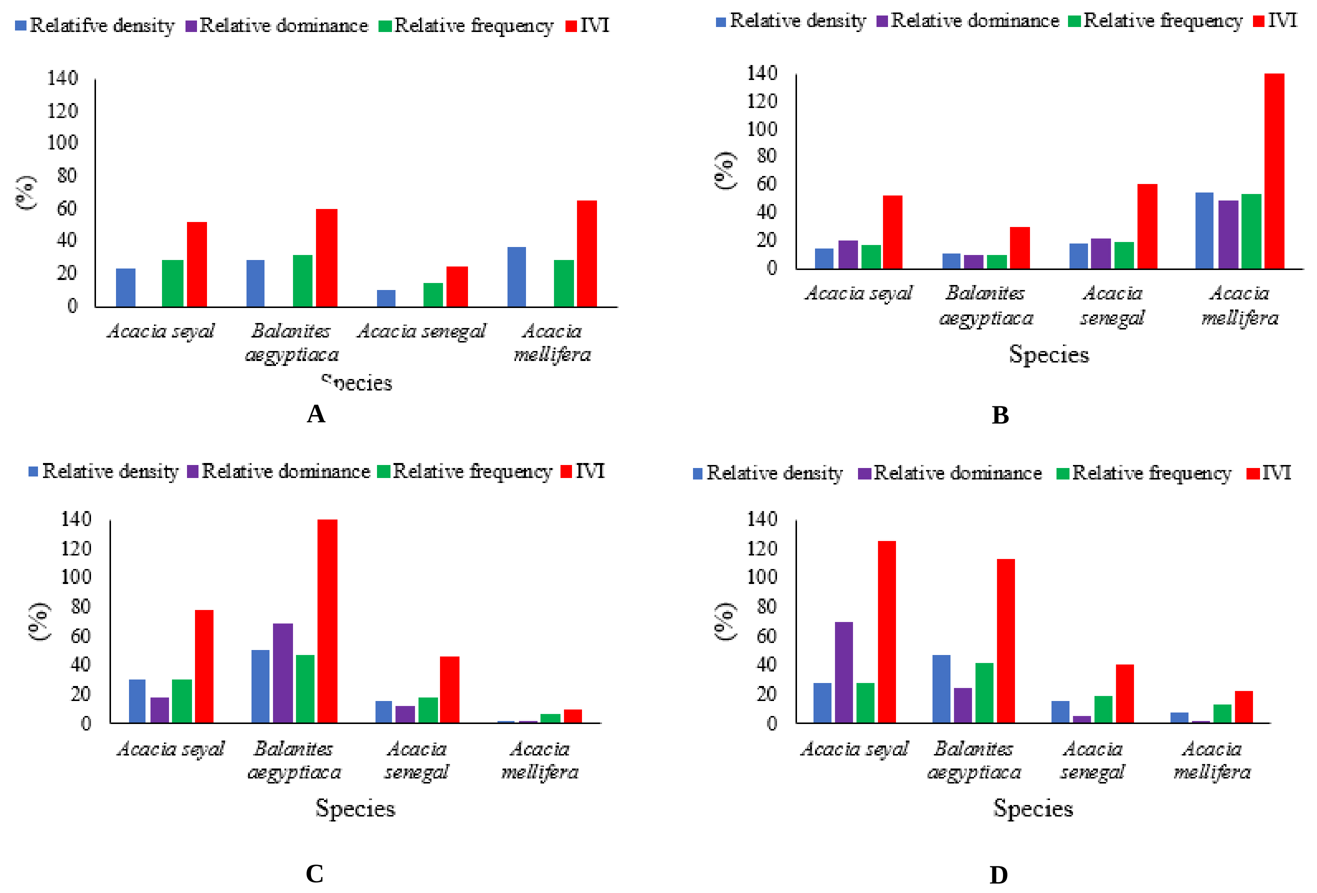

Figure 3. Important value index (IVI) of tree species in Tozi tropical dry forest, Sudan: A. seedlings; B. saplings; C. adults; and D all growth stages

