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Woody Plant Species Composition, Population Structure and Carbon Sequestration Potential of the *A. senegal* (L.) Willd Woodland Along a Distance Gradient in North-Western Tigray, Ethiopia

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Abstract

In Ethiopia, dry land vegetation including the fairly intact lowland and western escarpment woodlands occupy the largest vegetation resource of the country. These forests play a central role in environmental regulation and socio-economic assets, yet they received less scientific attention than the moist forests. This study evaluated the woody plant species composition, population structure and carbon sequestration potential of the *A. senegal* woodland across three distance gradients from the settlements. A total of 45 sample quadrants were laid along a systematically established nine parallel transect lines to collect vegetation and soil data across distance gradients from settlement. Mature tree dry biomass with DBH>2.5 cm was estimated using allometric equations. A total of 41 woody plant species that belong to 20 families were recorded and *A. senegal* was the dominant species with 56.4 IVI value. Woody plant species diversity, density and richness were significantly higher in the distant plots compared to the nearest plots to settlement ($p<0.05$). The cumulative DBH class distribution of all individuals had showed an interrupted inverted J-shape population pattern. There were 19 species without seedlings, 15 species without saplings and 14 species without both seedlings and saplings. A significant above ground carbon (5.3 to 12.7 ton ha^{-1}), root carbon (1.6 to 3.6 ton ha^{-1}), soil organic carbon (35.6 to 44.5 ton ha^{-1}), total carbon stock (42.5 to 60.7 ton ha^{-1}) and total carbon dioxide equivalent (157.7 to 222.8 ton ha^{-1}) was observed consistently with an increasing of distance from settlement ($p<0.05$). Distance from settlement had significant and positive correlation with species diversity and carbon stock at 0.64** and 0.78**. Disturbance intensity may directly influence the variation of species composition, richness and density along the *A. senegal* woodland. The sustainability of the *A. senegal* woodland needs urgent protection, conservation and restoration.

Key Words: *A. senegal*, regeneration, carbon stock, biomass, gum arabic

Introduction

Forest resources covered 4 million hectares (31%) of the total land area of the world (FAO 2010), where about 14% of the total land surface of Africa that represents about 25% of the natural vegetation was covered by dry woodlands

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(Eshete et al. 2011). In Ethiopia 27.5 million hectare land surface was covered by forest resource (EFAP 1994). Ethiopia is endowed with various vegetation types, where dry forests comprise the largest vegetation resource (Mengistu et al. 2005; Lemenih and Kassa 2011). In Ethiopia the dry land vegetation occupies about 50% of the land area and it resides in the arid and semi-arid lands (Jama and Zeila 2005). The morphological and physiological adaptive mechanism enables the dry land vegetation to survive and develop in an adverse water stressed soil and dry land environment (Gaafar 2005). The positive correlation between soil organic carbon and nitrogen content allows the dry woodland species offer better options for adaptation to and mitigation of climate change (Lemenih and Teketay 2004). Indeed the rates of carbon dioxide exchange were clearly coupled with the water status in the soil profile that implies the adaptation strategy to drought by maintaining a stable photosynthetic activity even under low leaf water potential (Lemenih and Kassa 2011). Forests act as sources of emissions through deforestation and forest degradation, and sinks through removal of greenhouse gases from the atmosphere and subsequent storage in biomass and soils (FAO 2010). Forest resources are recognized by the international agreements as a fundamental climate change mitigation measures (Perschel et al. 2007). The Sub-Saharan dry forests and woodlands are naturally rich in biodiversity that contributes to the supply of socio-economic and ecosystem services (Chidumayo and Gumbo 2010).

Terrestrial ecosystems are the principal component of the carbon cycle that has the potential to sequester carbon (Sheikh et al. 2014). Forest ecosystem is the largest carbon pool, where more than 80% of all terrestrial above ground carbon and more than 70% of all soil organic carbon were stored in the forest ecosystem (Six et al. 2002). In Ethiopia, forest and woody vegetation resources play a principal environmental regulation through carbon sequestration whereby 45.7% and 34.4% carbon stored was found in the woodlands and shrub lands respectively (Nune et al. 2009; Moges et al. 2010). The existing lowland woodlands of the country have remarkable potential for carbon sequestration (Alemu 2012). The presence of large net carbon sequestration in the woody biomass implies that woody vegetation of Ethiopia is in a state of fast biomass accumulation (Moges et al. 2010). In line to the environmental regulation, the existing dry woodland species plays principal role in socio-economic assets (Tadese et al. 2007). Variation in vegetation types could influence the level of soil organic carbon stocks through the photosynthetic manufacture of organic matter, then woodland that composed different tree species with differences in carbon storage capacity have high potential for storing substantial soil organic carbon stocks (Shelukindo et al. 2014).

Understanding the current woody plant species floristic composition and structure offer important indication on the vegetation of the intended area (Wendawek and Dessalegn 2014). The information on population structure of a tree species is used to forecast the current and future perpetuation of the population (Peters 1996). In the perspective of ecologist's population structure often is used as a sign of the overall species regeneration profile, whereby species population with an inverted J-shape population structure could be considered as healthy and hence more amenable to sustainable management (Esthete et al. 2011). A given population pattern with high developmental stage in the lower DBH class and gradual decreasing towards the old individuals DBH pattern indicates a normal population distribution of species with good reproduction status and regeneration potential that represented as an inverted J-shape population structure (Tilahun et al. 2015). Measuring the population structure of given vegetation can tell us something about the past and future population as well as the immediate means of identifying the poorly represented stages of life history of a given population (Gizaw 2006). Tree species types and structure has a great influence on the accumulation of above ground and below ground biomass, where biomass density plays an important role in the amount of carbon to be sequestrated (Beatrice 2012). In line with that, native vegetation and agroforestry respectively sequester high total organic carbon than cropland (Mohammed et al. 2014). This is because annual crops can fix more carbon than forestry systems in any given year, but their biomass usually decomposes rapidly, and the rate and return of sequestered carbon to the atmosphere are very fast (Lal et al. 2004).

In Ethiopia expansion of agricultural activity, settlement, deforestation and land degradation are the main challenges that faced forest resources of the country (Mebrat 2015). Variation in disturbance intensity was a leading cause for vegetation distribution variability (Eshete et al. 2011). Moreover, vegetation degradation is more prominently appear in nearby to settlements because people used to cut trees for various purposes from areas near to settlement and do not prefer to travel long distance from settlements as the condition is harsh (Gebreyowhans 2015). Expansion of settlement associated with resettlement was aggravated vegetation deforestation through clearance of tree for the farmland expansion and various purposes (Lemenih et al. 2014).

Most sub-Saharan African countries lack to estimate biomass carbon stock of the available wood land ecosystem (Matieu 2010). Thus to amend the current management practice and further conservation of vegetation resources to sustaining their existing carbon stock and future sequestration potential evaluating the current population and the regeneration status has to be a central focus of any carbon management activities (Assaye and Zerihun 2016). Despite the fact that tropical dry land forests including the *Acacia and Commiphora* woodlands in Ethiopia have high ecological and economic importance, still they have received far less scientific attention than moist forests (Muys et al. 2006). Similarly, despite the wide distribution and intact natural stands of woodland vegetation in the western and other lowland parts of Ethiopia, there is limitation of scientific data on the diversity, population structure and its ecological role to mitigate climate change that needs further studies (Demissew et al. 2005). The woodland vegetation of Ethiopia provides multiple socio-economic and ecological service, but it lacks due attention in scientific study as compared to the high forest resource of the country (Moges et al. 2010). Though the study area is known with diverse *A. senegal* woodland plant species, it lacks scientific study regarding to woody plant species composition, population structure and its potential carbon sequestration. This paper quantified woody plant species composition, density, diversity and population structure of the *A. senegal* woodland across three distance gradients from settlement. The above and belowground dry biomass, the above and below ground carbon stock, soil organic carbon, total carbon stock and carbon sequestration potential of the *A. senegal* woodland across three distance gradients was estimated. Finally, the relationship of distance gradient with woody plant species diversity and potential carbon stock was evaluated.

Materials and Methods

Site description

The study was conducted in the *A. sengal* woodland of Gemhalo peasant association (PA) located in Tahtay-Adyabo district in the Northwestern part of Tigray Regional State located at 37°78'62" E and 14°50'82" N and covers 34810.52 ha area (Fig. 1). Gemhalo PA has five administrative sub-villages with 6296 total population and 1366 households (TAWOPF 2015). It is characterized with a massive and unoccupied communal forest and grazing lands, which makes it to possess a large number and different types of homestead animals. According TAWOPF (2015) the total number of Cattle, Goat and Ship was estimated as 14243, 16468 and 4876 respectively.

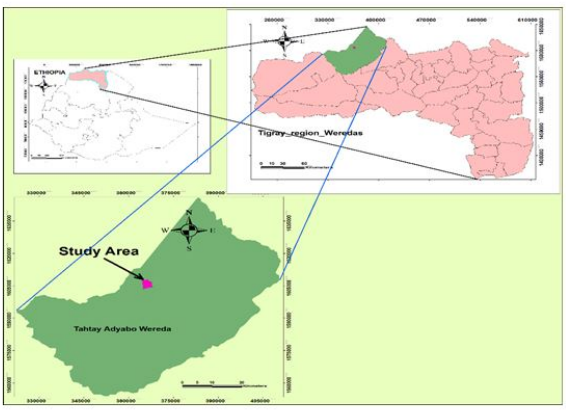

Fig. 1. Map of the study area.

