Universität für Bodenkultur Wien

Master thesis

EFFECT OF AREA EXCLOSURE ON ABOVE GROUND CARBON STORAGE AND DIVERISTY IN AMHARA REGION, ETHIOPIA.

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Vienna December, 2015 Hadera Kahesay Abraha

Vienna, Austria

Erklärung

Ich erkläre eidesstattlich, dass ich die Arbeit selbständig angefertigt habe. Es wurden keine anderen als die angegebenen Hilfsmittel benutzt. Die aus fremden Quellen direkt oder indirect übernommenen Formulierungen und Gedanken sind als solche kenntlich gemacht. Diese schriftliche Arbeit wurde noch an keiner Stelle vorgelegt.

Declaration

I herewith declare that I did the ground work by myself. No methods, but the described where used. Text passages, ideas and thoughts from other sources are distinguishable as such. I did not present this work at another place.

(Signature of Author)

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Abstract

Area exclosure is an important method to restore and rehabilitate the degraded grazing land and hill sides and to increase fertility and productivity of the soil in Ethiopia (Tefera et al., 2005). In this study, using different allometric equations, above ground biomass from RCD was estimated for 5 years (Ambober, 2014), at beginning when the area was enclosed (Ambober, 2009) and after 2 years (Gelawdiows) of exclosure in Amhara region, Ethiopia. The vegetation inventory was conducted in the 57 plots across the two districts of the study site, 42 plots from Ambober and 15 plots from Gelawdiows were used. The sample plots were taken in grid sampling method .Finally in each plot every tree and shrubs having a diameter <10 cm at above ground, and having height > 1.5 m was measured and 37 species were identified across study sites sample plots. Using five allometric equation, above ground biomass was estimated for a 19 ha area exclosure of Ambober, 2014 was 190.11-73.26 tons within 5 years enclosed. Ambober, 2009 was 0.14-1.89 tons estimated in the beginning of establishment. From 15 ha area exclosure Gelawdiows was estimated 0.94 - 4.34 tons within 2 years enclosed. Five models, estimated the mean above ground biomass for Ambober, 2014 (3.85-10.01 ton/ha), Ambober, 2009 (0.007-0.099 ton/ha) and Gelawdiows (0.06 - 0.28 ton/ha). The result showed, that estimated the mean carbon stocks of the above ground biomass in the Ambober, 2014 site were significantly higher ($p<0.05$) than of the Ambober, 2009 and Gelawdiows at all models. The mean biomass increment in Ambober area closure within 5 years was estimated from to be 4.78 -11.25 ton/ha and annual increment of above ground biomass in Ambober area exclosure were 0.96- 2.25 ton/ha.

Key words: Area exclosure, diameter, biomass, carbon stock, allometric equations.

Zusammenfassung

Die Einrichtung von Weideausschlussflächen stellt eine wichtige Methode in der Wiederherstellung degradierter Weideflächen und Hügel dar, um die Fruchtbarkeit und den Ertrag in Äthiopien zu steigern (Tefera et al., 2005). In dieser Studie in der Amhara – Region Äthiopiens wurde mit verschiedenen allometrischen Gleichungen die oberirdische Biomasse von RCD für 5 Jahre geschätzt, in Ambober (Beginn des Weideausschlusses 2009, somit 2014 nach 5 Jahren) und in Gelawdiwos nach 2 Jahren. Eine Bestandsaufnahme der Arten wurde auf 57 Parzellen in den beiden Versuchsgebieten durchgeführt, auf 42 Parzellen in Ambober und auf 15 Parzellen in Gelawdiwos. Die Probennahme wurde rasterartig durchgeführt. In jeder der Versuchsparzellen wurden alle Bäume und Sträucher mit einem Durchmesser von mehr als 10 cm sowie einer Höhe von mehr als 1,5 m vermessen, 37 Arten konnten auf den Flächen identifiziert werden. Mittels 5 allometrischer Gleichungen wurde die oberirdische Biomasse für das 19 ha große Gebiet in Ambober nach 5 Jahren Weideausschlusses (2014) auf 190,11 – 73,26 t geschätzt. Zu Beginn der Einrichtung der Versuchsfläche 2009 belief sich die Schätzung für dieses Gebiet auf 0,14 – 1,89 t. Für das 15 ha große Gebiet in Gelawdiwos wurden nach 2 Jahren Weideausschluss 0,94 – 4,34 t angenommen. 5 Rechenmodelle siedelten den Mittelwert für Ambober (2014) zwischen 3,85 und 10,01 t/ha an, für Ambober 2009 zwischen 0,007 und 0,099 t/ha und für Gelawdiwos zwischen 0,06 und 0,28 t/ha. Das Resultat aller Modellrechnungen zeigte, dass der geschätzte mittlere Kohlenstoffbestand der oberirdischen Biomasse auf der Versuchsfläche in Ambober im Jahr 2014 signifikant höher ($p < 0,05$) als auf derselben Fläche im Jahr 2009 sowie in Gelawdiwos war. Der mittlere Zuwachs an Biomasse wurde für die Ambober – Versuchsfläche innerhalb von 5 Jahren mit 4,78 – 11,25 t/ha beziffert, der jährliche Zuwachs für dieses Gebiet mit 0,96 – 2,25 t/ha.

Schlüsselwörter: Weideausschlussgebiet, Durchmesser, Biomasse, Kohlenstoffbestand, allometrische Gleichungen

1. INTRODUCTION

Area exclosure has been implemented for previous decades, and established on degraded grazing lands with the objective of restoring their productivity by controlling soil erosion and increasing soil and diversity by naturally regeneration. With proper management and enough time, there will be area closure which will facilitate formation of secondary forests (Worku et al.,2012; Mekuria and Aynekulu, 2013).Thus, this practice is recommended for increasing diversity of indigenous flora and improved physical and chemical soil properties in Ethiopia (Abiyu et al., 2011; Mengistu et al., 2005). The change in species composition in area exclosure through time is referred to as succession or, more generally, vegetation dynamics (Connell and Slatyer, 1977). Drivers of vegetation dynamics can be generalized as site availability, different species availability, and different species performance (Pickett and McDonnell, 1989).

Global warming has increased during the last century due to the greenhouse gas effect in the atmosphere. However, trees and forests play a great role in mitigating global warming in reducing atmospheric carbon dioxide, the major greenhouse gas, through carbon sequestration (Waston.et al., 2000) and storing in the form of above and below ground biomass (Breuer, 2012; Nair et al., 2009). Hence conserving and managing forests, and employing sound land management system is way that will to absorb more atmospheric carbon dioxide and to store carbon longer, is the main solution to combat climate change Even though the climate protection role of forests is apparent, it is complex to determine how much of the forest carbon sink and reservoir can be managed to mitigate atmospheric CO_2 and in what ways it can be built up.

To know the carbon sequestration, much information is need on the amount of forest biomass in different regions. The estimation of total biomass pools of great importance for the characterization of structure and function of ecosystems ,for applying sustainability reducing emissions of carbon dioxide and also important to know what are the ecological indicator for sustainability (Chave et al., 2003).

To estimate the amount of the biomass and carbon stock a combination of allometric equations were used and direct measurements such as diameter, height, and crow width were taken from the field. From mixed tropical species general and site specific allometric equations have been developed to estimate biomass (Djomo et al., 2010). Specifically for African tropical forests no allometric equations have been developed for estimating biomass and thus, general allometric equations are used (Chave et al., 2005).

