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Estimating Above Ground Biomass and Carbon Stock of Ambiki Remnant Natural Forest, Guangua District, Northwestern Ethiopia

Biazen Endalamaw*, Getachew Kassa, Amsalu Negatu, Takele Ferede and Menale Wondie

Amhara Agricultural Research Institute, Bahir Dar, Ethiopia

ABSTRACT

Reducing CO_2 emissions and carbon (C) sequestration have paramount importance to reverse climate change-induced challenges. Natural forests have great potential to sequester more C; hence, participatory forest management (PFM) has been practiced in Ambiki Remnant Natural forest (ARNF). Despite this, there are limitations of quantitative baseline data to evaluate the effect of PFM on C stock. This study was conducted at ARNF in Guangua district to estimate the aboveground biomass (AGB) and belowground biomass (BGB) and C stock of the forest.47 circular sample plots were established through systematic grid distance (500m) having 314m^{2}area. Inventory on diameter at breast height (≥ 5 cm) and Height (m) for 33 species (630 trees) was conducted. AGB of each species was calculated using the recommended allometric equation and BGB was calculated as 27% of the AGB. C stocks of the forest were also calculated as 50% of the biomass. As a result, AGB and BGB of the forest was 226.56 ton/ha and 61.2 ton/ha and the AGC and BGC was also 113.28 ton/ha and 30.59 ton/ha, respectively. Of which, 39.9%, 20.24%, 18.6%, and 19.67% were contributed by *Albizia schimperiana, Prunus africana, Croton macrostachys,* and others respectively. Our result was lower compared to that of other forests and gained by a few species. Even though, it could be used as baseline information to know additive C via PFM practice in the forest. Furthermore, assisted natural regeneration and integrated management approaches are needed to enrich forest species and sequester more C in short period.

Keywords: ARNF, Carbon stock, Ethiopia, Guangua district, PFM.

INTRODUCTION

Climate change and the associated environmental problems have emerged as the biggest global developmental challenges (Global Nature Conservation, 2017). These are the response of the increasing atmospheric carbon dioxide (CO_2) concentration, caused by fossil fuel burning, transportation, agricultural practices, deforestation and forest degradation (Werf et al., 2009). The total CO_2 emissions of Ethiopia are around 150 Mt, which is less than 0.3% that of the global emissions. The agricultural (50%) and forestry (37%) sectors of Ethiopia contributes more than 85% of these greenhouse gas (GHG) emissions. The Forestry CO_2 emission in 2010 i.e. 55 Mt derived from deforestation, of which50% for agricultural land, 46% for fuel wood, 4% logging. In addition to the global emission, the total CO_2 emission of the country is projected to be 400 Mt in 2030 from 150 Mt in 2010 following the current practice (Climate Resilience Green Economy, 2011). Because of this, removal of C from the atmosphere and storage in a reservoir such as oceans, vegetation or soil has been required to alleviate its effect. As a natural solution, the role of trees in the process of the carbon cycle is quite significant as it stores more carbon among the terrestrial ecosystems (Andl et al., 2006). This will make forest ecosystems to be the largest terrestrial carbon pool. Protected areas, with their all and diverse ecosystems including forests, are also vital systems to capture and store carbon from the atmosphere and to help people and ecosystems adapt to the impacts of climate change (Dudley et al., 2010).

In developing countries, agricultural and forestry practices can also mitigate the increasing CO_2 concentration by sequestering C (Jose, 2009). From many other land-use systems, the biomass produced by natural forests (NF) offers great potential for sequestering C via below and aboveground biomass and soil (Andl et al., 2006; Yuanming, 2014). The carbon stored in the aboveground living biomass of trees is typically the largest pool in the tropical counties (Birhanu, 2017) and the most directly impacted by deforestation and degradation. According to the reports of Food and Agricultural Organization, (2015), the forest areas and live biomass and carbon stock of Ethiopia have been in a decreasing trend from 1990 to 2015 due to deforestation and forest degradation. Hence, sustainable forest management and slowing down deforestation are recommended to solve those problems in the country.

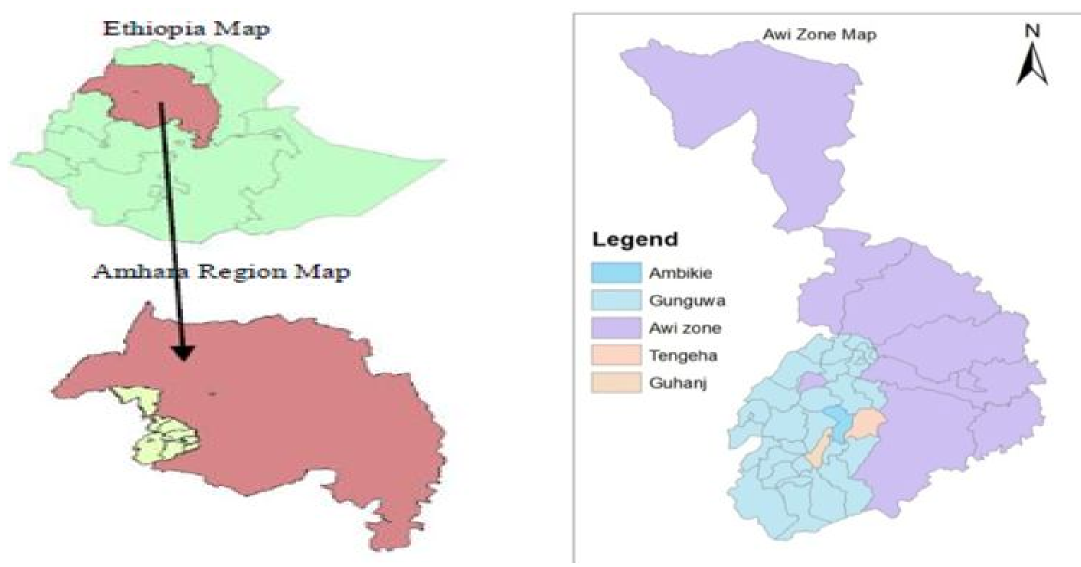
Participatory forest management (PFM) has also been given great attention for climate change mitigation as having the greatest potential for the increment of C storage by improving forest conditions specially in natural forests (Lusambo et al., 2016; Siraj et al., 2016), though it is considered as a low-cost GHG mitigation strategy under the Kyoto Protocol (Intergovernmental Panel on Climate Change, 2000). Now a day Amhara Regional State has been applying PFM practices in some natural state and community forests (Tesfaye et al., 2015) including ARNF (study site). Despite this, there is still the limitation of quantitative baseline data to evaluate the contribution of PFM for C stock improvement of Ethiopian forests (Food and Agricultural Organization, 2015) in general and in ARNF specifically. Estimating the forest biomass carbon is also the most critical step in quantifying carbon stocks and fluxes from tropical forests (Gibbs et al., 2007). Therefore, the objective of this research was to estimate the above and below-ground biomass and carbon stock of the ARNF.