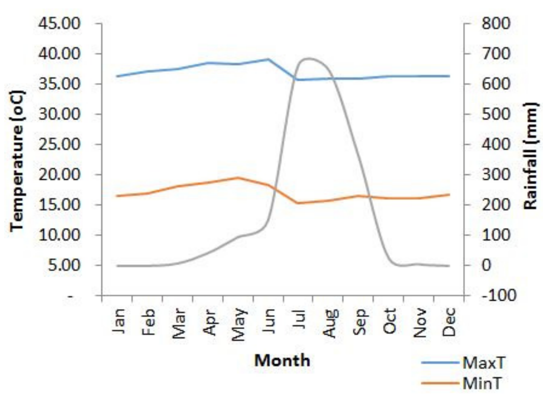

Fig. 2. Mean monthly temperature and rainfall of Gomhalo PA 2008-2015.

The study site is found in the lowland agro ecological zone with an altitude of 900-1,034 meter above sea level. It is characterized with erratic, low and unimodal rainfall pattern and high temperature with short growing period (TAWoARD 2015). The mean maximum and minimum mean annual temperature is 37.6°C and 20.2°C. The mean annual rainfall and growing period was 200-700 mm and 60-90 days respectively (Fig. 2). The study site receives very low and unreliable rainfall.

The geology comprises poorly metamorphosed sand stone, silt stone with minor meta-volcanic and marble (Tadesse 1997). Vertisols, Arenosols, Cambisols and Nitisols are the dominant soil types of the study area (TAWOARD 2015). Farmland, grazing land and forestlands are the three common land use systems in the district. The farmland is under continuous cultivation with some shifting cultivation. The forestland is composed of the predominant and unmanaged natural communal woodland vegetation, the insecure Kafta-sheraro national park and incense land. The grazing land is an open grassland composed of sparse tree species, shrubs and bushes. Rain fed agriculture with mixed farming system consisting of annual crop production and livestock rearing is the primary livelihood of the households in the area. The potential farming system of the area includes crop production, irrigation, livestock production, traditional gold mining and resin production from *B. papyrifera* and A. senegl as source of subsistence livelihood (TAWOPF 2015). The common crops varieties grown in the area includes; sesame, sorghum, finger millet and maize, where sorghum, finger millet and maize are the primary food crops and Sesame contribute as cash crops (TAWoARD 2015).

Methods

Site selection and layout

Reconnaissance survey was conducted to get an overview of the study area, while the woodland was delineated by using GPS. According to Tefera et al. (2006) and Asefa et al.

Table 1. Arbitrary distance gradients from settlements and their base lines

Criteria	Distance from settlement (disturbance gradient)		
	Near (<1.4 km)	Middle (1.45-3.25 km)	Far (>3.25 km)
Fuel wood access	Woman can collect and carry with short time. It does not need donkey and camel to carry the fuel wood. But now due to intensive selective cutting difficult to get fuel wood here.	The fuel wood was mostly collected by men and carried by donkey and camel. Where the fuel wood found in inaccessible form and time consuming to woman.	Fuel wood can be collected easily, but longer travel time and tiring. Then camel highly preferable to collect huge fuel wood in a single trip.
Fencing material Access	Fencing material can be easily carried and pulled by labor.	Pulling of fence must need camel or oxen	Time consuming and difficult to pass through.
Construction material	Can easily carried by labor. but now difficult to get easily here.	Difficult to be carried by labor. But it needs camel or oxen to carry or pull it. Where it found in inaccessible form.	Only for selective construction materials, that could not found in the two distance gradients.
Dried coppice intensity	Intensive number of dried coppice due to frequent tree/shrub cutting for fencing, fuel wood etc.	Sparse dried coppice mostly due to tree/shrub cutting for fuel wood and construction.	Sparse dried coppice mostly due to big tree cutting for animal feeding and construction purpose.
Foot path intensity	Intensive permanent sign of human/ animal tracks	Relatively sparse sign of human/animal tracks	Sparse sign of human/animal tracks (mostly temporary)
Intensity of sheet (reel) erosion	Continuous sign of sheet(reel) erosion, that can change to gully erosion	There is a sign of sheet (reel) erosion. But reduced in its continuity.	There is spars sign of sheet (reel) erosion and less connectivity.
Ground cover	Low tree/shrub ground cover and heterogeneity	Moderate tree/shrub ground cover and heterogeneity	Relatively high tree ground cover and heterogeneity
Disturbance level	Highly disturbed	Moderately disturbed	Least disturbed (fairly intact)

(2015) the *A. senegal* woodland was arbitrarily divided in to three distance gradient from the settlement as near, middle and far (Table 1). The grouping into three distance gradient was done after collecting the actual distance of the forests from settlement.

Vegetation and soil sampling techniques

Based on the group discussion and reconnaissance survey the study site was delineated to map and lay out parallel transect line. The parallel transect lines were laid 50 m apart from start of the settlement to the western direction systematically in such a way that all variations in the site was captured (Tefera et al. 2006). Depending on the DBH, height class distribution and heterogeneity level of the woody vegetation, 3 parallel transects line for each distance gradient with an interval of 300 meters was established. Along each transect line 5 sample quadrants with 20×20 m (400 m^2) and 100 meters spacing between adjacent plots was established and data was collected from sample quadrants established in each transects line (Fig. 3).

All matured woody plant species of tree and shrub were identified and measured in each plot. Height and DBH of woody plant species was measured using 6 m length graduated stick in 10 cm measuring steel for individuals having ≤6 m height and hypsometer for individuals having >6 m height and caliper respectively. Due to the dry nature of the area, species grow slowly 2.5 cm minimum DBH was taken to measure both DBH and DSH of all matured individual woody plant species (Pearson 2007). Small quadrants of 4 m×4 m (16 m^2) nested within the bigger plots were laid at the four corners and one at the center of the plot were used for regeneration study (Fig. 3). All germinating ((i) seedlings: with H < 0.5 m and D < 1 cm and (ii) saplings: with H=0.5 m^{-3} m and D=1 cm-2.5 cm) was counted and identified within the five sub-plots (Birhane 2002). The diameter (D) for seedling and sapling was taken as root collar diameter (RCD).

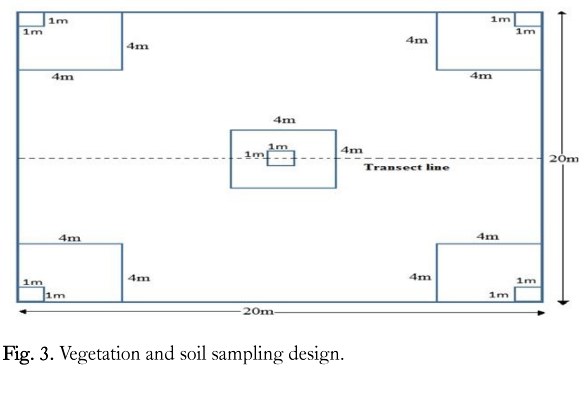

Fig. 3. Vegetation and soil sampling design.

Soil sample was collected from each sample quadrants laid at each distance gradient to examine the impact of woody vegetation on soil organic carbon (SOC). Five 1 m x 1 m soil samples from the four corner and one at the center of the quadrant was taken from each 400 m^2 plots along each transect line. From each pit, soil samples were collected from the top 0-15 cm and 15-30 cm and it was mixed to form a composite sample. This composite soil sample was divided into three equal parts and randomly one was selected as a working sample for further laboratory analysis. Similarly, from each depth category undisturbed soil sample collected using core sampler to analyze bulk density. The entire 180 soil samples were transported to Mekelle University and Tigray Agricultural Research Institute (TARI) for laboratory analysis. Altitude and geographical locations of each quadrant was measured using GPS. Woody plant species within the sample plots was recorded by local name and reported using their respective scientific names (Bein et al. 1996; Bekele 2007). Plant nomenclature followed Edwards et al. (2000).

Measurement and analyses techniques

The number of all woody plant species encountered in the sample plots of each distance gradients were used as a measure of species richness (S) where Shannon－wiener index (H') was taken as measure of heterogeneity (Magurran 2004). Population structure of the woody plant species was determined by employing measuring of height and diameter class ((i) seedlings: with H < 0.5 m and D < 1 cm; (ii) saplings: with H=0.5 m-3 m and D=1 cm-2.5 cm and (iii) Trees with H>3 m and D>2.5 cm) (Birhane 2002). The population structure and regeneration status of the woody vegetation, mature individuals from the main plot as well as saplings and seedling from 4 x 4 m sub plots established inside the main quadrants were recorded. All woody plant species that are recorded in the entire sample quadrants were arbitrarily grouped in to 12 DBH class as 1≤2.5, 2=2.5-6.5, 3=6.5-10.5, 4=10.5-14.5, 5=14.5-18.5, 6= 18.5-22.5, 7= 22.5-26.5, 8= 26.5-30.5, 9= 30.5-34.5, 10=34.5-38.5, 11=38.5-42.5, 12≥42.5 cm) and 8 height classes as (1≤3, 2=3-5, 3=5-7, 4=7-9, 5=9-11, 6=11-13, 7=13-15, 8≥15 m respectively (Wale et al. 2012). The top three dominant plant species were taken to show the overall population structure of the woody plant species across the three distance gradients. Tree density, height, frequency, diameter at breast height (DBH), species importance value (SIV) and basal area were calculated. The structural role of the species in the sampling plots was determined using the Importance Value Index (IVI) and was calculated using the percentage of relative density (RA), relative dominance (RD) and relative frequency (RF) (Wale et al. 2012).