Using direct or indirect methods biomass can be estimated, direct above ground biomass of shrub/tree prediction methods involves felling an appropriate number of shrub/ trees and estimating their field and oven-dry weights. An indirect method (non-destructive) is to use allometric regression equations based on some easily measurable inventory data such as stem diameter, height or crown diameter.

There are different tree/shrub biomass estimating methods employed by forest researchers and scientists, but the destructive method is the one mostly recommended to have plausible estimation (Cleemput et al., 2013, Negash et al., 2013a and Negash et al., 2013b). However, destructive methods have many limitations in practical application. It is not cost effective and is more laborious when studying large forest areas or many sample plots (Zhao et al., 2014); still it is also difficult to apply for endangered and rare tree species. In addition, destructive sampling creates the opportunity for illegal forest harvest by the local people. As a result, determining tree/shrub biomass in allometric equations using some measured tree parameters (like DBH, height) has become the most preferable method in many forest biomass studies (Hunter et al., 2013; Vieira et al., 2014, Chave et al., 2005; Djomo et al., 2010).

The study focuses on estimation of above ground biomass and carbon stock from inventory data (Root collar diameter) with five different models (allometric equation) and comparing the obtained biomass within and between study sites. Most importantly, this study will investigate potential biomass accumulation and carbon stock with in different age of the area closure.

2. Objectives

Estimation of carbon stock and change in living biomass of shrubs and trees in the area of exclosure.

2.1 Specific objective

- To estimate above ground carbon stock potential of the exclosure.
- To estimate total biomass for the last 5 years.
- To assess species diversity in the exclosure.

3. DATA

3.1 Study sites

The study areas for this study are found in Ambober and Gelawdiows. Ambober is found in north Gonder administration zone in northwestern Amhara. It is situated 30 km southeast from Gonder town. The Ambober exclosure is located between 1384750 and 1384200 m latitudes and between 340300 and 340400 m longitudes. Gelawdiows is found in south Gonder administration zone, central Amhara and located between 1287300 and 1287600 m latitudes and between 370100 and 371000 m longitudes.

The Ambober exclosure was established in March 2009 and has an area of 19 ha. Gelawdiows was established June 2012 and has an area of 15 ha. Previously both of sites were communal grazing land for the local community. The local people decided to enclose the area from human activities and livestock free grazing in order to reduce erosion and restore, increase productivity, species composition, diversity and species biomass.

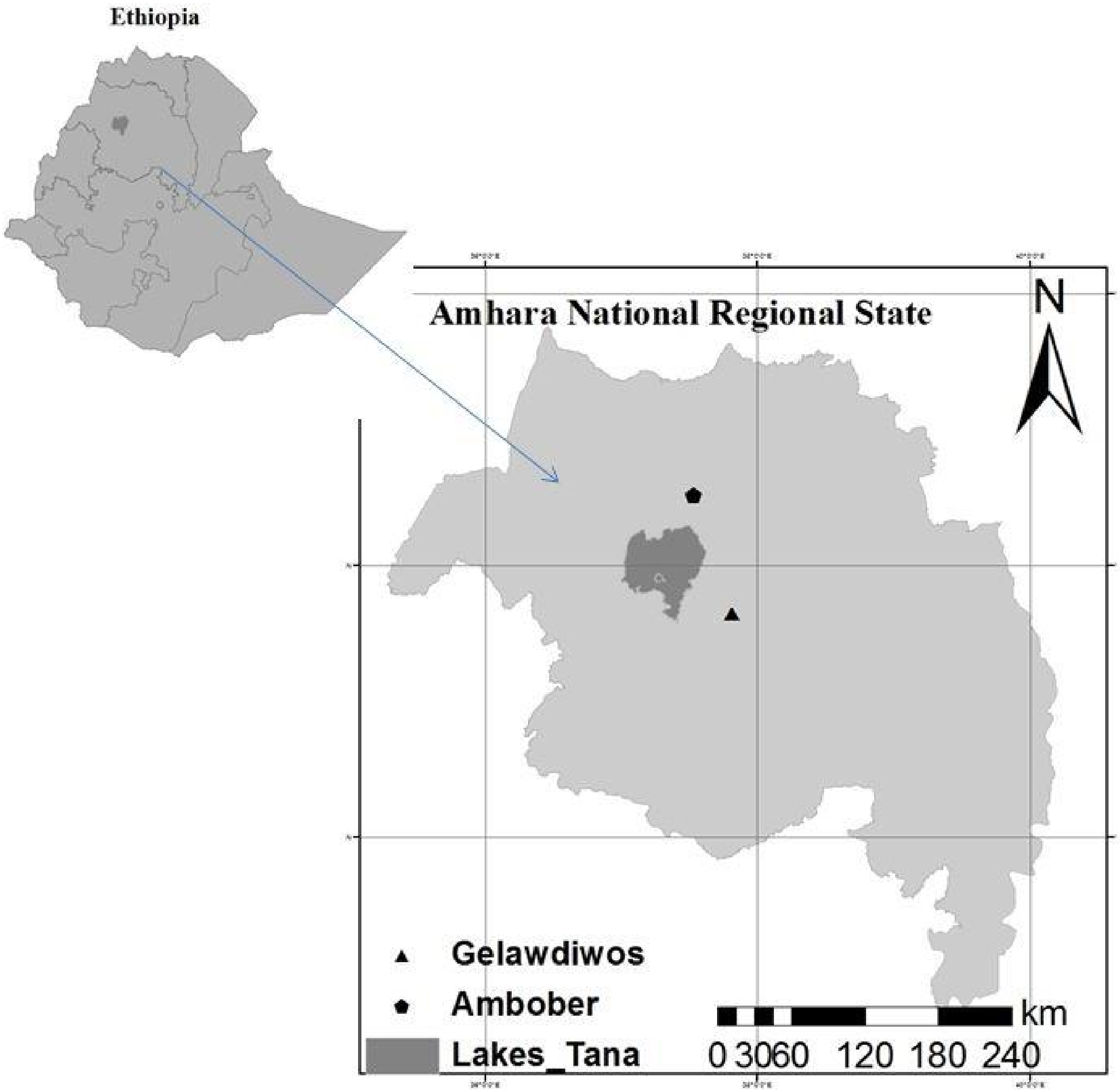


Figure 1: Location map of Ambober and Gelawdiows district in Amhara region, Ethiopia

3.1.1 Soil and climate

The dominating soils type are Andosols, Ultisols and Alfisols. The mean minimum and maximum temperature of the area are 13 and 27°C respectively, and the mean annual rain fall is 1085mm and varies between 1,000 and 1,500mm.The rain fall occurs from June to September and the remaining part of the year is dry (Gratzer, 2013). Gelawdiows elevation is 2466 ma.s.l, mean annual rainfall is 1200 mm and the temperature is 17°C. The dominant soil type are combisols and andosols.