MATERIALS AND METHODS

Study Area:

The study was conducted at ARNF in Guangua district of Awi Zone, Northwestern part of Ethiopia (Fig. 1). The District is located at about 168 km and 513 km away from Bahir Dar and Addis Ababa, respectively. The total area of the District is about 106,914 ha, in which 29% of the land is cultivated during the main season and 12% of the land is irrigated land. The annual rainfall of the district ranges from 1300 to 1800 mm and the mean maximum and minimum daily temperature are 27 and 15^{o}C, respectively. The total population of the District is estimated to be 223,066 of which 49.8 and 50.2% are males and females respectively and the household size is 11,936 (Central Statistics Agency, 2007). The major season crops cultivated in the district are finger millet, maize, *teff*, niger seed, wheat, and sorghum, respectively, in their order of importance.

The study site, ARNF with an area of 563 ha was found on Ambiki, Tengeha and Guhanj administrative Kebeles of the Guangua district (Fig. 1). Geographically, it is located between 10°47'29.8'' - 10°47'47.6''latitude and 36°32'57.2'' - 36°37'3.7'' longitude with a minimum and maximum altitude of 1985 and 2041 meter above sea level, respectively. It is one of the patches of Guangua Illala remnant natural forests and surrounded by the open agricultural land uses with a scattered *Prunus africana* and *Albizia schimperiana* remnant tree species (Yineger et al., 2014). It is a major source of fuel wood and timber for the nearest small Ambiki local town. Recently, the Amhara Regional State and Farm Africa/ SoS Sahel Ethiopia have been practiced PFM to improve the carbon sequestration potential and other essential ecosystem goods and services of the forest (Ministry of Environment Forest & Climate Change, 2015). However, the forest has been found under the pressure of local inhabitant through illegal logging of aged trees, fuel wood collection, and free grazing.



Sampling design, plot, and data:

Systematic grid distance was applied on the map of the forest to allocate circular sample plots (Fig. 2), which was employed for inventory with having a diameter of 10 meters and area of 314 m^2. The distance between each plot was 500 m. Each plot was searched by using GPS Garmin 72 and the center of those plots marked. Field inventory was conducted on 54 plots, of which 47 plots were continued for the next data analysis. During the inventory, the diameter at breast height (DBH) (≥5 cm) and height (m) for 33 species (630 trees) were measured using Caliper and hypsometer, respectively.

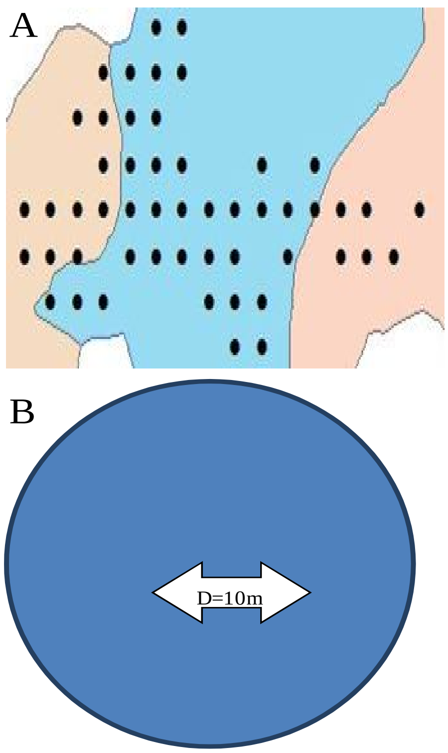


Fig. 2: Grid map on the study areas (500m x 500m) (A) and Sample plot design (B)

Species composition and structure:

In order to get an information on the species composition and structure of the study forest, the value of species frequency, Relative frequency (RF), dominance, Relative dominance or Basal Area, density, Relative density (RD) and importance value index (IVI) were obtained based on equations (Kent & Coker, 1992) listed in Fig. 3.