Biomass and carbon stock estimation across distance gradients

Species specific allometric equations were applied for *A. senegl* and *A. abyssinica* tree species. A general allometric equation developed in areas relatively with similar agro-climatic conditions to the study area was applied to estimate above ground dry biomass (Table 2). Fifty percent of the above ground dry biomass of each tree/shrub was taken as above ground carbon stock (Brown 2002). Root-to-shoot ratio relationship to above ground biomass was used to estimate below ground biomass of trees and shrubs. Below ground dry biomass were estimated to constitute about 27% of the above ground dry biomass for woody vegetation (IPCC 2003). Similarly 50% of the below ground dry biomass was taken to estimate below ground carbon stock of tree/shrub (Brown 2002). The total above ground dry biomass and total carbon stock of tree and shrub was calculated.

All soil samples were air-dried, homogenized and passes through a 2 mm sieve for soil organic carbon analysis following the Black and Walkley method (Schhnitze 1982). Undisturbed soil samples were collected by core sampler for bulk density determination and were allowed to dry in an oven dry at 105°C for 24hrs. The bulk density was determined by dividing the oven dry mass (g) at 105°C by the volume of core sampler (cm^3) (Grossman and Reinsch 2002). Soil organic carbon of the woodland was calculated at each distance gradient (Pearson 2007). Total biomass and carbon stock accumulation of the *A. senegal* wood land across the three distance (disturbance) gradient was calculated in the form of per plot and per hectare by summing the biomass and carbon stock of the different pools. Estimation of carbon sequestration potential of the *A. senegal* woodland across the distance gradients were made by converting the total carbon stock (ton ha^{-1}) to tons of carbon dioxide equivalent (CO_2^{-e}) by multiplying it by 3.67 (IPCC 2003; Pearson et al. 2007).

Statistical analysis

Histogram was drawn to show the population structure of the woody vegetation drawn based on the DBH and height class. Woody plant species diversity indices, richness and dominance across each distance gradient were analyzed using PAST version 3.32 software. One way ANOVA was employed to test the significant difference of above and below ground dry biomass and carbon stock of tree/shrub as well as soil carbon stock of the woody vegetation across each distance gradients using SPSS version 20. Similarly one way ANOVA was employed to examine variable relationship using SPSS version 20. Pearson correlation was employed to examine the possible relationship of distance gradient from settlement with woody plant species diversity and carbon stock.

Table 2. Species specific and general allometric equations used to estimate dry biomass

Allometric equations	R^2	Author	Applied
$Y=0.032\ dbh^3-1.016\ dbh^2+10.87\ dbh+7.427$	0.96	Thiam et al. 2014	*A. Senegal*
$Y=(1.0497\times dsh)+(0.0300\times(dsh\times exp2.8))$	0.90	Parent 2000	*A. abyssinica*
$Y=0.1428\times dbh\times exp2.2471$	0.96	Kuyah et al. 2014	Non dominant

Y, dry biomass in Kg; dbh, diameter at breast height; dsh, diameter at stump height.

Result and Discussion

Woody plant species composition

A total of 41 woody plant species that belong to 20 families were identified in all distance gradients of the *A. senegal* woodland. Fabaceae, Combretaceae, Moraceae, Rhamnaceae, Lamiaceae represented were the dominant families (Fig. 4a). In agreement with the present finding, Fabaceae was reported as the most dominant family in dry woodland ecosystems (Gizaw 2006; Mekonnen et al. 2009; Adamu et al. 2011; Eshete et al. 2011; Takele et al. 2012; Neelo et al. 2013; Dibaba et al. 2014; Yilma et al. 2015). The dominant nature of Fabaceae family reflects the dry environmental condition may be suitable for this family or it indicates the ability of this family to resist the anthropogenic and environmental stress. Tree, Shrub, Tree/Shrub and climbing were the dominant growth forms (Fig. 4b) and it was in agreement with the growth form reported by (Gizaw 2006; Wendawek and Dessalegn 2014).

Higher number of woody plant species recorded from the far distance followed by the middle distance (Table 3). Woody plant species composition could vary along the disturbance gradients and high number of woody plant species was recorded in the middle disturbance gradient (Asefa et al. 2015). The highest number of woody plant species was recorded in the middle distance gradients of the water point (Tefera et al. 2006). The present study supports woody vegetation composition can vary along disturbance/distance gradients while the highest number of woody plant species was recorded in the far distance gradients from the settlement. The increasing number of woody plant species with an increasing distance gradient, empirically shows decrease in the degree of human induced pressures particularly the expansion of rain fed agricultural activities, highlighting the severity of anthropogenic factors in the area.

The total number of woody plant species recorded across the three distance gradients reflects the *A. senegal* woodland was floristically diverse as compared to studies sites with more or less similar agro-ecology and vegetation formation in other dry woodland areas of the country and other neighboring countries. The woodlands of northern Ethiopia were composed of 23 species (Gerhiwot 2003) and the woodlands of southern Ethiopia had 23 species (Gizaw 2006). The *A. senegal* dominated dry woodland of Awash national park, eastern Ethiopia composed of 25 species (Mekonnen et al. 2009) and the dry woodlands of Abergele and Metema in north and north western Ethiopia were composed 23 and 36 species respectively (Eshete et al.

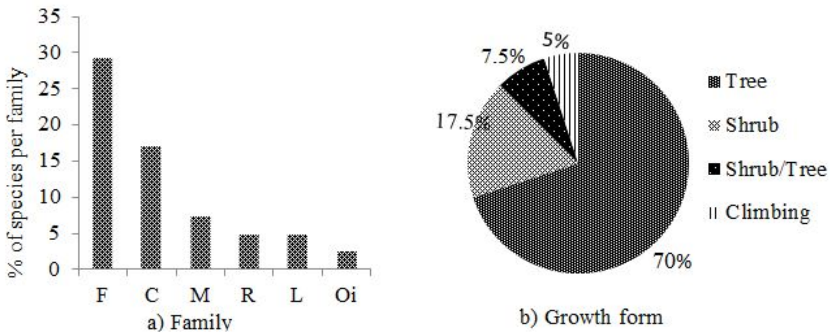

Fig. 4. The five dominant and other individual families (a) and growth form distribution (b). Where (F, fabaceae; C, combretaceae; M, moraceae; R, rhamnaceae; L, lamiaceae; Oi, other individuals).

Table 3. One way variance analysis of woody plant species composition, richness and diversity across each distance gradients

Parameters	Distance gradients			Along the woodland
	Near	Middle	Far	
Species composition	18	33	40	41
Species richness	7.87 ± 0.67^{a}	14.53 ± 0.65^{b}	16.81 ± 0.65^{c}	13.07 ± 0.63
Species diversity	1.58 ± 0.12^{a}	2.12 ± 0.06^{b}	2.24 ± 0.05^{b}	1.98 ± 0.08

*Different letters in the same rows are significantly different at ($p < 0.05$).

2011). Woodlands of Borona southern Ethiopia were composed of 24 species (Takele et al. 2012), the dry woodlands of northern Botswana were 27 species respectively (Neelo et al. 2013). Other lowlands of north western Ethiopia had 24 species (Alemu et al. 2015), Sherkole and Guba in western Ethiopia were composed of 18 and 23 species respectively (Yilma et al. 2015). Only 16 (39%) woody plant species were recorded in common in the three distance gradients. There were 15 (36.6%) woody plant species in common between the middle and far distance gradient while 7 (17.1) were only found at far distance gradients. The semi-arid of Borana in southern Ethiopia had more than 53% of the total 54 woody plant species recorded in common between the three distance gradients (Tefera et al. 2006). Woody plant species distribution across the disturbance gradients as a function of distance gradient from the settlement along the *A. senegal* woodland were comparatively inequitable and the number of woody plant species decreased with increasing disturbance.

Woody plant species richness, diversity and similarity

The number of plant species per plot increased with increased distance gradients (Table 3). Woody plant species richness was significantly different between the distance gradients ($p < 0.05$). Woody plant species diversity was significantly different between the distance gradients (Table 3). The Sorenson's similarity coefficient was 0.65, 0.62 and 0.89 for the nearest and middle, nearest and far and, middle and far distance gradients respectively.

Woody plant species richness, diversity and similarity were dependably varied across the three distance gradients from settlement, while specie richness and diversity consistently increased with an increasing of distance from the settlement (Table 3). A similar report from the semi-arid of Borana shows range of watering point distance leads variation of species richness, diversity and similarity (Tafera et al. 2006). Whereas Asefa et al. (2015) from the Afromontane Forest of Bale Mountains underlies level of disturbance as function of proximity to the settlement would bring a variation in species richness and diversity. Shannon-Weiner diversity index normally varies between 1.5 and 3.5 and rarely exceeds 4.5 (Kent and Coker, 1992). The level of woody plant species diversity of the present study implies relatively high diversity as its H' value ranges from 1.58-2.24 depending upon the distance gradients.

Sorenson's Coefficients (SJ) ranges between 0 and 1, in which 0 indicates complete dissimilarity and 1 indicates complete similarity in species composition (Neelo et al. 2013). The lower Sorenson's similarity Coefficients value recorded between the nearest and far distance gradients and the highest similarity coefficients was between the middle and far distance gradients. The higher similarity index between the distance gradients indicate the study area had earlier covered with the same woody plant species, but the gradual land use change related to the encroachment leads to the present woody plant species composition across the given distance gradients.