3.1.2 Vegetation

Most of the study area is covered by bush shrub species, composed of *Dodonaea angustifolia*, vernonia sp, Clutia abyssinica, *Maytenus arbutifolia*, Otostegia integrifolia, *Entada abyssinica Rumex nervosus*, Senna singueana, *Jasminum abyssinicum*, *Acanthus sennii*, *Senna didymobotrya*, *Hypericum quartinianum* and naturally growing tree species (big and scattered trees olea europeana ,croton macrostachyus), *Carissa spinarum*, *Acacia abyssinica*, *Rosa abyssinica*, *Grewia ferruginea*, *Rhus vulgaris*, *Ilex mitis*, *Myrsine africana*, *Rhus glutinosa* and planted tree species composed of *Chamaecztisus proliferus*, *Schinus molle*, *Cajanus cajan*, *Acacia decurence* , *Acacia saligna*, *Ficus thonningii.*

3.2 Data collection

3.2.1 Sampling technique

Ambober study area was mapped at 1:20,000 scale and the x: y interval 50*50 m (the inter distance of the sample plot) and Gelawdiows was mapped at 1:50, 000 scale, and the x: y interval 100*100 m. To find the sample plot point the x: y coordinates were entered into the GPS. Next, the center of the plot was marked with an iron stick and the length was corrected along slopes. Starting from the center of the plot, circles were created with a 5 m radius and data measurements were taken, starting from the plot center.

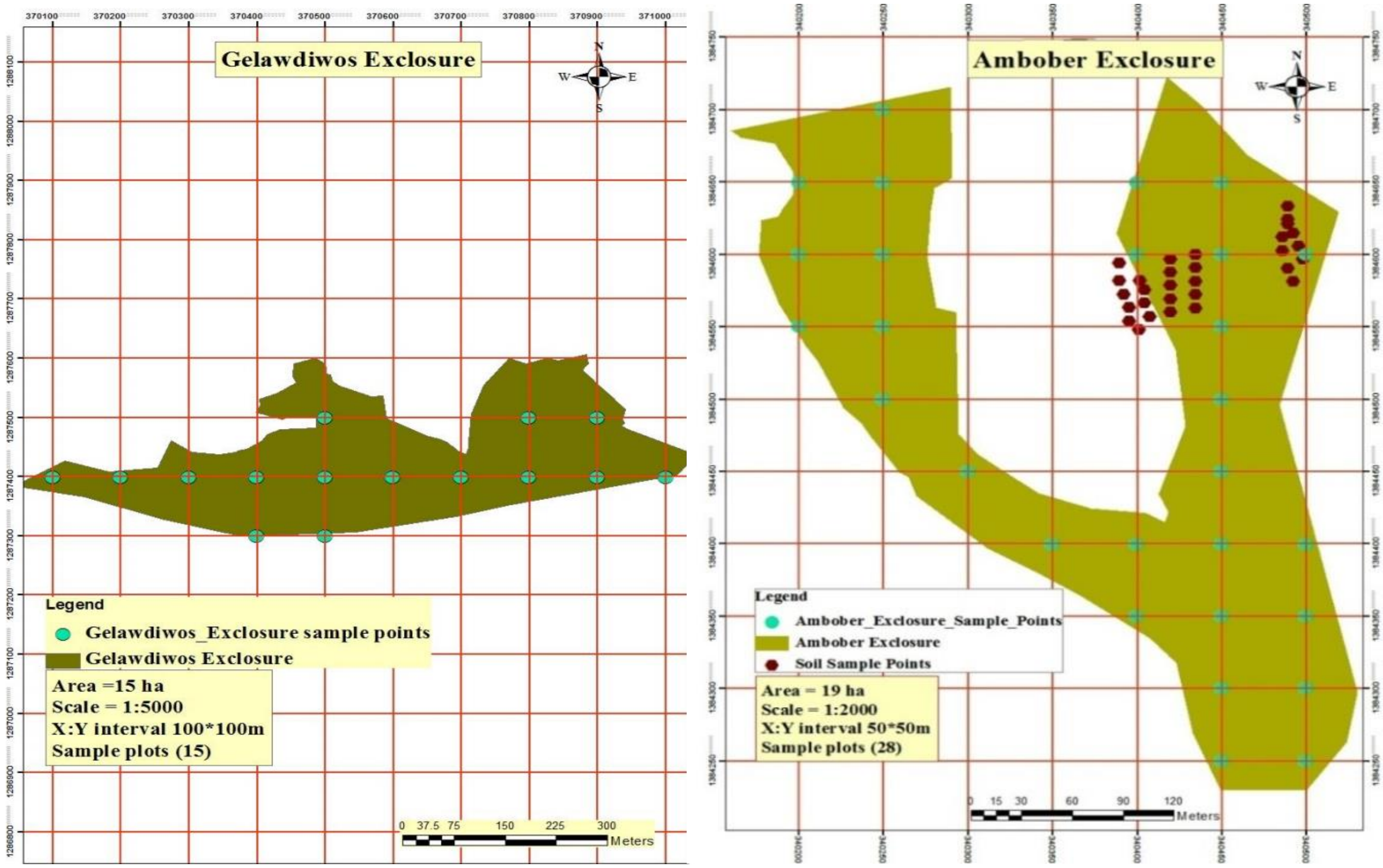


Figure 2: Layout of sample points of Ambober and Gelawdiows area exclosure

Figure 3: Before establishment (Photo by Abrham Abiyu, 2009)

Figure 4: After 5 years (2014).

Ambober exclosure was established (enclosed) in March, 2009. In the beginning of the establishment of the exclosure plants were highly browsed and small diameter. There have been significant increases of the vegetation cover, total height, crown width and diameter of shrubs and trees of the exclosure.

Figure 5: During data collection, Ambober, 2014

Figure 6: Gelawdiows area exclosure (2014)

3.2.2 Sample design

On each permanent plot, circular pilot plots with a 5m radius ($79m^2$) were distributed at 50 m (Ambober) and 100 m (Gelawdiows) spacing. A total of 42 sample plots from Ambober, 2014 (14 plots from Ambober, 2009 plot) and 15 plots from Gelawdiows was established. Finally in each plot every tree and shrubs with a diameter <10 cm at above ground, and having height > 1.5 m was measured. The following, measurements were recorded for these plants individuals: Root Collar Diameter (RCD), Height (H), Crown Radius (CR) in four direction (N, S, W and S), Slope, Distance from centre, Azimuth, Aspect, Liana Load (%) and using a Calliper graduated in mm and stick pole graduated in m, compass, metre tape, clinometers and Blume-Leiss.

Measurements were always taken starting from the nearest shrub/ tree to the plot centre. Additionally, in 2m*2m circle plots, all living shrub/tree species <1.5 m height in the circle plots were counted and recorded to investigate the regeneration status of the study sites.

4. METHOD

4.1 Biomass

4.1.1 Sample shrub/tree selection for biomass function

To estimate biomass direct or indirect methods can be used. The direct methods to predict above ground biomass of shrub/tree requires the felling of an appropriate number of shrub/ trees and estimating their field and oven-dry weights. An indirect method (non-destructive) uses allometric regression equations based on some easily measurable inventory data such as stem diameter, height or crown diameter.

The selection of sample shrubs/trees for biomass functions was based on the population information collected from the 57 plots. All measured shrubs/trees species in the area exclosure were grouped in to families within site.

4.1.2 Above ground biomass and carbon stock estimation

Model selection

Different allometric equation/models can be used to estimate above ground biomass using non - destructive methods (without tree felling). The usual methods for determining the above ground biomass (AGB) of forests are the combination of forest inventories with allometric shrub/tree biomass regression models (Guy parent, 2000), (Cleemput et al., 2013) and (K. Giday et al., 2013). Easily measured parameters from forest inventories like diameter at stump height (DSH) alone or using height (H) together can be used to estimate shrub biomass.