Methods of estimation:

Above and below Ground Biomass calculation:

The Above ground biomass of each species was calculated by using the most recently recommended allometric equation for pan-tropical forests in Fig.3 (Eq. 8) (Chave et al., 2014). The value of wood specific density (WD) was used depending on the Ethiopian forest reference level (Ministry of Environment Forest & Climate Change, 2016). Then, Summing up of each AGB of a tree (in kg) and at plot level (in ton/ha) was conducted.

The recommended root to shoot ratio to estimate the below-ground biomass of Ethiopia's dry A fromontane forests is 1: 0.27, which is about 27% of the above-ground biomass (Food & Agricultural Organization, 2010). Therefore, the below-ground biomass of each species was also calculated as 27% of that of the AGB and converted into plot level in ton/ha.

Carbon calculation:

Fifty percent of the oven-dried biomass is taken as C (Brown & Lugo, 1982; IPCC, 2006; Petrokofsky et al., 2012). Therefore, converting AGB and BGB generated from the above calculation by

$$\text{Frequency of species} = \frac{\text{The number of plots in which that species occur}}{\text{s a total number of plots}} \text{ -------------------------- (Eq.1)}$$

$$\text{Relative frequency(RF)} = \frac{\text{Frequency of species A}}{\text{Total frequency of all species}} * 100 \text{ -------------------------------- (Eq. 2)}$$

$$\text{The density of species} = \frac{\text{The number of individuals of the at species}}{\text{Area sampled}} \text{----------------------------- (Eq. 3)}$$

$$\text{Relative Density(RD)} = \frac{\text{density of species A}}{\text{total density of all species}} * 100 \text{----------------------------- (Eq.4)}$$

$$\text{Basal Area(BA)or Dominance} = \frac{\pi \text{DBH\^{}2}}{4} \text{--- (Eq.5)}$$

$$\text{Relative Dominance(RBA)} = \frac{\text{Basal area of each species}}{\text{total Basal area}} * 100 \text{---------------------- (Eq.6)}$$

Important Value Index (IVI) = RD + RBA + RF-------------------------------------- (Eq.7)

AGB = 0.0673 * (WD * DBH^2 * H) ^0.976------------- (Eq. 8)

Where; Π= 3.14, AGB = above-ground biomass (in kg dry matter), WD = wood density (g/cm³), DBH = diameter at breast height (cm), H = total height of the tree (m).

multiplying 0.5 as a conversion factor was carried out to estimate the above and below ground C.

RESULTS

Species composition and structure:

A total number of 630 individuals having a DBH ≥5cm from 33 trees and/or shrub species were recorded within 47 sampled plots, out of these, eight species were locally unidentified. The most frequently located eight species were *Croton macrostachys* (16.75%), *Albizia schimperiana* (14.72%), *Solanum gigantum* (8.63%), *Pavette abyssinica* (7.61%), *Berssama abyssinica* (5.08%), *Millettia ferruginea and Gimbltani* (Agewegna) (4.06%) and *P. Africana &* unknown 1(3.05%) respectively as shown in Table 1. The population density of ARNF was 427 individuals per hectare, in which *C. macrostachys* (25.4%), *A. schimperiana* (14.92%), *Solanum gigantum* (11.11%), *Pavette abyssinica* (9.52%), *B. abyssinica* (5.71%), *M. ferruginea* (4.29%), unknown 2 (3.81%), and Gimbltani (Agewegna) (2.70%) were also the most frequent species,

Table 1; Share of all tree and/or shrub species (DBH≥5cm) found at ARNF for Relative Frequency (%), Relative Density (%), Relative Dominance (%), and Important Value Index

Scientific Name	Relative Frequency (%)	Relative Density (%)	Relative Dominance (%)	Important Value Index
Albiziaschimperiana	14.72	14.92	40.03	69.67
Croton macrostachys	16.75	25.40	23.00	65.15
Solanumgigantum	8.63	11.11	0.36	20.10
Pavetteabysinica	7.61	9.52	0.25	17.38
Prunusafricana	3.05	1.27	12.19	16.51
Berssamaabyssinica	5.08	5.71	0.68	11.47
Millettiaferruginea	4.06	4.29	1.09	9.44
Gimbitani	4.06	2.70	1.04	7.80
Unknown-2	2.03	3.81	0.93	6.77
Dracaena steudneri	2.03	1.90	2.12	6.06
Apodytesdimidiata	1.02	0.32	4.62	5.95
Vernoniaamygdalina	2.54	1.90	0.90	5.34
Unknown-1	3.05	1.59	0.43	5.06
Cordiaafricana	2.54	0.95	1.52	5.01
Ficus sur	1.02	1.43	1.84	4.28
Celtisafricana	1.02	0.79	2.34	4.15
Combretummolle	2.54	1.43	0.05	4.02
Enseteventricosum	2.03	0.95	0.91	3.89
Maytenusarbutifolia	2.03	1.75	0.03	3.81
Unknown-3	1.52	1.27	0.54	3.34
Acacia abysinica	1.52	0.63	1.15	3.31
Unkown-4	1.02	2.06	0.12	3.20
Shamli	2.03	1.11	0.02	3.16
Ekebergiacapensis	0.51	0.16	2.01	2.68
Dombeyatorrida	1.52	0.32	0.74	2.58
Calpurnia aurea	1.52	0.79	0.02	2.33
Allophylusabyssinicus	1.02	0.48	0.45	1.94
Grewiavillosa	1.02	0.32	0.08	1.42
Bahusti	0.51	0.32	0.41	1.24
Carissa spinarum	0.51	0.32	0.02	0.84
Unkown-5	0.51	0.16	0.05	0.72
Euphorbia abyssinica	0.51	0.16	0.04	0.71
Oliniarochetiana	0.51	0.16	0.01	0.67

respectively. The population density we got in ARNF was nearly similar compared with that of the adjacent Apini (434.4) and higher than that of the Dabkuli (365.6) remnant forests, however, it was lower than that of the Tsahare (664.1), Bari (620.3) and Kahtasa (501.6) remnant forests in Awi zone reported by Gebeyehu et al. (2019).