The density of *A. seyal*, *B. aegyptiaca*, *A. senegal*, and *A. mellifera* for sapling and adult stages were 25, 41, 14, and 7 trees/ha, respectively. In Nuara reserved forest, Sudan, the highest density was also *A. seyal* (218 trees/ha), followed by *B. aegyptiaca* (32 trees/ha), *A. senegal* (27 trees/ha), and *A. mellifera* (20 trees/ha) (Hasoba et al. 2020). However, the relative frequency in Tozi tropical dry forest is slightly different from Nuara reserved forest. In Tozi tropical dry forest, the highest relative frequency was *B. aegyptiaca* (41.07%), followed by *A. seyal* (27.50%), *A. senegal* (18.39%), and *A. mellifera* (13.04). Whereas, in Nuara reserved forest the relative frequency of *B. aegyptiaca*, *A. seyal*, *A. senegal*, and *A. mellifera* were 84.20%, 27.80%, 2.36%, and 0.31%, respectively (Hasoba et al. 2020).

A similar result was also found in Dinder Biosphere Reserve in Sudan, in which the density of *A. seyal*, *B. aegyptiaca*, *A. senegal* in disturbed and non-disturbed areas was less than 10 trees/ha for sapling and adult trees (Mohammed et al. 2021a). While, the seedlings of *A. seyal*, *B. aegyptiaca*, *A. senegal* showed a density below 25 seeds/ha (Mohammed et al. 2021a). Both Tozi dryland forest and Dinder Biosphere Reserve showed a similar pattern. The density of seedlings was higher than the density of saplings and adult trees and showed a reverse J-shape. The reverse J-shape indicates that regeneration is occurring in the dryland forest of Sudan.

In terms of seedling stages, *A. mellifera* and *B. aegyptiaca* were recorded in most areas of the Tozi tropical dry forest. *A. mellifera* was distributed in the north to the west area of Tozi tropical dry forest, while the *B. aegyptiaca* was distributed in the east to south areas (Figure 4). On the other hand, *A. seyal* was found in the southwest area of Tozi tropical dry forest, while *A. senegal* was found in a lower frequency and distributed in random areas. Interestingly, all the species also formed an association with other species which associated seedlings occurred in central areas.

A. mellifera showed a high relative density value for the seedlings and saplings stage. *A. mellifera* was the species that have high growth ability in degraded land in Rawashda forest, Gedarif State (Eltayb and Magid 2013), and Dinder Biosphere Reserve, Sinnar State (Mohammed et al. 2021a). Unfortunately, for saplings and adult trees, the *A. mellifera* and *A. senegal* showed a low density and less dominance in Tozi tropical dry forest (Figure 4). The conservation program of *A. mellifera* and *A. senegal* should be prioritized because they are important species for local communities (Hasoba et al. 2020).

The low density in dryland forests was also reported by Abdelkarim et al. (2021) in Elhelgi and Geli forests, Sudan in which the density of *Hyphaena thebaica* was 12 and 50 trees/ha. The low density and basal area of trees and shrubs in dryland forests in Sudan are affected by erratic and low precipitation (Mohammed et al. 2016). Although the vegetation density in dryland forests was low, the forests provide tangible benefits in the form of fuelwood, NTFPs and building materials, and intangible benefits such as carbon storage, shading for animals and soil nutrients (Alam et al. 2013).

Overall, *A. seyal* and *B. aegyptiaca* were the dominant species in Tozi tropical dry forest (Figure 5). This result is in line with another study in Dinder Biosphere Reserve, which showed a similar pattern, both of disturbed and non-disturbed areas, in which the dominant species were *B. aegypitaca*, *Combretum hartmannianum*, and *A. seyal* (Mohammed et al. 2021a). A similar result was also shown in the lowland and highland area of Abu Gadaf natural reserved forest Sudan, in which the top six dominant species were *A. seyal*, *B. aegyptiaca*, *Boswellia papyrifera*, *C. harmannianum*, and *Lannea fruticose* (Mohammed et al. 2021b). In general, *A. seyal* is widely distributed in Sudan, encompassing an area of 3.6 million ha in latitude ranging 10º-14º north, on clay soil and the rainfall ranging from 300 to 400 mm/year (Adam et al. 2013).