However, for Ethiopian shrub species most of the equations were developed using diameter at stump height (DSH) depend on agro ecology and shrub /tree species family. Hence, to estimate carbon stock and change in living biomass of shrubs and trees in Ambober and Gelawdiows exclosure, using non-destructive different allometric equations were selected after being reviewed from literatures. From 57 sample plots (Ambober and Gelawdiows exclosure) 37 species were obtained and the species were grouped into 16 families. As a result, a total of 40 allometric equation were taken based on the family and agro ecology. Five allometric equation were used to calculate carbon stock or change per family. Two of the allometric equations were used for all family in common (Table 1). Especially the allometric equation given by Guy parent, (2000), Cleemput et al., (2013), K. Giday et al., (2013) and Negash et al., (2013b) were used. These equation were developed based on shrub/tree species and Agro ecology using Diameter at Stump Height (DSH) and Diameter at 40 cm (d_{40}).

To select the appropriate allometric equation for each family, biomass was calculated by five allometric equation and the results were compared with to each other in relation to the corresponding stump height diameter. Finally, the estimated AGB using allometric equation was converted into carbon stocks for the two exclosure. Generally the following steps were used to calculate the final carbon stock and change for each study site in species, plot, family and hectare level.

1. The selection and application of an allometric equation function for the estimation of individual shrub/tree biomass based on family.
2. Calculating and summing of the individual shrub/tree above ground biomass to estimate plot level above ground biomass.
3. Calculating the total biomass and carbon stock for each family.
4. Analyzing the five-year biomass increment using the 2009 and 2014 above ground biomass result from 14 sample plots.

Table 1: Data used for model calibration to estimating biomass of different species family, Dry weight mass(Y), Number of stem (N), Diameter at stump Height (DSH), Diameter at 30 cm (D_{30}), Diameter square at 40 cm (d^2_{40}),total dry weight (TDW), b1 & b0 (coefficient), Maximum Diameter at Stump Height (MAX.DSH), Adjusted R-squared (R^2).

			Data used for model calibration				Remark
Family	**N**	**Models/Equations**	**Number of sample**	**MAX .DSH**	**R2**	**Source**	
Fabaceae	339	Y=(-0.5385*DSH)+ (0.5341*(DSH exp1.6))	9	23	0.98	(Guy parent, 2000)	
		Y=(0.9511*DSH)+ (0.0295*(DSH exp2.4))	12	14	0.98	(Guy parent, 2000)	
		Y=230.98*(D30^(1.47)	5	-	0.87	(Cleemput et al., 2013)	
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Apocynaceae	68	Y=(0.0345*DSH)+ (0.0377*(DSH exp3.3))	13	7	0.91	(Guy parent, 2000)	
		Y=(0.1788*DSH)+ (0.0319*(DSH exp2.6))	25	29	0.96	(Guy parent, 2000)	
		Y=(0.3658*DSH) +(0.1144*(DSHexp2.2))	-	-	0.86	(Guy parent, 2000)	For all moist weyna dega specis
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514,	39	28.6	0.98	(K. Giday et al., 2013)	

		b1=2.827					
Euphorbiaceae	161	Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-	-	0.86	(Guy parent, 2000)	For all moist weyna dega species
		Y=(0.2972*DSH)+ (0.1588*(DSH exp2.2))	30	37	0.88	(Guy parent, 2000)	
		Y=(0.3679*DSH)+ (0.0459*(DSH exp2.5))	22	47	0.99	(Guy parent, 2000)	
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Sapindaceae	184	Y=(0.3989*DSH)+ (0.0126*(DSH exp2.9))	-	-	0.82	(Guy parent, 2000)	
		Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	-	39	0.93	(Guy parent, 2000)	For all dry weyan dega species
		Y=(0.2313*DSH)+ (0.1073*(DSH exp2.0))	8	37	0.98	(Guy parent, 2000)	
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Lamiaceae	168	Y=(0.3989*DSH)+ (0.0126*(DSH exp2.9))	-	-	0.82	(Guy parent, 2000)	
		Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	17	17	0.93	(Guy parent, 2000)	
		Y=45.80*(D30^(2.26))	7	-	0.99	(Cleemput et al.,	

						2013)	
		$Y=b1d^2{}_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Anacardiaceae	26	Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	8	18	0.97	(Guy parent, 2000)	
		Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	21	17	0.84	(Guy parent, 2000)	
		Y=(0.0884*DSH)+ (0.0331*(DSH exp2.8))	4.20E+01	17	0.86	(Guy parent, 2000)	
		$Y=b1d^2{}_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Rosaceae	11	Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	21	17	0.84	(Guy parent, 2000)	
		Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-	-	0.86	(Guy parent, 2000)	For all moist weyna dega species
		Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	8	18	0.97	(Guy parent, 2000)	
		$Y=b1d^2{}_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Asteraceae	119	Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	-	39	0.93	(Guy parent, 2000)	For all dry weyan dega

							species
		Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-	-	0.86	(Guy parent, 2000)	For all moist weyna dega species
		Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	17	14	0.93	(Guy parent, 2000)	
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Celastraceae	9	Y=(0.2685*DSH)+ (0.0492*(DSH exp2.3))	22	31	0.88	(Guy parent, 2000)	
		Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	17	14	0.93	(Guy parent, 2000)	
		Y=(0.2451*DSH)+ (0.0271*(DSH exp2.6))	133	34	0.93	(Guy parent, 2000)	
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Oleaceae	33	Y=(0.6806*DSH)+ (0.0422*(DSH exp2.7))	16	23	0.91	(Guy parent, 2000)	
		Y=(0.1517*DSH)+ (0.1518*(DSH exp2.3))	15	23	0.91	(Guy parent, 2000)	
		Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	-	39	0.93	(Guy parent, 2000)	For all dry weyan dega species
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	

		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Primulaceae	3	Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-	-	0.86	(Guy parent, 2000)	For all moist weyna dega species
		Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))		39	0.93	(Guy parent, 2000)	
		Y=(0.1517*DSH)+ (0.1518*(DSH exp2.3))	15	23	0.91	(Guy parent, 2000)	
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Polygonaceae	14	Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-	-	0.86	(Guy parent, 2000)	
		Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	21	17	0.84	(Guy parent, 2000)	
		Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))			0.93	(Guy parent, 2000)	
		Y=b1d^2_{40}, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Malvaceae	4	Y=(0.5983*DSH)+ (0.0017*(DSH exp3.7))	29	17	0.96	(Guy parent, 2000)	
		Y=(0.1532*DSH)+ (0.2018*(DSH exp1.9))	7	14	0.98	(Guy parent, 2000)	
		Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-		0.84	(Guy parent, 2000)	For all moist weyna dega

							species
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Combretaceae	4	Y=(0.0922*DSH)+ (0.1540*(DSH exp2.2))	13	29	0.96	(Guy parent, 2000)	
		Y=(0.1135*DSH)+ (0.1140*(DSH exp2.3))	27	29	0.94	(Guy parent, 2000)	
		Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	-		0.86	(Guy parent, 2000)	For all moist weyna dega species
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	
Melianthaceae	14	Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	-	39	0.93	(Guy parent, 2000)	For all dry weyan dega species
		Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))			0.86	(Guy parent, 2000)	For all moist weyna dega species
		Y=(0.1189*DSH) +(0.0011*(DSHexp4.0))	39	17	0.98	(Guy parent, 2000)	
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514,	39	28.6	0.98	(K. Giday et al., 2013)	

		b1=2.827					
Hypericaceae	3	Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	-	39	0.93	(Guy parent, 2000)	For all dry weyan dega species
		Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	21	17	0.84	(Guy parent, 2000)	
		Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	8	18	0.97	(Guy parent, 2000)	
		$Y=b1d^2_{40}$, b1(0.147)	31	22.8	0.8	(Negash et al., 2013b)	
		lnTDW=b0 + b1lnDSH, b0= -3.514, b1=2.827	39	28.6	0.98	(K. Giday et al., 2013)	

4.1.3 Estimation of carbon stock

Tree biomass is converted to carbon stock using the following formula ((MacDicken, 1997):

$$C = \mathbf{AGB} * \mathbf{0.5} \qquad (1)$$

Equation 1: Carbon stock

Where:

C = above ground carbon

AGB= above ground biomass

Then, carbon stock estimation was calculated using five selected models or equations for each species family and carbo storage per plot, per shrub/tree, per hector and total storage was calculated for the study sites of the sample plot.