The average DBH size and height of the tree and/or shrub species in the study forest were 19.7 cm and 13.3 m, respectively. The total basal area of the sitewas 28.89 m^2/ha, in which more than 75% was contributed by few dominant species like *A. schimperiana* (40.03%), *C. Africana* (23%), *C.macrostachys* (12.19%), followed by *Solanum gigantum* (4.62%), *Grewiavillosa* (2.34%), *B. abyssinica* (2.12%), *Gimbltani* (Agewegna) (2.01%), unknown 1 (1.84%) and *Acacia abyssinica* (1.52%), respectively as displayed in Table 1. The Importance Value Index (IVI) of each species was calculated using Eq. 7. Therefore, *Albizias chimperiana* was the first most important species in the site with the highest IVI (69.67), followed by *Croton macrostachys* (65.15), *Solanum gigantum* (20.1), *Pavette abyssinica* (17.38), *Prunus africana* (16.51), *Berssama abyssinica* (11.47), *Millettia ferruginea* (9.44), and Gimbitani (Agewegna) (7.8) in a descending order.

Biomass and Carbon stock of the Forest

The result revealed that the mean total (above and below ground) biomass (TB) and carbon (TC) stock of the ARNF was 287.76 and 143.87 ton/ha, respectively, in which the mean AGB and BGB of the forest stored by species was 226.56 ton/ha and 61.2 ton/ha, respectively. Accordingly, the AGC and BGC of the forest were also 113.28 ton/ha, 30.59 ton/ha, respectively. The recorded minimum TB and TC stock were zero in plot two, three and thirty-five due to the absence of tree and/or shrub species. Besides, Plot twenty-three and thirty-four were also recorded less than one ton/ha of TB and TC. Accordingly, the recorded maximum TB and TC was 1629.3 ton/ha and 814.64 ton/ha in plot twenty-four, followed by 1270.06 ton/ha and 635.04 ton/ha in plot thirty-six, respectively (Fig.4).

Contribution of Species for Biomass and Carbon Stock in the Forest

The above eight most important species (Table 1) and the rest as others were used further to calculate their contribution for AGB and AGC in the site. Therefore, our result indicates (Fig. 5) that approximately 79% of the biomass (287.76 ton/ha) and carbon stock (143.87 ton/ha) of the ARNF was contributed only by the three most dominant species in the forest. Of which, the 39.9%, 20.24%, and 18.6% of were shared by *Albizia schimperiana*, *Prunus Africana* and *Croton macrostachys*, respectively (Fig.5 A and B). The rest 19.67% of the biomass and carbon stock was also contributed by the species categorized as others (the remaining 25 species) in the forest (Table 1).

However, the biomass and carbon stock contribution of the third (*Solanum gigantum)*, fourth (*Pavette abyssinica)*, sixth (*Berssama abyssinica*) and seventh (*Millettia ferruginea)* most

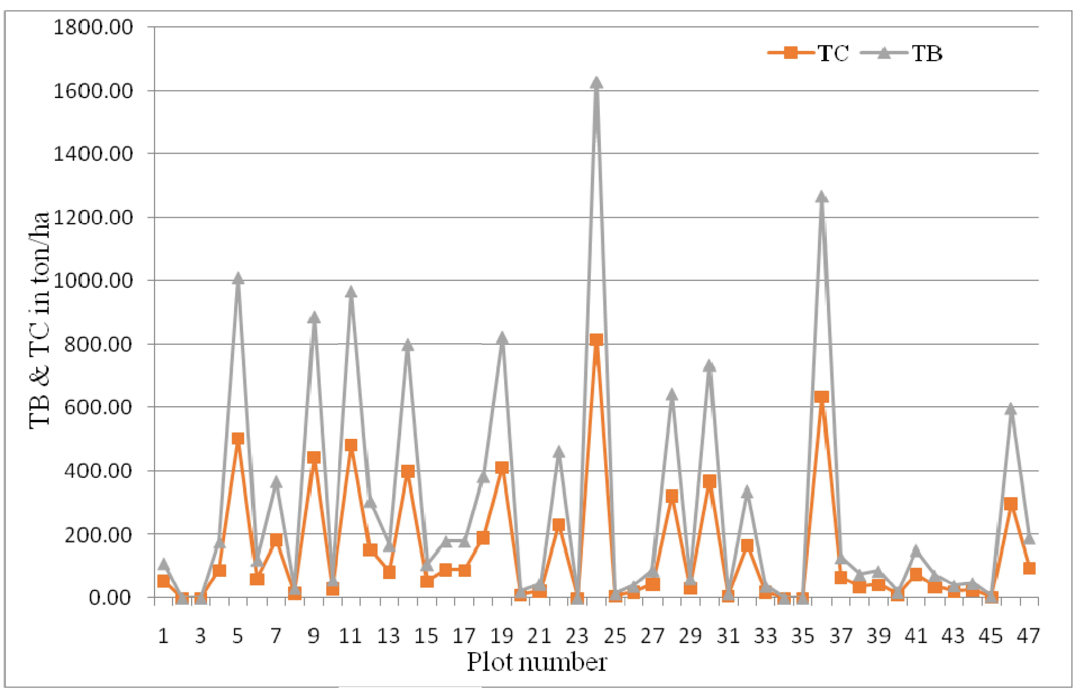
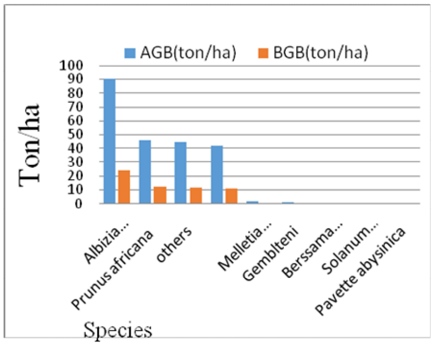
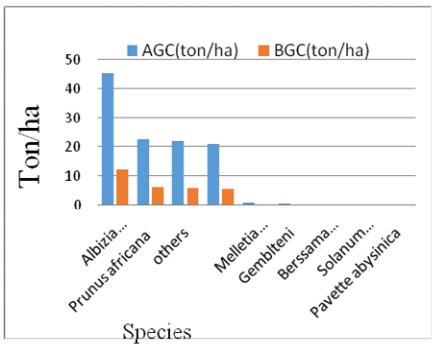