Abundance, frequency and density

A total of 1499 individual woody plants were recorded in the near (321), middle (570) and far (608) distance gradients respectively. A significant difference was found between near and middle, near and far distances ($p < 0.05$), but the difference was not significant between middle and far distance gradients (Fig. 5). *A. senegal* and *A. abyssinica* were the two abundant and frequently recorded species across each distance gradients. *A. senegal* was recorded in all plots and it represented 34.3%, 34% and 33.3% of the individual woody plant species recorded from the near, middle and far distance gradients respectively. *Ficus glumosa*, *Acacia sieberiana* and *Tamarindus indica* for the near distance, *Senna singueana*, *Combretum aculeatum*, *Carissa edulis*, *Ficus sycomorus* and *Maerua angolensis* for the middle distance and *Flueggia virosa*, *Ziziphus abyssinica*, *Securidaca longepedunculata* and *Combretum molle* for the far distance were the less abundant and frequent species.

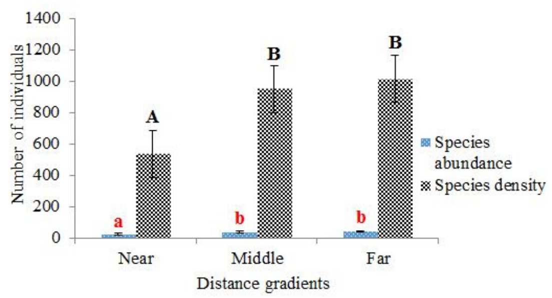

Fig. 5. Average woody plant species density (ha^{-1}) and abundance. Different letters with the same pattern are significantly different at ($p < 0.05$).

On average of 535 ha^{-1}, 950 $ha^{-1}$and 1013 ha^{-1} individual woody plant density were recorded along the near, middle and far distance gradients respectively. The average woody plant density per hectare across the *A. senegal* woodland was 832.8. Woody plant species density was significantly different between the near and middle distance gradients (p=0.001), and the nearest and far distance gradients (p=0.001). There was no significant difference in species density between the middle and far distance gradients (Fig. 5). The average woody plant species density of the *A. sengal* woodland had relatively high compared to those reported from lowlands of Metema (376.86 ha^{-1}) in northwest Ethiopia (Wale et al. 2012; Alemu et al. 2015) and Lagadara (682 ha^{-1}) in southern Ethiopia (Wendawek and Dessalegn 2014).

A. senegal, *A. abyssinica* and *B. aegyptiaca* were the three abundant species accounted 60.4%, 49.5% and 47.7% from the total density of individual woody plant species along the near, middle and far distance gradients respectively (Fig. 6). *A. senegal* was the abundant and frequent specie and had a significant contribution to the total density of the woody plant species of each distance gradients (Fig. 6). *A. senegal* was the most abundant and frequent species across the three land management types in the woodland of Awash national park (Mekonen et al. 2009).

Disturbance caused a significant variation density, abundance and frequency of woody plant species along each distance gradients. In agreement with this finding Oqbazgi (2001) had reported woody plant species abundance and distribution decreases with increasing disturbance intensity with a greater abundance found in remote areas from livestock grazing. The species that appeared in higher frequency has regular horizontal distribution (Tilahun et al. 2015). The high abundance, frequency and contribution of *A. sengal* species to the total density of the woodland species implies the ability of this species to resist and survive the joint effect of dry land environment and anthropogenic factors through morphological and physiological adaptive mechanisms.

Woody plant species basal area and importance value index (IVI)

Woody plant species mean basal area was significantly different between the near and middle, near and far (p=0.001) and between the middle and far distance gradients (p=0.003, Fig. 7). The mean total basal area of all woody plant species with DBH > 2.5 cm were 2.63 m^2 ha^{-1}, 8.7 m^2 ha^{-1} and 11.44 m^2 ha^{-1} for the near, middle and far distance gradients respectively and the average basal area of *A. senegal* woodland was 7.7 m^2 ha^{-1} (Table 4).

The average basal area of the *A. senegal* woodland was comparable with the average basal area (9.7 m^2 ha^{-1}) reported from the *B. papyrifera* woodlands of north- western Ethiopia (Alemu et al. 2015) and from 5.8-12.4 and 7.6-16.4 m^2 ha^{-1} in Abergelle and Metema woodlands respectively of north and north- western Ethiopia (Eshete et al. 2011). The lower basal area recorded in the near distance gradient shows the intensity of selective removal of woody plant species with large DBH class as compared to the far distance gradients, in which relatively highest basal area was recorded.

The contribution of DBH class to the basal area was

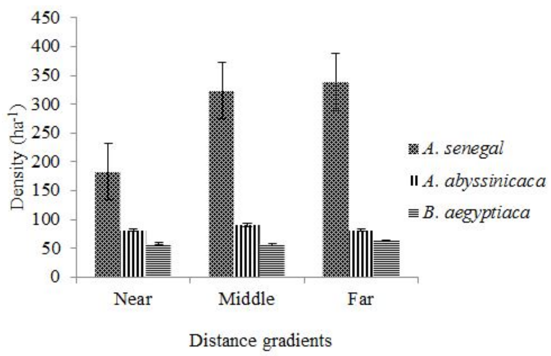

Fig. 6. Density proportion of the three abundant woody plant species along the three distance gradients.

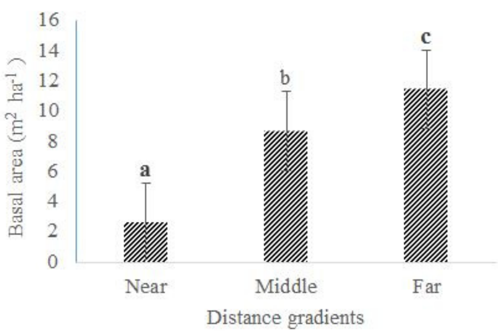

Fig. 7. Mean total woody plant species basal area along each distance gradients (m^2 ha^{-1}).

Table 4. Proportional contribution of DBH class to the total density ha^{-1} and basal area (m^2 ha^{-1})

DBH class (cm)	Near distance		Middle distance		Far distance		Across the woodland			
	D	BA	D	BA	D	BA	AD	%	ABA	%
<2.5	91.70	-	186.70	-	250.00	-	176.10	21.20	-	-
2.5-6.5	210.00	0.20	216.70	0.19	176.70	0.16	201.10	24.20	0.19	2.50
6.5-10.5	113.31	0.34	193.30	0.66	145.00	0.63	150.50	18.10	0.55	7.20
10.5-14.5	41.70	0.23	128.30	0.88	155.00	1.06	108.30	13.00	0.73	9.40
14.5-18.5	8.50	0.09	61.70	0.78	78.30	0.91	49.50	5.90	0.60	7.80
18.5-22.5	23.30	0.31	40.00	0.88	70.00	1.24	44.40	5.30	0.82	10.60
22.5-26.5	21.70	0.33	28.30	0.78	35.00	1.18	28.30	3.40	0.77	10.00
26.5-30.5	6.70	0.11	38.30	1.19	30.00	0.91	25.00	3.00	0.74	9.60
30.5-34.5	8.30	0.51	20.00	0.91	23.30	1.43	17.20	2.10	0.95	12.40
34.5-38.5	5.00	0.20	20.00	0.81	13.30	0.31	12.80	1.50	0.45	5.80
38.5-42.5	3.30	0.25	8.30	0.63	18.30	1.36	10.00	1.20	0.75	9.70
>42.5	1.70	0.00	8.30	0.96	18.30	2.51	9.40	1.10	1.16	15.10
	535	2.63	950.00	8.70	1013.00	11.44	832.80	100	7.70	100

D, density; BA, basal area; AD, average density; ABA, average basal area.

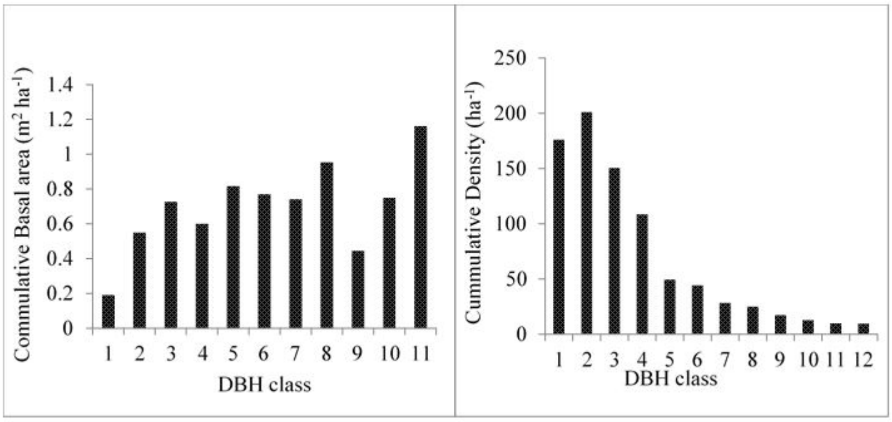

Fig. 8. Cumulative basal area and density of woody plant species across the *A. senegal* woodland: (1, <2.5 cm; 2, 2.5-6.5 cm; 3, 6.5-10.5 cm; 4, 10.5-14.5 cm; 5, 14.5-18.5 cm; 6, 18.5-22.5 cm; 7, 22.5-26.5 cm; 8, 26.5-30.5 cm; 9, 30.5-34.5 cm; 10, 34.5-38.5 cm; 11, 38.5-42.5 cm; 12, >42.5 cm).

found inversely related to its contribution to the total woody plant species density across each distance gradients (Fig. 8). The DBH class > 42.5cm contributed the highest (15.1%) to the average basal area and the lowest to the average density. DBH class < 10.5cm contributed the lowest 9.7% to the accumulative basal area and the highest 63.5 to the cumulative density. This result was comparable to Abebe and Dessalegn (2014) shows woody plant species density declined with increasing DBH class. About 69% of the total density was contributed by DBH class < 10 cm and it accounted very low for the total basal area, whereas few woody plant species with DBH > 50 cm were accounted 50.6% of the total basal area. Species with the highest basal area do not necessarily have the highest density, which indicates the presence of size difference between woody plant species.