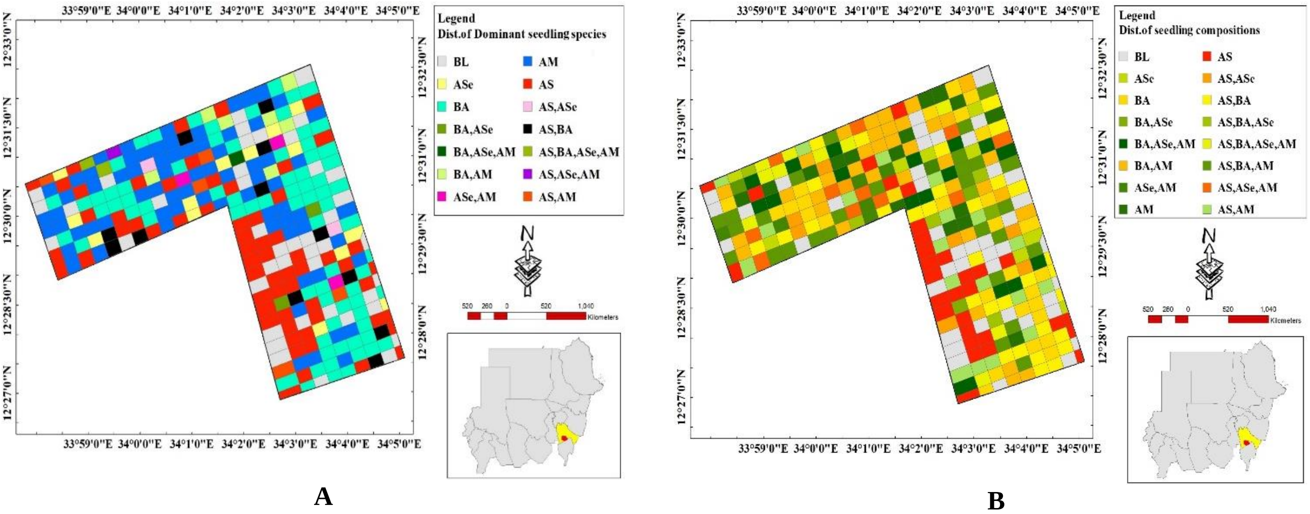

Figure 4. Spatial distribution of species composition for seedlings in Tozi tropical dry forest. Notes: BL: bareland; AS: *A. seyal*; ASe: *A. senegal*; AM: *A. mellifera*; BA = *B. aegyptiaca*