4.1.4 Estimations of biomass change

Change of biomass or carbon stock in shrubs/tree species in a year (annual change) between two successive verifications in estimated on the assumption of liner change (UNFCCC, 2013). To estimate the biomass increment or change we used 14 sample plot from Ambober, 2009 that means from the start of establishment of the exclosure, the area was measured and then again the 14 sample plots were measured after 5 years in 2014 (Ambober, 2014).

For our study, in Ambober area exclosure to calculate the biomass increment or change within five years we used the following formula:

$$\Delta \mathbf{B}_{\mathbf{SHRUB}} = \mathbf{B}_{\mathbf{SHRUB,\ T2}} - \mathbf{B}_{\mathbf{SHRUB,\ T1}} \qquad (2)$$

Equation 2: Biomass change

Where**:**

$\Delta \mathbf{B}_{\mathbf{SHRUB},\ \text{change}}$ is the shrub biomass during the period between $\mathbf{T_1}$ and $\mathbf{T_2}$

$\mathbf{B}_{\mathbf{SHRUB,\ T2}}$ **=** shrub biomass at time $\mathbf{T_2}$

$B_{SHRUB, T1}$ = shrub biomass at time T_1

T_1= Time during the establishment starting and T_2= Time after 5 years.

4.2 Diversity

Shannon-Weiner Index (H')

The Shannon-Weiner Index (H) and Shannon evenness (E) indices are calculated as a measure to incorporate both species richness and species evenness (Magurran, 2004). The value of Shannon-Weiner Index usually falls between 1.5 and 3.5 and rarely surpasses 4.5 (Frosini and Magurran, 1988). A rich ecosystem with high species diversity has a large value for the Shannon Diversity Index (H'), while an ecosystem with little diversity has a low H'. The Shannon-Weiner index of diversity (H') was calculated from the equation:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad (3)$$

Equation 3: Shannon Diversity Index

Where:

H' = the Shannon Diversity Index

Pi = is the proportion of individuals found in the i^{th} species

S = total number of species (1, 2, 3…..n).

Shannon evenness (E)

Evenness compares the observed distribution with the maximum possible even distribution of the number of species in the studied forest or it is the distribution of individuals among the species in a studied forest. Evenness is at its maximum when all the species have the same or nearly equal number of individuals. The Shannon evenness index (E) was calculated from the ratio of observed diversity to maximum diversity using the equation:

$$E = \frac{H'}{H'_{max.}} = \frac{\sum_{i=1}^{s} p_i \ln p_i}{\ln s} \qquad (4)$$

Equation 4: Shannon evenness

Where:

E= Equitability (evenness) index which has values between 0 (a situation in which the abundance of all species are completely disproportional) and 1 (all species are equally abundant).

H' = the Shannon Diversity Index

$H'_{max=}$ is the maximum level of diversity possible within a given population

Pi = is the proportion of individuals found in the i^{th} species

S = total number of species (1, 2, 3…..s)

Simpson's Index (D)

Simpson's index reflects the dominance because it is more sensitive to the most abundant species than the rare species and was calculated as:

$$D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)} \qquad (5)$$

Equation 5: Simpson's Index

Where:

n_i= the number of individuals in the i^{th} species; and

N= the total number of individuals.

5. RESULTS

5.1 Biomass

5.1.1 Shrub/tree characteristics

A total of 37 species were recorded across the study sites i.e. 33 in Ambober area exclosure, additionally 4 species in Gelawdiows (Table 2). *Calpurnia aurea ((295) Fabaceae), Dodonaea angustifolia ((183) Sapindaceae), Otostegia integrifolia ((169) lamiacea), Clutia abyssinica ((116) Euphorbiaceae)* were found to be the dominant shrub species in Ambober, 2014. However, during the beginning of area exclosure (Ambober, 2009) *Otostegia integrifolia ((87) lamiacea)* and *Dodonaea angustifolia* (32) *Sapindaceae)* were dominant. However, in Gelawdiows only *Bersama abyssinica (*14) *Melianthaceae)* were dominant. In general in Ambober, 2014 the highest of stem number (1154) and species number (33) were recorded and the lowest recorded in Gelawdiows (number of stem 26) and 4 species (Table 2).

Table 2: Number of plots (N), number of stems and each species family across study site sample plot.

Site	N	Number of stems	Species	Family
Ambober, 2014	**42**	4	Acacia abyssinica	Fabaceae
		2	Acacia decurence	Fabaceae
		10	Acacia saligna	Fabaceae
		295	Calpurnia aurea	Fabaceae
		10	Chamaecztisus proliferus	Fabaceae
		1	Cajanus cajan	Fabaceae
		2	Entada abyssinica	Fabaceae
		12	Senna singueana	Fabaceae
		2	Senna didymobotrya	Fabaceae

68	Carissa spinarum	Apocynaceae
116	Clutia abyssinica	Euphorbiaceae
47	Croton macrostachyus	Euphorbiaceae
4	Combretum molle	Combretaceae
183	Dodonaea angustifolia	Sapindaceae
2	Ficus thonningii	Moraceae
7	Grewia ferruginea	Malvaceae
3	Hypericum quartinianum	Hypericaceae
9	Maytenus arbutifolia	Celastraceae
32	Olea europeana	Oleaceae
1	Jasminum abyssinicum	Oleaceae
169	Otostegia integrifolia	Lamiaceae
1	Premna schimperi	Lamiaceae
12	Rhus glutinosa	Anacardiaceae
8	Rhus vulgaris	Anacardiaceae
2	Schinus molle	Anacardiaceae
14	Rumex nervosus	Polygonaceae
11	Rosa abyssinica	Rosaceae
1	Ilex mitis	Aquifoliaceae
119	vernonia sp.	Asteraceae
2	Acanthus sennii	Acanthaceae

		1	Phytolacca dodecandra	Phytolaccaceae
		1	ye-embosa lebek/local name	
		3	Myrsine africana	Primulaceae
Ambober, 2009	14	32	Dodonaea angustifolia	Sapindaceae
		87	Otosteg integrifolia	lamiaceae
		23	Vernonia sp.	Asteraceae
		24	Croton macrostachyus	Euphorbiaceae
		21	Rhus vulgaris	Anacardiaceae
		18	Maytenus arbutifolia	Celastraceae
Gelawdiows	15	14	Bersama abyssinica	Melianthaceae
		1	Osyris quadripartita	Lamiaceae
		9	Combretum molle	combretaceae
		2	Croton macrostachyus	Euphorbiaceae