Fig. 4: Total (above and belowground) biomass (TB) and carbon (TC) stock for each plot in ton/ha.

A



B



important species (Table 1) in the study forest were 0.06%, 0.02%, 0.2% and 0.87 %, respectively (Fig.5 A and B), which were very low as compared to the above three species in the study forest.

Biomass and Carbon Stock versus DBH and Height of Species

The result indicates that the DBH and height of the tree and/or shrub species found in the study forest varies in between 5–143 cm and 2.5–46 meters, respectively (Fig. 6).The average DBH size and height of the tree and/or shrub species in the study forest were 19.7 cm and 13.3 m, respectively. The recorded DBH and height for the most dominant species found in the forest such as *A.*

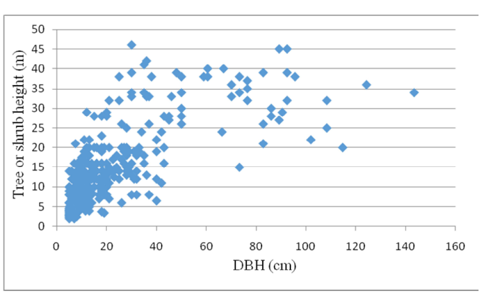


Fig. 6: Scatter plot of observed total tree height (m) against DBH in cm for all tree species

schimperiana, *P. africana* and *C. macrostachys* were also found in the ranges from 5–143 cm and 2.5 – 46 m, respectively (Fig. 6 and 7). The average DBH and height with 29.6 cm and 18 m were also recorded for *A. schimperiana* with 56.6 ton/ha of AGB and 28.3 ton/ha AGC stock, 62.5 cm and 30 m for *P. Africana* with that of 239.5 ton/ha and 119.8 ton/ha, and 17.2 cm and 12.3 m for *C. macrostachys* with 14.43 ton/ha of AGB and 7.4 ton/ha of AGC stock, respectively.

However, the recorded DBH and height for *Solanum gigantum*, *Pavette abyssinica*, *Berssama abyssinica*, *Millettia ferruginea*, and Gimbitani (Agewegna) were lies between the ranges of 5 to 30cm (Fig. 6 and 7) and 2.5 to 28 m, respectively. Due to these reasons, the carbon stock potential of those species with wide ranges of DBH and height were higher than those species with narrow ranges. Accordingly, tree species having high values of DBH and height resulted in high estimated AGB and AGC in the forest.