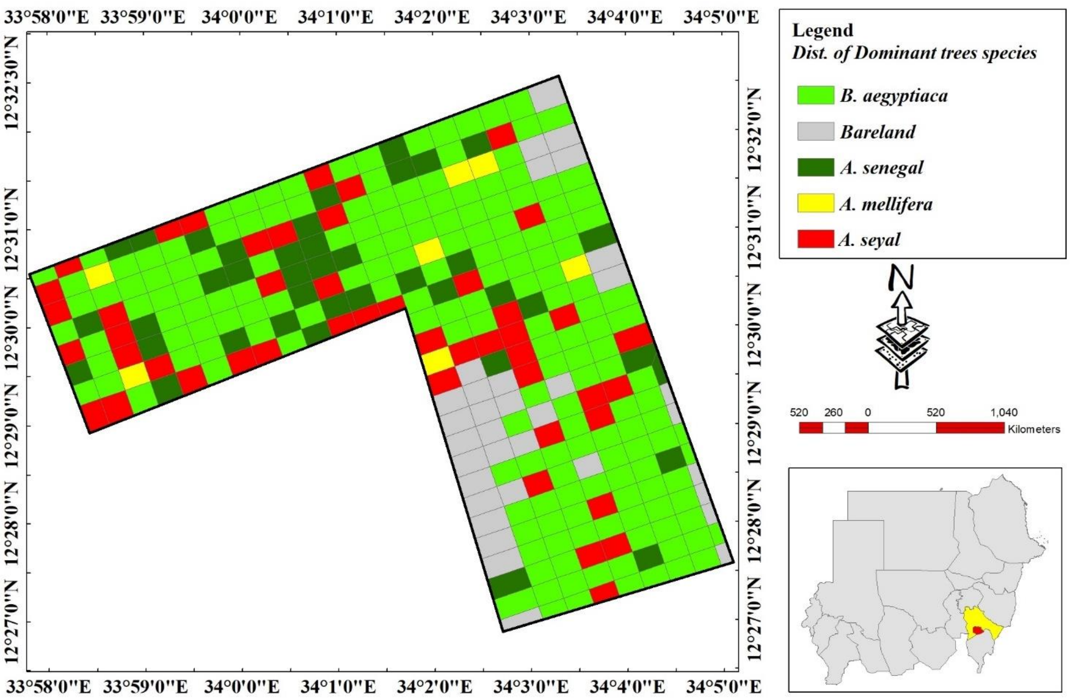

Figure 5. Spatial distribution of dominant species in Tozi tropical dry forest, Sudan

Tree species diversity and carbon stock

The highest carbon stock of tree species in the dryland forest of Tozi was *B. aegyptiaca* (55.89 kg C/tree), followed by *A. seyal* (17.42 kg C/tree), *A. senegal* (14.28 kg C/tree), and *A. mellifera* (2.53 kg C/tree). *B. aegyptiaca* was distributed in 230 sampling plots with an average of dbh was 14.70 cm (Table 2). The carbon stock of *B. aegyptiaca* in this study was lower than that in the Abu Geili forest with 63.32 kg C/tree (Gurashi and Hassan 2018).

The average total above ground carbon per unit area for *B. aegyptiaca* was 2,602.78 kg C/ha, while the Acacia (*A. seyal, A. senegal*, and *A. mellifera*) was 775.32 kg C/ha (Figure 6). Above ground carbon of *A. senegal* in western Sudan (El Demokeya forest reserve and El Hemaira forest) were 5,550 kg C/ha (7 years), 4,695 kg C/ha (15 years), 6,890 kg C/ha (20 years), and 5,200 kg C/ha (24 years) (Abaker et al. 2016). The above-ground carbon for *Acacia* woodland Savannah in Sudan using satellite images analysis was 1,120 kg C/ha (Alam et al. 2013). The low carbon stock for Acacia in Tozi tropical dry forest because of overgrazing and illegal logging. The density of *A. seyal*, *A. senegal*, and *A. mellifera* in the Tozi tropical dry forest were 25, 14, and 7 trees/ha respectively.

Based on Figure 6, it was obvious that the carbon stock in the dryland forest of Tozi was dominated by *B. aegyptiaca*. Most of Tozi tropical dry forest has carbon stock ranging from 1,001 kg C/ha to 9,841 kg C/ha. Meanwhile, the Acacia (*A. seyal*, *A. senegal*, and *A. mellifera*) have shown an average of carbon stock of less than 1,000 kg C/ha. Nevertheless, one plot could be consisted of one, two, three, or four species and have formed different total carbon stock (Table 3).

Refer to Table 3, mono-species occurred in 79 plots (29.15%) and multi-species were distributed in 192 sampling plots (70.85%). The highest carbon stock was in sampling plots that consisted of three species (32,625.97 kg C/ha), followed by two species (3,640.24 kg C/ha), single species (2,680.67 kg C/ha), and four species (2,346.11 kg C/ha). Although the carbon stock value in four species was lower than in single and two species, the minimum carbon stock in four species was higher. High carbon stock value in multi-species compared to mono-species was also shown in dryland of Ethiopia with agroforestry system (Manaye et al. 2021) and tropical forest in Indonesia, such as in community forest (Wirabuana et al. 2021) and mangrove forest (Purwanto et al. 2021).