The basal area of the woody plant species of the nearest distance gradient had interrupted shapes (Fig. 9a) and concentrated in the middle DBH class. The basal area of the woody plant species of the middle distance gradient had irregular shape (Fig. 9b) and concentrated in the higher DBH class. The total basal area of the woody plant species of the far distance gradient had interrupted J-shape (Fig. 9c) and concentrated in the higher DBH class. The cumulative basal area had an interrupted J-shape, but the cumulative density had an inverted J-shape. The absent of high

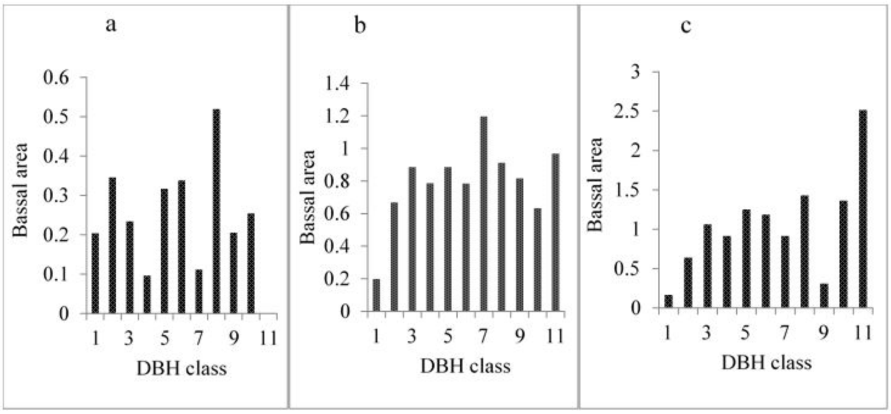

Fig. 9. DBH class in relation to the total basal area of the (a) near, (b) middle and (c) far distance gradients: (1, 2.5-6.5 cm; 2, 6.5-10.5 cm; 3, 10.5-14.5 cm; 4, 14.5-18.5 cm; 5, 18.5-22.5 cm; 6, 22.5-26.5 cm; 7, 26.5-30.5 cm; 8, 30.5-34.5 cm; 9, 34.5-38.5 cm; 10, 38.5-42.5 cm; 11, >42.5 cm).

DBH class in the near distance gradient implies the extent of selective cutting of the large tree species for the expansion of the subsistence farming system, for construction purpose, fuel wood, for farm round fencing and for livestock feeding. The far distance makes the area to be inaccessible to remove the higher DBH class woody plant species.

The important value index of a given species indicates its level of importance in the given vegetation, where species with the highest IVI value reflects the degree of abundance, dominance and occurrence of a given species in relation to the other associated species in the area (Wendawek and Dessalegn 2014). Accordingly the present result indicates *A. sengal*, *Balanites aegyptiaca*, *A. abyssinica*, *A. polyacantha* and *Dichrostachys cinerea* for the near, *A. sengal*, *Balanites aegyptiaca*, *A. polyacantha*, *A. abyssinica* and *Combretum fragrans* for the middle, and *A. sengal*, *Albizia amara*, *Balanites aegyptiaca*, *A. abyssinica* and *Anogeissus leiocarpus* for the far distance gradients were the top five dominant woody plant species, that accounted 66.51%, 49.8% and 46.2% of the total IVI value of the near, middle and far distance gradients respectively. Similarly Didita et al. (2010); Wale et al. (2012); Tilahun et al. (2015) from comparable woodland vegetation reported the top 5, 9 and 5 dominant species were accounted 25.7%, 63% and 54.5% of the total IVI respectively.

Gardenia lutea, *Flueggia virosa*, *Ficus glumosa*, *Acacia sieberiana* and *Tamarindus indica* for the near, *Securidaca longepedunculata*, *Maerua angolensis*, *Combretum aculeatum*, *Carissa edulis* and *Jasminum abyssinicum* for the middle, and *Grewia flavescens*, *Ziziphus abyssinica*, *Securidaca longepedunculata*, *Combretum molle* and *Flueggia virosa* for the far distance gradients in descending order were the five least dominant woody plant species accounted only 3.5%, 1.4% and 3.8% of the total IVI value of the near, middle and far distance gradients respectively. Woody plant species with the lowest IVI value had low contribution to the total IVI value and it implies their low ecological significance in the intended area (Worku 2006; Wale et al. 2012; Tilahun et al. 2015).

In the present study *A. sengal* was dominant species across each distance gradients with relatively high IVI value. Similar finding from Awash National Park was reported that *A. senegal* was growing abundantly in spite of ecological variation in the park and it recorded the highest IVI value across the three disturbance types (Mokenen et al. 2009). Neelo et al. (2013) shows species with relatively the highest IVI value indicates their high value of density, frequency and dominance, while ecologically considered as the most significance species. Besides Worku (2006) suggest that the relatively high IVI value of *A. senegal* implies the species was among the best adapted, dominated and with relatively healthy population status in the area. Only few species were found with the highest IVI value implies their well adaptation to the high pressure of anthropogenic disturbance, natural and environmental factors (Erenso et al. 2014). IVI value recorded for each woody plant species was dissimilar across each distance gradients. In line with this finding, Gizaw (2006); Wale et al. (2012); Erenso et al. (2014) reported almost all woody plant species showed variation in terms of their IVI value, that implying the difference in ecological significance of each species in the study area.

Population structure and regeneration status of woody plant species

DBH and height class distribution: The cumulative DBH and height class distribution of all individuals across each distance gradients showed interrupted inverted J-shape pattern (Fig. 10 and 11). The highest portion of the total density of individual woody plant species was recorded for DBH class less than 10.5 cm and height class less than 7 m across the nearest, middle and far distance gradients, while the numbers of individual woody plant species were decreased with an increased in the DBH and height class.

In line with the current result, Burju et al. (2013); Wendawek and Dessalegn (2014) found the highest proportion of the total density of individual trees and shrubs were recorded for the lower (< 10 cm) DBH class and individual density was declining with increasing DBH size. Majority of individual woody plant species in the lower DBH and height class with gradual decrease towards the highest DBH and height class is a general pattern of normal population structure, implies the probability of good reproduction and recruitment manner (Didita et al. 2010; Dibab et al. 2014; Tilahun et al. 2015).

The cumulative DBH class distributions of all individuals in the nearest distance gradient were clearly differing from the cumulative DBH class distribution of all individuals in the middle and far distance gradients. The DBH pattern in near distance shows a rapid increasing from DBH class one towards DBH class two and followed by rapid decreasing towards the higher DBH class. The reason for the fewer seedling and sapling stage individuals in the lower DBH class than the middle diameter class may be due to species in the youngest stage were trampled and

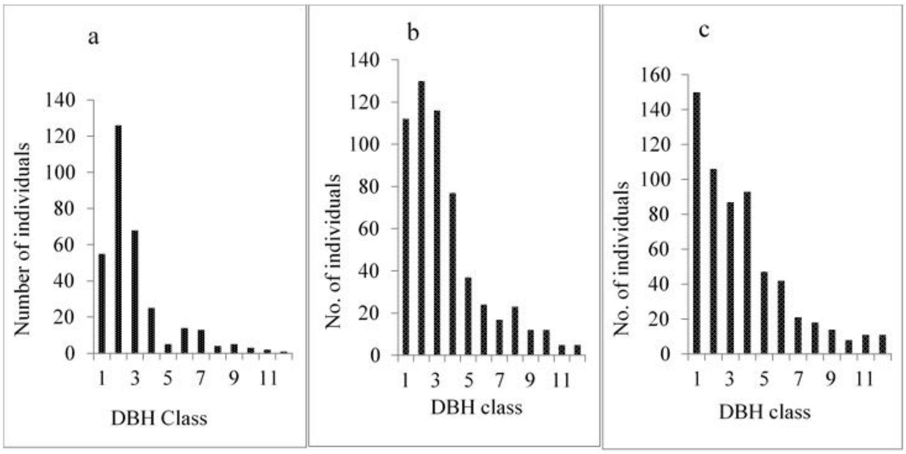

Fig. 10. DBH class distribution of all woody plant species across (a) near, (b) middle and (c) far distance gradients: (1, <2.5 cm; 2, 2.5-6.5 cm; 3, 6.5-10.5 cm; 4, 10.5-14.5 cm; 5, 14.5-18.5 cm; 6, 18.5-22.5 cm; 7, 22.5-26.5 cm; 8, 26.5-30.5 cm; 9, 30.5-34.5 cm; 10, 34.5-38.5 cm; 11, 38.5-42.5 cm; 12, >42.5 cm).