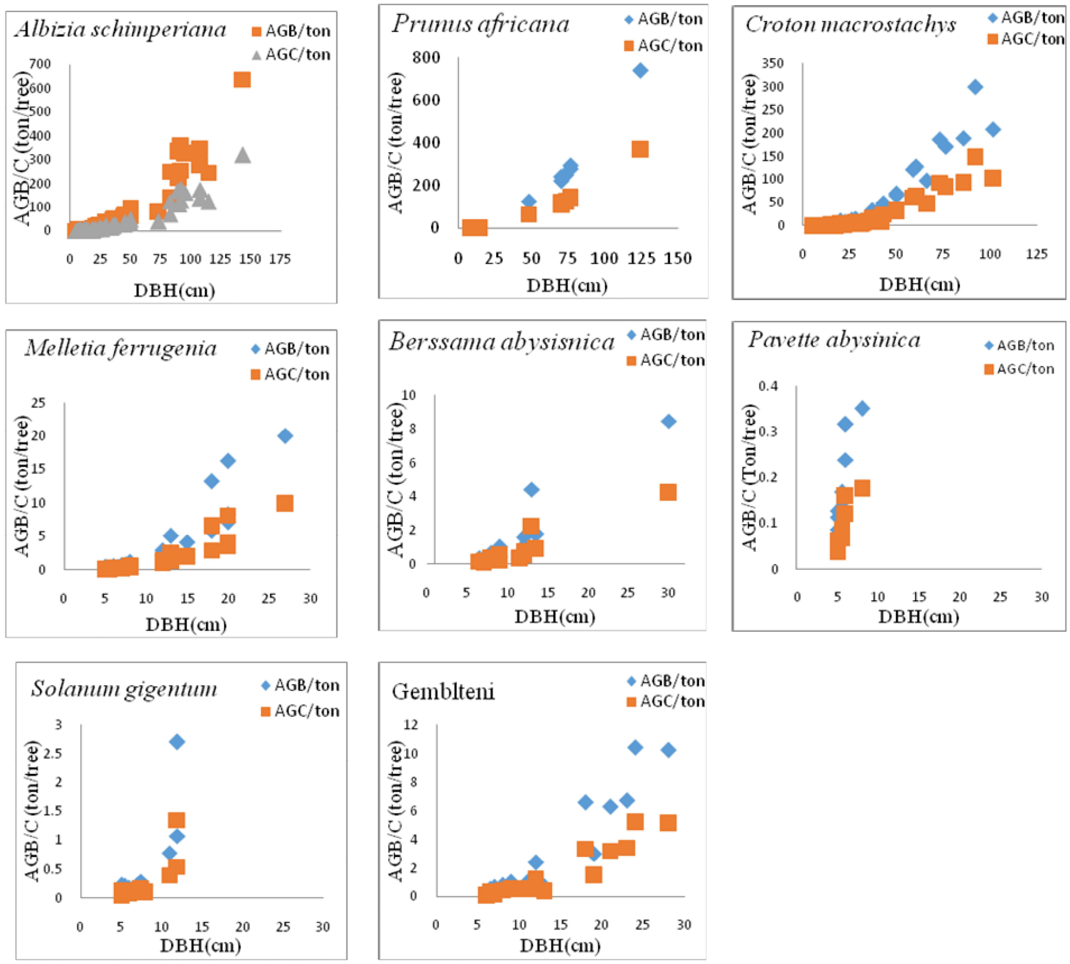
DISCUSSION

Comparison of Biomass and Carbon stock of ARNF with previous studies:

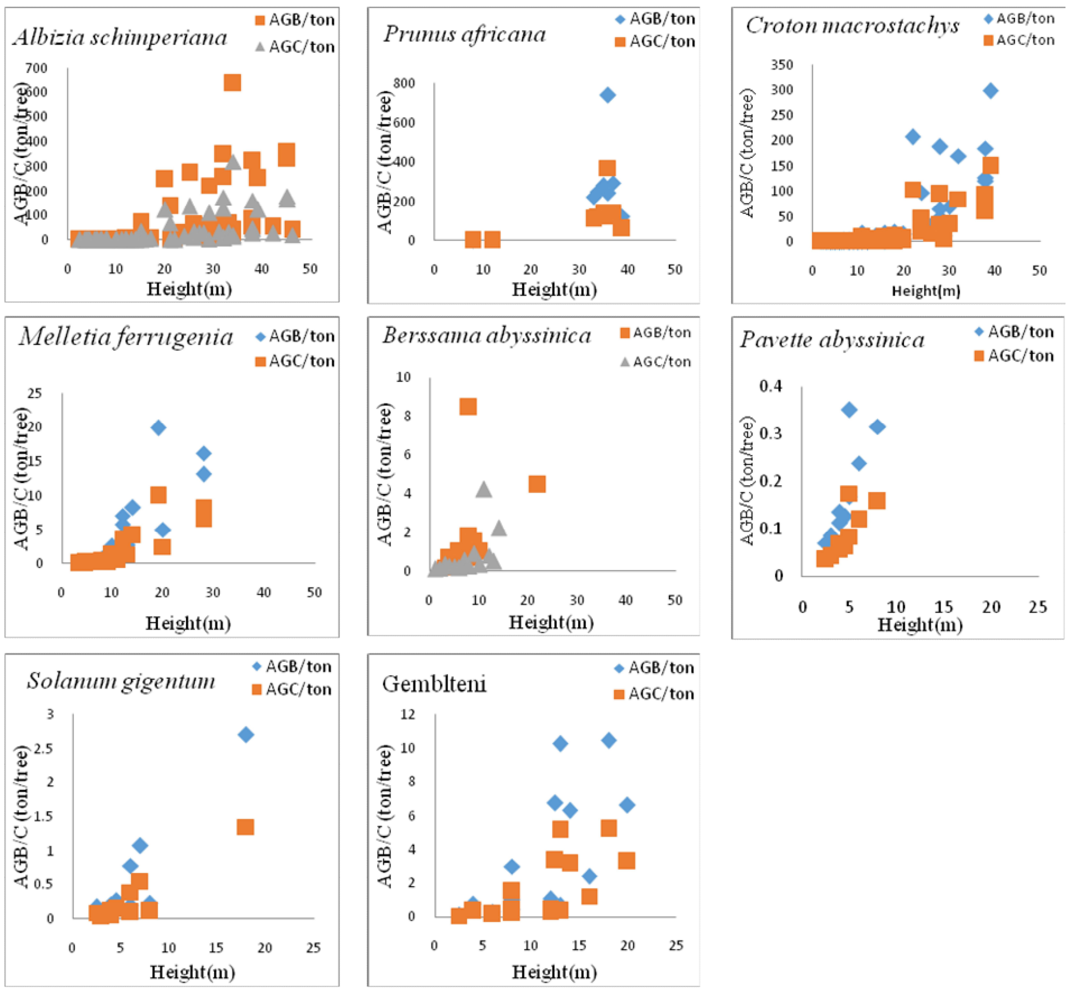
The allometric equations developed by Brown, (1997), Chave et al. (2005), and Chave et al. (2014) are the most commonly used to estimate the AGB for tropical natural forests. Of which Chave et al. (2014) has been the recently developed accurate equation and used in most literature as depicted in Table 2, therefore, applied to generate our result in ARNF. Hence, the comparison of our result on the biomass and carbon stock with other recently conducted researches as shown in Table 2, for the continental assessment and similar studies in Ethiopia. The result we got on the AGC of the study forest (ARNF) was higher than that of Gelawudewose, Enjebara, Tara Gedam, Mahebere Selasie protected (Sibhatu, 2015) and Ambober NF (Solomon et al., 2019). It was also comparable with the results of Gebeyehu et al. (2019) for the Kahtasa NF in Awi Zone and that of Tura and Eshetu (2013) for Selected church forests in Addis Ababa in Table 2.