According to Figure 7, the Tozi tropical dry forest had above-ground carbon stock of around 1,000-1,566,530.81 kg C/ha. The lowest total carbon stock was in a bare land area in which there were no trees, and the highest carbon stock was 39,251.13 kg C/ha which was composed of *B. aegyptiaca* (18,901.51 kg C/ha) and *A. senegal* (59,600.75 kg C/ha). Above ground carbon stock in dryland in West African Sahel with a traditional management system ranged from700 kg C/ha to 5,400 kg C/ha (Takimoto et al. 2008). While the above-ground carbon stock with an integrated watershed management system in Ethiopia was 9,080 ± 1,440 kg C/ha (Gessesse et al. 2020). Furthermore, the above-ground carbon stock in the agroforestry system in Ethiopia, namely home garden, parkland, woodlot, and boundary planting, were 5,360; 5,270; 21,430; and 2,780 kg C/ha, respectively (Manaye et al. 2021).

Table 2. Carbon stock of each species in Tozi tropical dry forest, Sudan

Species	Number of plots	Above-ground carbon stock (kg C/ha)		
		Minimum	Maximum	Average
A. seyal	154	0.84	17,273.53	990.95
B. aegyptiaca	230	12.73	20,191.90	2,602.78
A. senegal	101	39.54	29,800.38	1,085.82
A. mellifera	76	0.02	7,115.98	249.20

Table 3. Species diversity and carbon stock in Tozi tropical dry forest, Sudan

Species composition	Number of plots	Density (individuals/ha)			Above-ground carbon stock (kg C/ha)		
		Minimum	Maximum	Average	Minimum	Maximum	Average
Single species	79	10	480	59	39.54	17,530.29	2,680.67
Two species	106	20	370	76	267.59	39,251.13	3,640.24
Three species	71	30	520	127	715.78	2,088,707.75	32,625.97
Four species	15	50	180	112	676.55	4,309.64	2,346.11