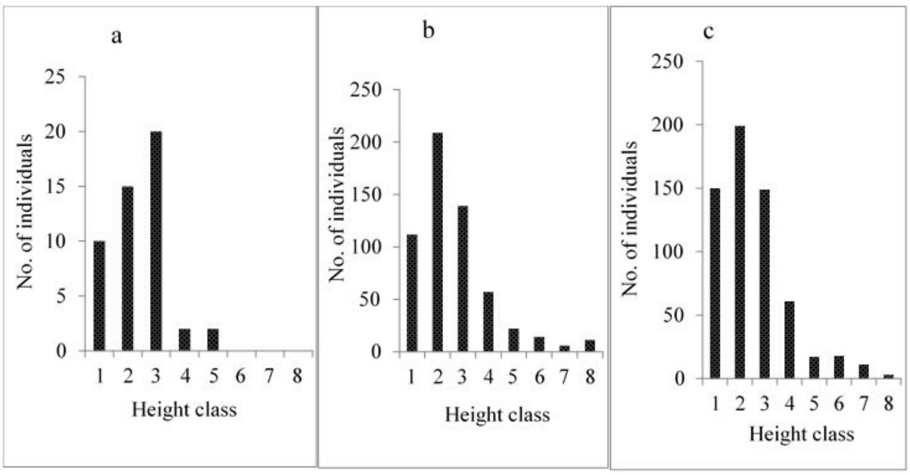

Fig. 11. Height class distribution of all woody plant species across the (a) near, (b) middle and (c) far distance gradients: (1, <3 m; 2, 3-5 m; 3, 5-7 m; 4, 7-9 m; 5, 9-11 m; 6, 11-13 m; 7, 13-15 m; 8, >15 m).

browsed by livestock. The general inverted J-shape pattern from cumulative DBH class may not represent the general trend of population dynamics and recruitment process of a single species, but analysis DBH pattern for each individual tree or shrub species could bring the realistic and specific information to forecast the future population dynamics of the woody plant species (Gizaw 2006; Didita et al. 2010). The frequency distribution of DBH class of the top three selected woody plant species across the three distance gradients had revealed different patterns (Fig. 11). Evaluation of DBH pattern of the top selected important species had varied in population structures indicating different population dynamics between each species (Wale et al. 2012; Burju et al. 2013; Dibaba et al. 2014; Tilahun et al. 2015).

The DBH pattern of both *A. senegal* and *A. abyssinica* species in the near distance gradient (Fig. 12A) exhibited rapid increasing from class 1 towards class 2 followed by rapid decreasing towards class 3, 4, 5 and 6 with DBH distribution absent in the large DBH class. The lower frequencies in class 1 (seedling and sapling stage) may indicate the level of low survival rate in the lower stage of the species

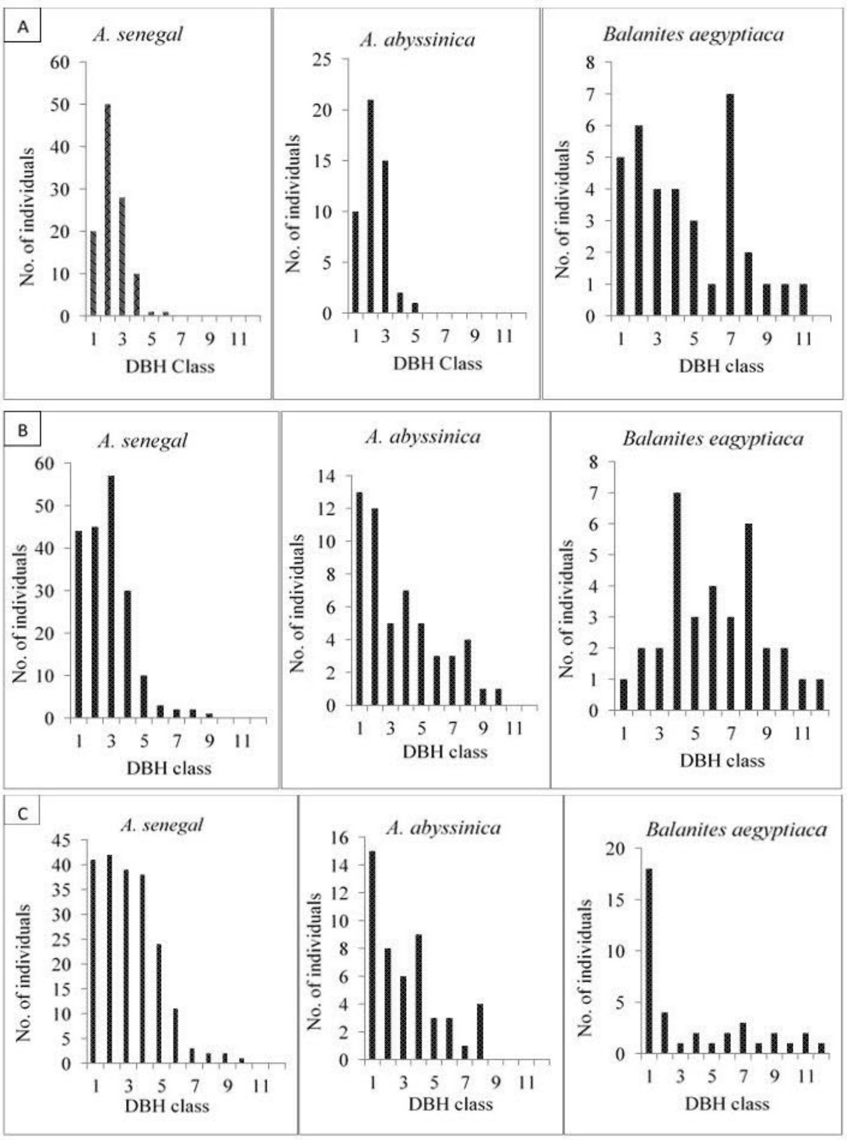

Fig. 12. DBH class distribution of the top 3 woody plant species in the (A) near, (B) middle and (C) far distance gradients: (1, <2.5 cm; 2, 2.5-6.5 cm; 3, 6.5-10.5 cm; 4, 10.5-14.5 cm; 5, 14.5-18.5 cm; 6, 18.5-22.5 cm; 7, 22.5-26.5 cm; 8, 26.5-30.5 cm; 9, 30.5-34.5 cm; 10, 34.5-38.5 cm; 11, 38.5-42.5 cm; 12, >42.5 cm).

due to trampling, consuming and over throw by livestock in relation the longest dry season. Absence of DBH pattern in the medium to larger DBH class implied that there is selective removal of large individuals of the species for construction purpose, charcoal production, fuel wood, agricultural expansion and farm round fencing as the two species are thorny. Where species with such pattern could become scarce for the future, as individuals are being harvested before reaching the reproductive ages, and this could result in the future decline of the species population because these reflects a bad recruitment with relatively good reproduction (Tilahun et al. 2015). The DBH pattern of *B. aegyptiaca* species was gradually increasing from class1 towards class 2 and decreasing towards class 6 and rapid increasing towards class 7 and decreasing towards class 11 and absent in class 12 (Fig. 12A). The rapid decreasing and absence of DBH pattern towards the highest DBH class indicated selective cutting of the large DBH size. The irregular population structure of *B. aegyptiaca* is reflecting the existence of bad recruitment that could have a negative impact on the future population structure of the species.

In the middle distance gradient (Fig. 12B) the DBH pattern of *A. senegal* species has revealed gradual decrease as the diameter class increase and absent in the largest DBH class. The DBH pattern of *A. abyssinica* (Fig. 12B) showed normal population structure. In both species the trend of decreasing as well as absence of DBH frequency towards the highest DBH class indicates selective cutting of the large DBH size of the species. The interrupted bell shape population structure of *B. aegyptiaca* (Fig. 12B) showed the low survival rate of the saplings due to trampling and browsing associated with the longest dry season and selective cutting of the large DBH class.

The DBH pattern of *A. senegal* species had gradually increasing from class 1 towards class 2 and decreasing towards class 10 and absent in the largest DBH class (Fig. 12C). The DBH pattern of *A. abyssinica* had showed normal population structure with gradual decreasing from class 1 towards class 8 (Fig. 12C). The trend of decreasing and absent of DBH frequency towards the highest DBH class had implied selective cutting of the large DBH size of the species for charcoal production, construction, fuel wood production and fencing. The inverted J population structure of *B. aegyptiaca* (Fig. 11c) is reflecting the advanced survival rate of the youngest stage due to decreasing in anthropogenic effects associated with the increased distance from the settlements. *B. aegyptiaca* showed an inverted J population pattern with increasing distance from settlement. The population pattern of *A. senegal* and *A. abyssinica* species showed obstructed pattern regardless of distance gradients. The population structure of *A. senegal* showed discontinuity towards the highest DBH class due to selective cutting of the larger DBH class for various purpose in the Awash national park in Ethiopia (Mekonen et al. 2009).

Regeneration status of the woody plant species: Evaluation of seedlings/saplings density and composition could contribute to predict the regeneration status of the woody plant species, where abundance of seedlings and saplings are empirical indicator of establishment of young individuals in a given area (Tilahun et al. 2015). The lowest and highest seedling and sapling were found in the nearest and farthest distance gradients respectively (Fig. 13). On Average 132 (73.3 ha^{-1}) seedlings, 185 (102.8 ha^{-1}) saplings and 1182 (656.7 ha^{-1}) mature tree/shrubs were recorded from the total 45 sample quadrats measured across all distance gradients of the *A. senegal* wood land, where 8.81%, 12.34% and 78.85% of the developmental structure was contributed by seedlings, saplings and mature tree/shrubs respectively with the highest portion of it was covered by the mature tree/shrubs. Similar findings from Lagadara woodland and Egdu forest, in Ethiopia indicated that the proportional pattern of the three developmental stage were constituted as seedling < sapling < mature tree/shrub, where such pattern implies poor reproduction and hampered regeneration of the major species associated with the sensi-

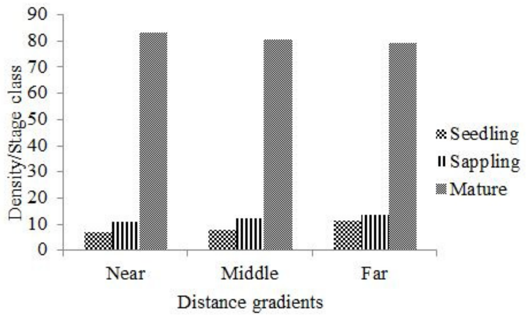

Fig. 13. Developmental structure of all habit forms across each distance gradients.

tiveness of seedlings and saplings to climatic variability, edaphic factors and human induced disturbance (Wendawek and Dessalegn 2014; Tilahun et al. 2015). Young regenerating individuals i.e., sapling and seedling were observed increasing from high to low disturbed forests which reflected that the forest fragmentation adversely affected the regeneration in Temperate forests of western Himalya (Tiwari et al,. 2019).