While our result on the AGC was lower compared with similar continental assessment reports on that by Sullivan et al. (2017) for Africa (183 ton/ha, Tropical Asian (197 ton/ha) and South America tropical forests (140 ton/ha) even using similar estimating allometric equations. Similarly, the previous studies conducted on Ethiopia's Afromontane forests such as; Guangua Illala forests (Ayen, 2015), Tsahare, Apini, Dabkuli and Bari remnant natural forests (Gebeyehu et al., 2019), Banja natural forests (Abere et al., 2017), Lake Hawassa natural forests (Wondrade et al., 2015), Gedo forest (Yohannes et al., 2015) and Dry area forest of Simien Mountains (Simegn et al.,

2014) were higher than our results. Because, there were high population densities, for example, in the Tsahare (664.1), Bari (620.3) and Kahtasa (501.6) remnant forests in Awi zone with large DBH size and diversified species (Gebeyehu et al., 2019). In addition, our result was also lower compared with that of Akako- Telamo, Arossa-Garagalo, and Abo-Bokaso forests (Molla et al., 2017), Weiramba forest (Teshager et al., 2018), however, these variations might be due to the application of different allometric equations (tab. 2). Similarly, it is also greatly far from the AGC (306.37 ton/ha) of Tara Gedam church forest estimated by Gedefaw et al, (2014) using allometric equations, however, there was a great deviation of values reported for the same forest (Tara Gedam church forest) by Sibhatu, (2015) and Gedefaw et al. (2014) even nearly in similar years. Because, the estimation of AGB and AGC can be influenced by altitude, slope and aspect and the allometric equations used (Gedefaw et al., 2014; Teshager et al., 2018). In our case study, the absence of trees and/or shrubs on some plots (2, 3, 35) or it’s rarely occurrence (23 and 34) in the ARNF leading to zero and less than one ton/ha of TB and TC stocks (Fig. 5) can be the indicators for the severity of disturbance and degradation in the area. This may also be one reason for the population density as well as the biomass and carbon stock of ARNF being lower compared with the previous studies conducted in similar conditions (Abere et al., 2017; Gebeyehu et al., 2019). Accordingly, the results of Gebeyehu et al.(2019) agreed that the high level of disturbance especially illegal cutting reduces the TB and TC stocks of the forest.



Furthermore, the carbon stock of Adaba-Dodola dry Afromontane community forest (278.03 ton/ha) in Oromia Region has been improved due to the implementation of community-based management practices (Muluken et al., 2015). In our case, the forest conditions such as population density, basal area as well as biomass and carbon stock of the ARNF were poor compared with the above managed natural forests, even though, can be enhanced through the action of PFM in the forest (Lusambo et al., 2016; Siraj et al., 2016). Because, there is a positive direct relationship between biomass, carbon stock and forest conditions (Li et al., 2018; Mensah et al., 2016; Sullivan et al., 2017; Wassihun, 2018). Therefore, our result could be used as baseline information to estimate the effect of PFM on the ARNF conditions as well as carbon stock.



Variation in the Contribution of Species for Biomass and Carbon Stock

Stand basal area and/or dominance of the species have a positive effect on the forest biomass and carbon stock (Gebeyehu et al., 2019; Mensah et al., 2016). Our result in Fig, 3 indicates that the most dominant species with high RD (Table 1) found in the ARNF such as *Albizia schimperiana*, *Croton macrostachys*, and *Prunus africana*, contributed nearly 79 % of the AGB and carbon stocks. Similarly, Gebeyehu et al. (2019) revealed that 72.4% and 22.9 % of AGB and carbon stock in the Tsahare and Apini forests are contributed by a single *Albizia schimperiana* species. 71.2% and 81.3% of the AGB and carbon stock in Dabkuli and Bari natural forests, respectively, are also contributed by *Albizia gummifera*, *Apodytes dimidiata*, and *Prunus africana* together. Besides, the great contribution of *Albizia gummifera*, *Croton Macrostachyus and Prunus Africana* for the AGB and AGC stock of Injibara and Banja NF have been reported by Sibhatu, (2015) and Abere et al. (2017), respectively.

But the biomass and carbon stock contributed by *Solanum gigantum (0.06%)*, *Pavette abyssinica* (0.02%), *Berssama abyssinica* (0.2%) and *Millettia ferruginea (*0.87%*)* were very lower as compared to others most important species in the study forest due to their lower relative dominance. The reports of Sibhatu (2015) in Injibara, Abere et al. (2017) in

Table 2; Comparison of the AGC stock of our result with other related studies; where, AE= Allometric Equation, AGC= Above Ground Carbon, BGC= Below Ground Carbon, CF = community forest, RNF= Remnant Natural Forest, NF = Natural forest, SMNP = Simien Mountains National Park; the values for AGC were derived as 50% of the AGB nearly in all literature.