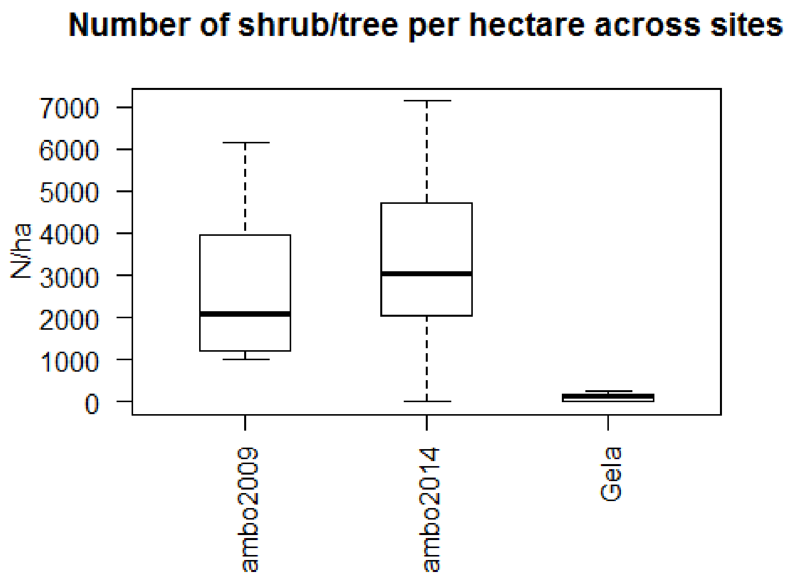


Figure 7: Average number of shrubs/trees per ha across study site sample plot.

In Ambober, 2014 the average number of shrub/tree was 3501 per ha and Ambober, 2009 was 2913 per ha. In Gelawdiows, the lowest average number of shrub / tree 220 per ha was recorded (Table 3). In total, there is no significant difference in stem density between Ambober, 2014 and Ambober, 2009 of shrub/tree per ha. However, Gelawdiows site was significantly different from Ambober, 2014 and Ambober, 2009 (Figure 7).

According to the analysis result (Table 3) the mean of RCD (3.02 cm) and height (2.80 m) of the shrub/tree species was larger at Ambober, 2014 compared to Ambober, 2009 (0.34 cm and 2.05 m) and Gelawdiows (1.57 cm and 1.45m) and the lowest RCD were recorded at Ambober, 2009. The smallest diameter was recorded in Ambober, 2009 may be resulted that shows due to data was taken at the beginning or establishment stage of exclosure area (Table 3).

Table 3: Statistical summary, Root collar Diameter (RCD), height (H), Mean, Minimum (min), Max (max), Standard deviation (SD), Number of shrub/tree per ha (N/ha) of the study sites.

		RCD(cm)				H(m)				
Site	**Number stems**	**Mean**	**Max.**	**Min.**	**STD**	**Mean**	**Max.**	**Min.**	**STD**	**N/ha**
Ambober, 2014	1154	3.02	12.40	0.34	1.36	2.8	5.70	1.64	0.50	3501.41
Ambober, 2009	205	0.34	0.80	0.10	0.23	2.05	3.80	1.44	0.65	2913.10
Gelawdiows	26	1.57	5.00	1.00	1.04	1.45	2.30	1.50	0.86	220.69

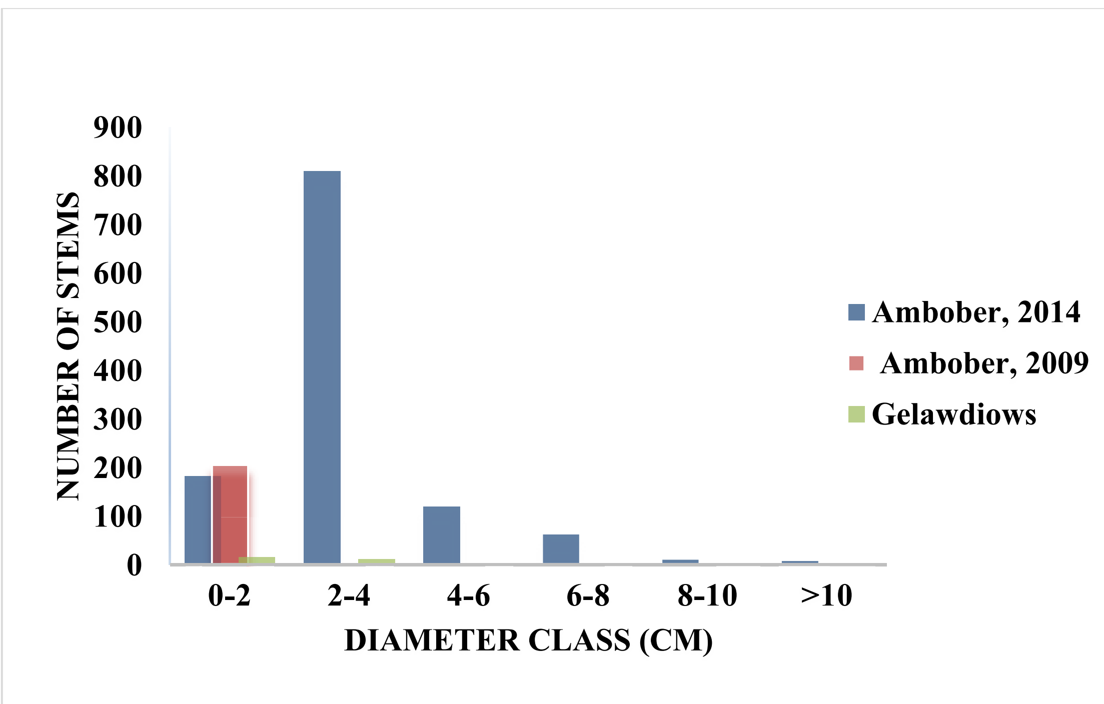


Figure 8: Diameter distribution with stem number across the study sites.

The population structure of the entire shrub species showed higher densities in the middle diameter classes (2-4 cm) and progressively declining stem densities with increasing diameter classes at Ambober, 2014. However, in Ambober, 2009 there was a higher number of stems in the lower diameter class (0-2 cm) because the diameter (RCD) of the shrub/tree was measured at the early stage of the establishment of exclosure. In Gelawdiows study site the lowest stem number was recoded at all diameter class (Figure 8).