There were 19 species without seedlings (e.g. *Combretum hartmannianum*, *Poliostigma thonningii*, *Flueggia virosa*, *Ficus glumosa*, *Acacia sieberiana*, *Jasminum abyssinicum*, *Senna singueana*, *Vangueria madagascariensis*, *Combretum* spp, *Ormocarpum pubescens*, *Boscia angustifolia*, *Ficus sycomorus*, *Ziziphus abyssinica*, *Securidaca longepedunculata*, *Combretum aculeatum*, *Carissa edulis*, *Diospyros mespiliformis*, *Maerua angolensis* and *Tamarindus indica*) and 15 species without saplings (e.g. *Combretum hartmannianum*, *Poliostigma thonningii*, *Ficus glumosa*, *Acacia sieberiana*, *Senna singueana*, *Vangueria madagascariensis*, *Ximenia Americana*, *Combretum* spp, *Ficus sycomorus*, *Ziziphus abyssinica*, *Securidaca longepedunculata*, *Combretum aculeatum*, *Carissa edulis*, *Diospyros mespiliformis* and *Maerua angolensis*). There were 14 species without both seedlings and saplings (e.g. *Combretum hartmannianum*, *Poliostigma thonningii*, *Ficus glumosa*, *Acacia sieberiana*, *Senna singueana*, *Vangueria madagascariensis*, *Combretum* spp, *Ficus sycomorus*, *Ziziphus abyssinica*, *Securidaca longepedunculata*, *Combretum aculeatum*, *Carissa edulis*, *Diospyros mespiliformis* and *Maerua angolensi*) which had low regeneration ability and they may disappear in the future. Evaluation of stage structure of the given vegetation could play a central role to set vegetation conservation priority in the intended area. Wendawek and Dessalegn (2014) stated three conservation priorities as priority 1 for species that lacked both seedlings and saplings, priority 2 for species that lacked seedlings whereas priority 3 for species that lacked saplings respectively. The regeneration capacity of the constituent species were a measure of vegetation sustainability, as such matured tree/shrub species that lacked seedlings and/or saplings had reduced trends of regeneration from their seedlings and saplings and these species may disappear in the future. The sustainability of the current comparable diversified ingenious woody plant species of the *A. senegal* woodland was in question, that needs urgent protection, conservation and restoration.

Dry biomass, carbon stock and carbon sequestration estimation

Above and below ground tree and shrub dry biomass

The mean dry biomass of trees and shrubs of the *A. senegal* woodland ranged 13.72-32.45 ton ha^{-1} across the three distance gradients, where the mean dry biomass was 13.72, 26.81 and 32.45 ton ha^{-1} for the near, middle and far distance gradients respectively (Table 5). The mean total dry biomass stock of trees and shrubs between the three distance gradients was significantly different ($p < 0.05$). The lowest (13.72 ton ha^{-1}) and relatively the highest (32.45 ton ha^{-1}) mean total dry biomass (MTDBM) of the trees and shrubs were found for the nearest and far distance gradients respectively. High woody plant species density with moderate DBH class distribution may contribute for the highest mean total dry biomass of trees and shrubs in the far distance gradients. In line with current finding, Almeida et al. (2014) sites or plots with a high density of mature tree species contain higher dry biomass than the sites or plots with the lowest mature woody plant species density.

The mean total above ground dry biomass stock of the *A. senegal* woodland was relatively high as compared with

Table 5. Mean above ground (AGDBM), below ground (BGDBM) and total dry biomass (TDBM) across each distance gradients

Different pools	Distance gradients			Along the woodland
	Near	Middle	Far	
AGDBM (ton ha^{-1})	10.6±0.93^{a}	20.9±1.40^{b}	25.4±1.30^{c}	18.97±1.21
BGDBM (ton ha^{-1})	3.1±0.26^{a}	5.9±0.42^{b}	7.1±0.36^{b}	5.37±0.35
TDBM (ton ha^{-1})	13.7±1.20^{a}	24.8±1.60^{b}	32.5±1.70^{c}	23.67±1.50

*Different letters in the same row are significantly different at ($p < 0.05$).

mean above ground dry biomass reported from the *Acacia* sparsely dominated Sudanian arid and semi-arid woodland (Alam et al. 2013) and the semi-arid grass land of Southern Ethiopia (Bosco 2014) respectively. Moreover, the present mean total dry biomass of the trees and shrubs was comparable with mean total dry biomass of trees/shrubs reported from the Kitulangalo forest reserve, Tanzania (Malimbwi et al. 1994) and the semi-arid of Borana, Ethiopia (Rathjen 2012) respectively.

Above and below ground trees/shrubs carbon stock

The mean total biomass carbon stock of the trees/shrubs ranged from 6.861-16.226 tone ha^{-1} across the *A. senegal* woodland. The mean total biomass carbon stocks of trees/shrubs were 6.861, 13.403 and 16.226 ton ha^{-1} in the near, middle and far distance gradients respectively (Table 6). The lowest and highest mean total biomass carbon stock of trees/shrubs was recorded in the near and far distance gradients. The mean total biomass carbon stock of the trees/shrubs was significantly different across each distance gradients ($p < 0.05$) (Table 6). The above ground biomass carbon stock of trees and shrubs were significantly different across each distance gradients at ($p < 0.05$). The below ground biomass carbon stock of trees and shrubs were significantly different between near and middle and near and far distance gradients ($p < 0.05$).

The lowest and highest above ground, below ground and mean total biomass carbon stock were recorded in the near and far distance gradients respectively. Stand structure and composition, level of disturbance and fuel wood collection are some of the main determinant factors for the variation of above and below ground biomass carbon stock, where less disturbed or protected woodlands could promote the ecosystem carbon stock (Alemu 2012). An area under protection or less distressed from human interference possess a high tree density and that contributes as potential biomass carbon stock than the disturbed area (Feyssa et al. 2013). Similarly Munishi et al. (2010) stated that variation in the degree of exposure to human disturbance, difference in the age of the tree species and the type of the intended woodland were leading factors for variation of carbon stock. Indeed increasing the level of disturbance leads to decline by 37% biomass carbon stock from the least disturbed to the most disturbed site (Daryant et al. 2013), in agreement with this finding the present result showed reduction of the mean total biomass carbon stock by 40% from the far distance gradient (least disturbed area) to the near distance gradient (more disturbed area). The mean above ground biomass carbon stock recorded across the *A. senegal* woodland was high as compared with reported from the Acacia dominated semi-arid Sudanese woodland, Sudan (Alam et al. 2013); Pugu forest reserve, Tanzania (Bosco 2014); Miombo woodland , Tanzania (Malimbwi et al. 1994); Semi-arid of Borana, Ethiopia (Rathjen 2012) and Semi-arid grass land of Southern Ethiopia (Bosco 2014). However the mean total biomass carbon stock recorded across the *A. sengal* was far less when compared to the mean biomass carbon stock of most tropical dry forest and woodlands (Casey et al. 2010; Munishi et al. 2010; Mohammed and Bekele 2014).

The variation in mean total carbon stock between different areas may be due to methodological approach such as

Table 6. Above ground carbon stock (AGCS), below ground carbon stock (BGCS), total biomass carbon stock (TBCS) of trees and shrubs along the three distance gradients (Mean±SE)

Carbon Pools	Distance Gradients		
	Near	Middle	Far
AGCS (ton ha^{-1})	5.29 ± 0.46^{a}	10.43 ± 0.69^{b}	12.69 ± 0.65^{b}
BGCS (ton ha^{-1})	1.57 ± 0.13^{a}	2.97 ± 0.21^{b}	3.53 ± 0.18^{b}
TBCS (ton ha^{-1})	6.86 ± 0.59^{a}	13.40 ± 0.90^{b}	16.23 ± 0.83^{c}

*Different letters in the same row are significantly different at ($p < 0.05$).

Table 7. Top soil organic carbon (TSOC), sub soil organic carbon (SSOC), total soil organic carbon stock (TSOCS) along the three distance gradients (Mean±SE)

Carbon pools	Distance gradients		
	Near	Middle	Far
TSOC (0-15 cm) (ton ha^{-1})	19.31 ± 10^{a}	21.22 ± 1.60^{a}	23.48 ± 1.10^{a}
SSOC (15-30 cm) (ton ha^{-1})	16.32 ± 0.90^{a}	$19.35 \pm 1.10^{a,b}$	20.99 ± 1.06^{b}
TSOCS (0-30 cm) (ton ha^{-1})	35.63 ± 1.73^{a}	$40.57 \pm 2.63^{a,b}$	44.48 ± 2.08^{b}

*Different letters in the same row are significantly different at ($p < 0.05$).

sample size and allometric equations applied to calculate biomass and site variations (Assaye and Zerihun 2016). Selective cutting of tree species with medium to large DBH size was the causal factor to reduce biomass carbon stock of the forest ecosystem (Beda 2013). The low mean total biomass carbon stock in the present study may be related to those species specific and general allometric equations used to calculate dry biomass of the woody plant species and difference in geographical location of the area and the high level of human interference. Besides the present finding proved that the variation of biomass carbon stock across each distance gradients may implying the impact of the past and ongoing anthropogenic disturbance associated with microclimatic conditions declined the current and future carbon stock potential that needs protection, conservation and rehabilitation of the native woody plant species of the *A. senegal* woodland. The woodland may be source of atmospheric carbon dioxide emission than carbon stocking, as destruction of the dry tropical forest by human could accelerated the global warming by releasing around 17% global carbon dioxide (Munishi et al. 2010).