No	Forests	Country's location	AGC Stock in ton/ha	References	Ways of estimation
1	Africa Tropical forests	Africa	183	(Sullivan et al., 2017)	AE (Chave et al., 2014)
2	Tropical Asia forests	South Asian countries	197	(Sullivan et al., 2017)	AE (Chave et al., 2014)
3	South America tropical forests	South America	140	(Sullivan et al., 2017)	AE (Chave et al., 2014)
4	Banja natural forests	Amhara, Ethiopia	338.72	(Abere et al., 2017)	AE (Chave et al., 2014)
5	Lake Hawassa natural forests	Southern Ethiopia	100.45	(Wondrade et al., 2015)	AE (Chave et al., 2005)
6	Gedo forest	Oromia, Ethiopia	281	(Yohannes et al., 2015)	AE (Pearson et al., 2005)
7	Dry area forest of SMNP	Amhara, Ethiopia	270.89	(Simegn et al., 2014)	AE (Brown et al., 1989)
8	Adaba-Dodola CF	Oromia, Ethiopia	278.03	(Muluken et al., 2015)	AE (Chave et al., 2005)
9	Gelawudewose church forest	>>	53.6	(Sibhatu, 2015)	AE (Chave et al., 2005)
10	Enjebara natural forest	>>	32.3	(Sibhatu, 2015)	>>
11	Tara Gedam church forest	>>	16.7	(Sibhatu, 2015)	>>
12	MahebereSelasie church forest	>>	9.6	(Sibhatu, 2015)	>>
13	Guangua Illala RNFs	>>	291.78	(Ayen, 2015)	Remote Sensing & GIS
14	Tsahare RNF	>>	170.1	(Gebeyehu et al., 2019)	AE (Chave et al., 2014)
15	Apini RNF	>>	171.2	(Gebeyehu et al., 2019)	>>
16	Dabkuli RNF	>>	207.4	(Gebeyehu et al., 2019)	>>
17	Bari RNF	>>	269.1	(Gebeyehu et al., 2019)	>>
18	Kahtasa RNF	>>	140.8	(Gebeyehu et al., 2019)	>>
19	Selected church forests	Addis Ababa, Ethiopia	122.85	(Tura & Eshetu, 2013)	AE (Brown et al., 1989)
20	Akako- Telamo NF	Southern Ethiopia	201.1	(Molla et al., 2017)	AE (Brown, 1997)
21	Arossa-Garagalo NF	>>	179.3	(Molla et al., 2017)	AE (Brown, 1997)
22	Abo- Bokaso NF	>>	240.4	(Molla et al., 2017)	AE (Brown, 1997)
23	Weiramba NF	Amhara, Ethiopia	152.33	(Teshager et al., 2018)	AE (Chave et al., 2014)
24	Ambober NF	Amhara, Ethiopia	8.3	(Solomon et al,, 2019)	AE (Chave et al., 2014)
25	Gesha-Sayilem forest	Southwestern Ethiopia	174.95	(Admassu et al,, 2019)	AE (Chave et al., 2014)
26	Ambiki RNF (present study)	Amhara, Ethiopia	113.28	Our Result	AE (Chave et al., 2014)

Banja and Gebeyehu et al. (2019) in Tsahare, Apini, Dabkuli, Bari and Kahtasa natural forests are also agreed with our results on these species, however, they are the most important species on those forests including our study area (Table 1).

Biomass and Carbon Stock versus DBH and Height of Species

DBH, tree height and wood density of each species are the predictors of the allometric equation Chave et al. (2014) used to estimate AGB and AGC in the forest (Gebeyehu et al., 2019). The dominant species in the forest such as *A. schimperiana, P. africana* and *C. macrostachys* with a wide ranges of DBH and height (5–143 cm and 2–46 m, respectively) while that of the remaining important species of the study site, however, with lower RD *(Solanum gigantum*, *Pavette abyssinica*, *Berssama abyssinica*, and *Millettia ferruginea*) (Fig. 7 and 8) were found in the smallest ranges (from 5 to 30 cm and 2.5 to 28 m, respectively). Due to these reasons, the biomass and carbon stock potential of those species with wide ranges of DBH and height were higher than those species with narrow ranges. Accordingly, tree species having high values of DBH and height resulted in high estimated AGB and AGC in the forest. Because, there is a direct positive relationship between the size of DBH, tree height, and biomass and carbon stock in the forest (Dibaba et al., 2019; Hunter et al., 2013; Li et al., 2018; Mensah et al., 2016).

Similarly, Gebeyehu et al. (2019) revealed that the Bari and Dabkuli natural forests in the dry Afromontane forests of Awi Zone with large average DBH size and tree height have greater AGC stock compared with Apini, Tsahare and Kahtasa natural forests having relatively small average DBH size and tree height. Because DBH and height of the species are the most determinant factors of the allometric equation used to estimate the AGB (Chave *et al*., 2014; Gebeyehu et al., 2019). Even though, the carbon stocked by the biomass of tree and/or shrub species in the ARNF was lower than that of the adjacent forests. In this case, sustainable forest management including PFM will be important to improve the density and growth rate of species in the forest as well as to enhance their carbon sequestration potential.

In conclusion, this result attempts to reveal the biomass and carbon stocked by the Ambiki remnant natural forest. It was lower than that of the continental assessment reports and even with the adjacent forests and contributed by a few dominant species having a large size of DBH and height. Even though; it could be used as baseline information for monitoring to estimate the effect of participatory forest management on the carbon stock of the forest. Further, it needs regular monitoring and to be improved by integrating with additional data on the remaining remnant forests in the area and the action of integrated forest management approaches (including regeneration improvement) to enrich the forest species and sequester more carbon in a short period.

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