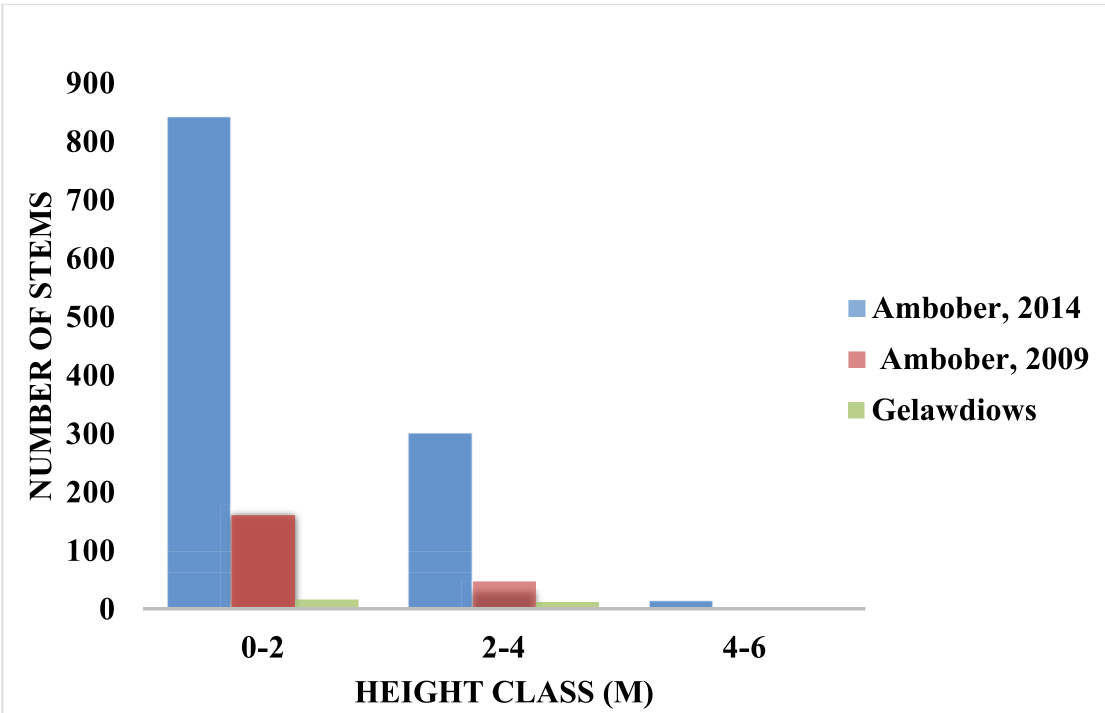


Figure 9: Height distribution with stem number across the study sites.

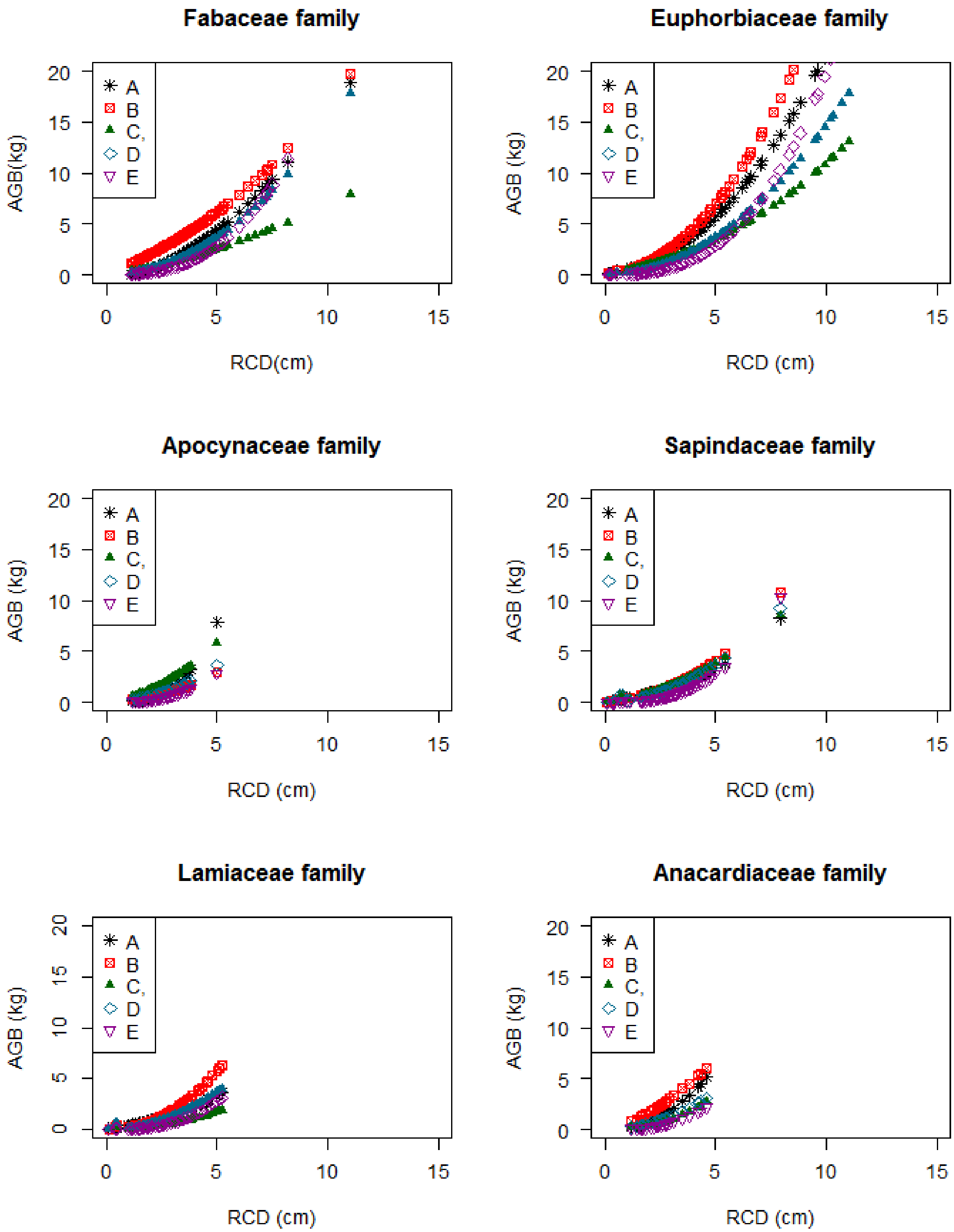
In Ambober, 2014 the highest number of stems and in Gelawdiows the lowest number of stems was recorded at all height classes. The population structure of the entire shrub species showed higher densities in the lower height classes (0-2 m) and progressively declining stem densities with increasing height classes at all study sites. In general at all sites, higher densities (number of stems) were recorded in the lower height class (0-2 m) (Figure 9).

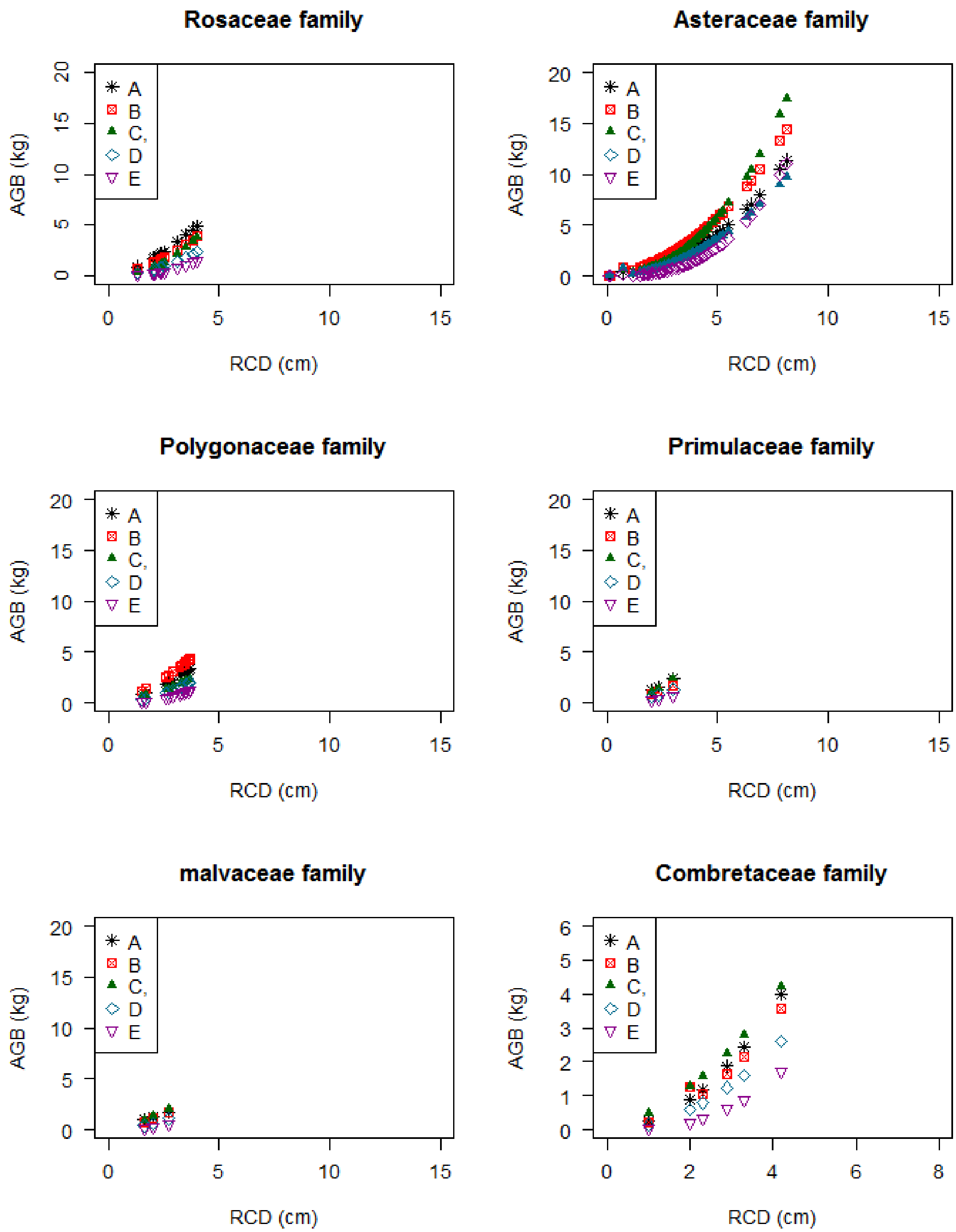
5.1.2 Comparing of shrub/tree family biomass