Soil organic carbon stock

The mean soil organic carbon stock of the *A. senegal* woodland was ranged from 35.63-44.48 ton ha^{-1} (Table 7), with a mean of 35.63, 40.57 and 44.48 ton ha^{-1} for the near, middle and far distance gradients respectively. The mean soil organic carbon stock was significantly different between the near and far distance gradients ($p < 0.05$). The large mean soil organic carbon was recorded in the upper than the lower soil strata along each distance gradients.

The biomass and soil organic carbon pools had similar trends following each distance gradients, reflecting the positive relationship of the two carbon pools. The available level of trees and grass cover have potential contribution for biomass and carbon deposition, therefore conversion of any form of natural vegetation to cultivated or over grazing field will result to reduce the biomass carbon and soil organic carbon content of the area (Assaye and Zerihun 2016). Intensive disturbance with excessive grazing has determinant influence on soil organic carbon similar to the effect of mining soil fertility by inappropriate cropping (Lal et al. 2004).

Decreasing of mean soil organic carbon stock was observed as the soil depth increases, which was in agreement to those reported by (Belay and Kebede 2010; Beda 2013; Daryanto et al. 2013; Almeida et al. 2014; Nega et al. 2015). The high concentration of biological activities particularly organic residues were deposited in the top soil and organic matter tends to accumulate in the upper soil profiles leads to possess relatively large soil organic carbon than the lower soil profile. The mean total soil organic carbon stock recorded in this study was higher compared with those similar soil depth reported from the Miombo woodland, Mozambique (Casey et al. 2010), untapped and tapped *B. papyrifera* woodland, Ethiopia (Alemu 2012). There was a comparable mean total soil organic carbon stock of similar soil depth was reported from tapped *B. papyrifera* woodland, Ethiopia (Alemu 2012) and Mangrove Forests, Mozambique (Almeida et al. 2014).

Total carbon stock and sequestration potential of the woodland

The total mean carbon stock was ranged from 42.49-60.7 ton ha^{-1} across the *A. senegal* woodland, with a mean total carbon stock of 42.49, 53.97 and 60.7 ton ha^{-1} for the near, middle and far distance gradients respectively. The lowest and highest mean total carbon stock was recorded in the near and far distance gradients respectively (Table 8). The mean total carbon stock was significantly different between

Table 8. Total mean carbon stock (TMCS) and total mean carbon dioxide equivalent ($TMCO_2^{-e}$) (ton ha^{-1}) along the three distance gradients

Variables	Distance gradients			Cumulative mean total across the *A. senegal* woodland (ton ha^{-1})
	Near	Middle	Far	
TMCS	42.5 ± 2.13^a	53.9 ± 2.87^b	60.7 ± 2.50^b	52.4 ± 2.50
$TMCO_2^{-e}$	156 ± 7.80^a	198.1 ± 10.50^b	222.8 ± 9.20^b	192.3 ± 9.20

*Different letters in the same rows are significantly different at ($p < 0.05$).

the near and middle, near and far distance gradients. Woodland ecosystem could play as a source of capturing and retaining a huge amount of carbon for a long period of time as trees captivated carbon through photosynthesis process, where mature trees act as a reservoir and young tree sequester additional carbon to achieve their growth. The root part contributes to the below ground biomass carbon as well as soil organic carbon through root death, decomposition and rhizodeposition. The increase in total mean carbon stock towards the far distance gradients reflects the effect of human interference on the carbon sequestration and climate mitigation potential of the woodland. Such pressure which can change the land use could adversely affect the biomass and soil organic carbon stock (Mohammed and Bekele 2014).

Soil organic carbon content varied from low in the arid regions and high in the temperate regions and extremely high in peat soils, but due to the long turnover time of organic matter and less inter-annual variability, soil is the most effective carbon sequestration pool in many ecosystems, where the total carbon pool is four times of the biotic (tree) pool and about three times of the atmospheric pool (Lal et al. 2004). Soil organic carbon stock, above ground biomass carbon stock of trees/shrubs and the below ground (root) biomass carbon stock of trees/shrubs contributed about 76.8%, 18.1% and 5.1% to the mean total carbon stock of the *A. senegal* woodland. Similar reports from the Pugu Forest reserve, Tanzania Beda (2013) and Miombo Woodland of Mozambique Cassey et al. (2010) had revealed about 78.2% and 72.4% of the total mean carbon stock was contributed by soil organic carbon respectively. The proportional contribution of soil organic carbon to the total carbon stocks was higher than the other pools (Alemu 2012; Almeida et al. 2014; Assaye and Zerihun 2016).

Correlation of distance gradient, woody species diversity and carbon stock

The distance was significantly and positively correlated with the woody plant species diversity, biomass carbon stock and mean total soil organic carbon (Table 9). The increasing distance from the settlement stimulated the improvement of woody plant species diversity, biomass carbon stock and mean total organic soil carbon.

Species diversity and total carbon stock across the heavy, moderate and less human disturbed forest area was significantly and positively correlated (Kpontsu 2011). Level of human disturbance has significant effect and positive correlation with woody plant species diversity, biomass carbon stock and soil organic carbon in southern Ethiopia woodlands (Yohannes et al. 2015). Other study from the tropical forest had revealed that the proximity towards the large forest fragment has positive relationship with biomass carbon stock, soil organic carbon and species diversity (Fernandos et al. 2015).

A mutual relationship between woody plant species diversity and carbon stock reflects the carbon stock management and biodiversity conservation can be performed simultaneously (Assaye and Zerihun 2016). Therefore minimizing the level of disturbance could be a dual solution to maintain woody plant species diversity and total carbon stock potential of the *A. senegal* woodland ecosystem and thereby to biodiversity and ecosystem services from these fragile resources.

A significant and positive relationship was detected between woody plant species diversity and biomass carbon stock across the *A. senegal* woodland (Table 9). The current findings of co-benefit relationship between woody plant species diversity and biomass carbon stock was in agreement with the reports of (Mekuria et al. 2009; Wang et al. 2011; Fernandos et al. 2015; Kemeuze et al. 2015; Jhariya and Yadav 2018) suggesting that increasing structural diversity enhances biomass carbon storage capacity.

Table 9. Relationship between distance from settlement, diversity and carbon stock

Variables	Pearson co-relation	p-value
Distance gradient and diversity	0.641**	0.000
Distance gradient and biomass carbon stock	0.780**	0.000
Distance gradient and mean soil organic carbon	0.405**	0.006
Diversity and biomass carbon stock	0.516**	0.000
Diversity and mean soil organic carbon stock	0.332*	0.026
Biomass carbon stock and mean TSOC	0.477**	0.001

*Correlation is significant at the 0.05 level. **Correlation is significant at the 0.01 level.

But in contrast to these finding, Zhang et al. (2011); Alex et al. (2012) has reported a negative relationship between woody plant species diversity and biomass carbon stock and suggesting that the amount of carbon stock was not determined only by the number of species but more likely to be determined by DBH and density characteristics of the species present. Similarly a significant and positive relationship was found between biomass carbon stock and soil organic carbon stock, which is similar to the findings of (Mekuria et al. 2009; Alam et al. 2013), indicating that a broad dependence of soil organic carbon on woody plant species and root litter production that increase the input sources of soil carbon density through the naturally available biomass and the associated microbial activities.

Conclusion

Woody plant species composition consistently increased with increased distance from settlements indicated the adverse effect of human disturbance on woody plant species floristic composition. Yet the total number of native woody plant species identified across the *A. senegal* woodland was high that reflect the woodland was still floristically diverse. The higher and lower woody plant species similarity coefficient between the middle and far, near and far distance gradients respectively in the study area reflects the negative impact of the gradual land use change on the existing woody plant species composition across each distance gradients. *A. senegal* was the most abundant and frequently recorded in each sample plots of the three distance gradients with high IVI value, indicating its ecological significance as well as its adaptation to the adverse environmental condition and resistance to the anthropogenic disturbance. The highest woody plant species density and basal area were recorded in the far distance gradients with the inversely contribution of DBH class to the woody plant species density and basal area. While the cumulative DBH and height class of all woody plant species across the *A. senegal* woodland was resembling interrupted inverted J-shape population pattern. The lowest and highest seedling and sapling were found in the nearest and farthest distance gradients respectively with 78.85% of the developmental structure was contributed by the mature tree/shrubs individuals, implies the sensitiveness of seedlings and saplings to climatic variability, edaphic factors and human induced disturbance. There were 14 woody plant species without both seedlings and saplings reflecting their low regeneration ability and they may disappear in the future. The higher mean total carbon stock and carbon dioxide equivalent was recorded in the far distance gradient leading to conclude that the stand structure and composition associated with level of disturbance are the main determinant factors for the variation of carbon stock. More over distance gradient was found significantly and positively correlated with the woody plant species diversity and mean total carbon stock.

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