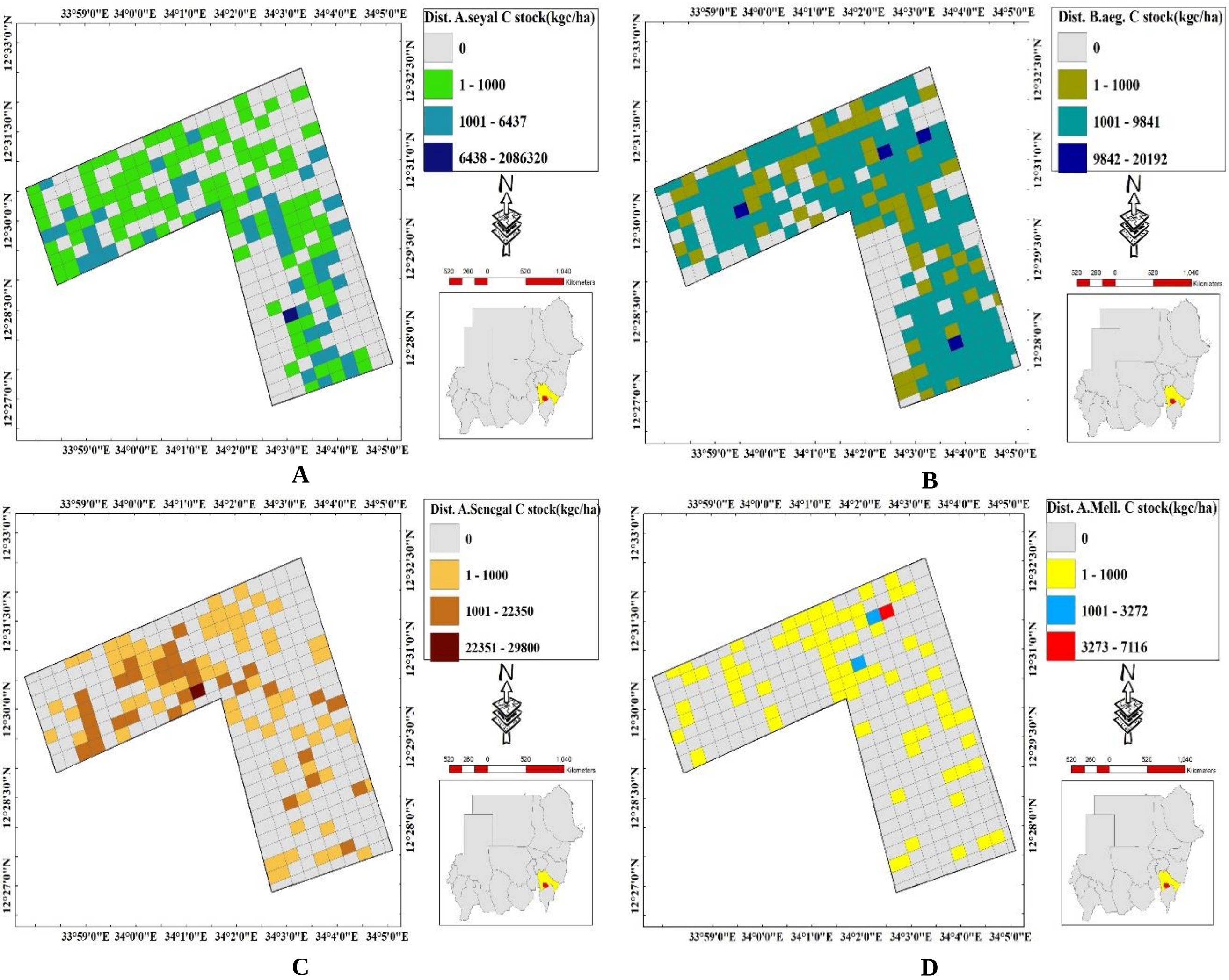

Figure 6. Spatial distribution of carbon stock: a. *A. seyal*; b. *B. aegyptiaca;* c. *A. senegal;* D. *A. mellifera*

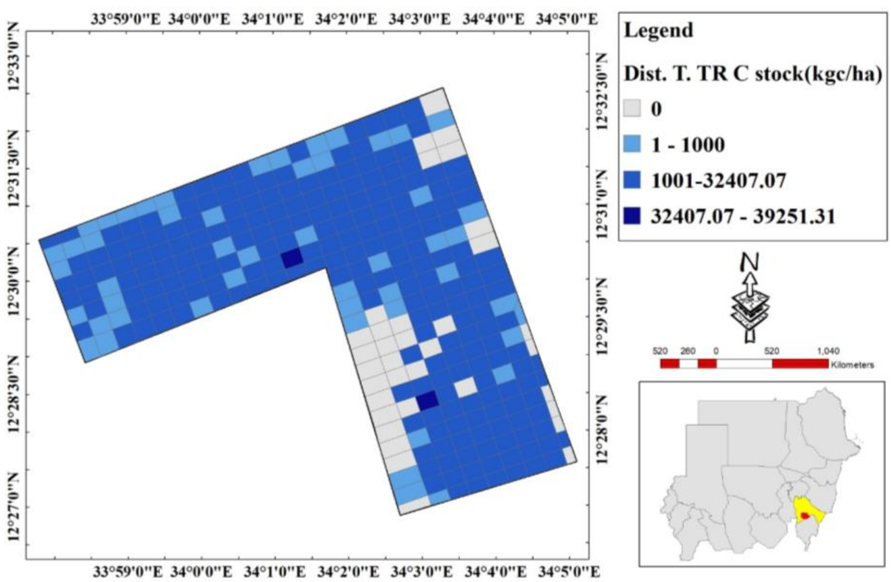

Figure 7. Spatial distribution of total above-ground carbon stock in Tozi tropical dry forest, Sudan

In conclusion, this study showed low tree diversity (0.264) in Tozi tropical dry forest in the southwestern part of Sinnar state, Sudan. The forest included only four species (*A. seyal, B. aegyptiaca, A. senegal* and *A. mellifera*), which typically occur in the dryland forest. The *A. seyal* and *B. aegyptiaca* were the species with a highly important value index. Both species were widely distributed in Tozi tropical dry forest and had all growth stages (seedlings, saplings, and adults). The state of tree species richness and relative density in the study area was low compared to similar environments in the world. Species composition, which consisted of 3 species, resulted in the highest carbon stock compared to one, two, and four species composition. Based on our findings, the tree density in Tozi tropical dry forest was low (less than 40 trees/ha) and it needs a serious management intervention by enrichment planting and law enforcement for illegal logging.

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