The figure below illustrates how to affect root collar diameter to biomass of different shrub/tree species family (Figure 10). In the *Fabaceae* family, the five allometric equations have shown different biomass results in relation to diameter. Equation B has shown the highest /sharpest biomass increase, followed by equation A. In contrast, equation C has shown the lowest increase. However, the biomass result of equation D and E were found to be the mean of the five allometric equations. Similarly, for *Euphorbiaceae*, *Lamiaceae* and *Anacardiaceae* families, equation B showed the highest /sharpest biomass value and followed by equation A whereas equation C showed the lowest value. Still equation D and E were found to be the mean of the five allometric equations/models. For the *Asteraceae* family equation C and B showed high performance compared to the other equations and equation A has showed middle performance while equation E and D has the lowest value.

For *Apocynaceae* and Sapindaceae family, all 5 methods showed similar results regarding the shrubs/trees with a small diameter (RCD). With an increasing diameter the deviation in the results of each method as well as the deviation between the different methods enlarged.

Generally, for almost every family, equation E showed the lowest value at small diameter of family shrub/tree species, however for all the families the diameter of the shrub/tree species increased while at the same time the above ground biomass also increased.


Fabaceae family
AGB(kg)
RCD(cm)
Euphorbiaceae family
AGB (kg)
RCD (cm)
Apocynaceae family
AGB (kg)
RCD (cm)
Sapindaceae family
AGB (kg)
RCD (cm)
Lamiaceae family
AGB (kg)
RCD (cm)
Anacardiaceae family
AGB (kg)
RCD (cm)
A
B
C,
D
E
0
5
10
15
20


Rosaceae family
Asteraceae family
Polygonaceae family
Primulaceae family
malvaceae family
Combretaceae family
AGB (kg)
RCD (cm)
A
B
C,
D
E

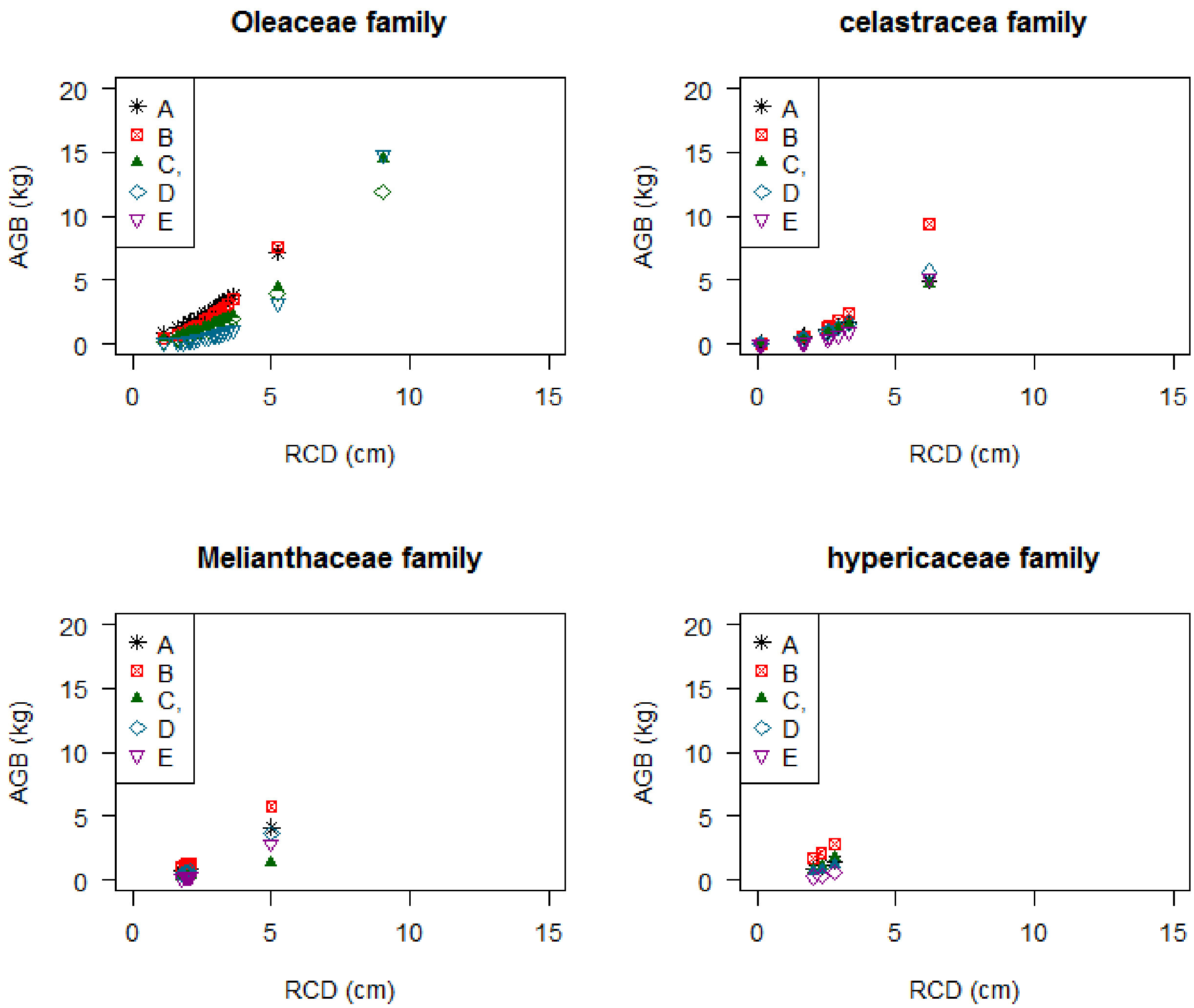
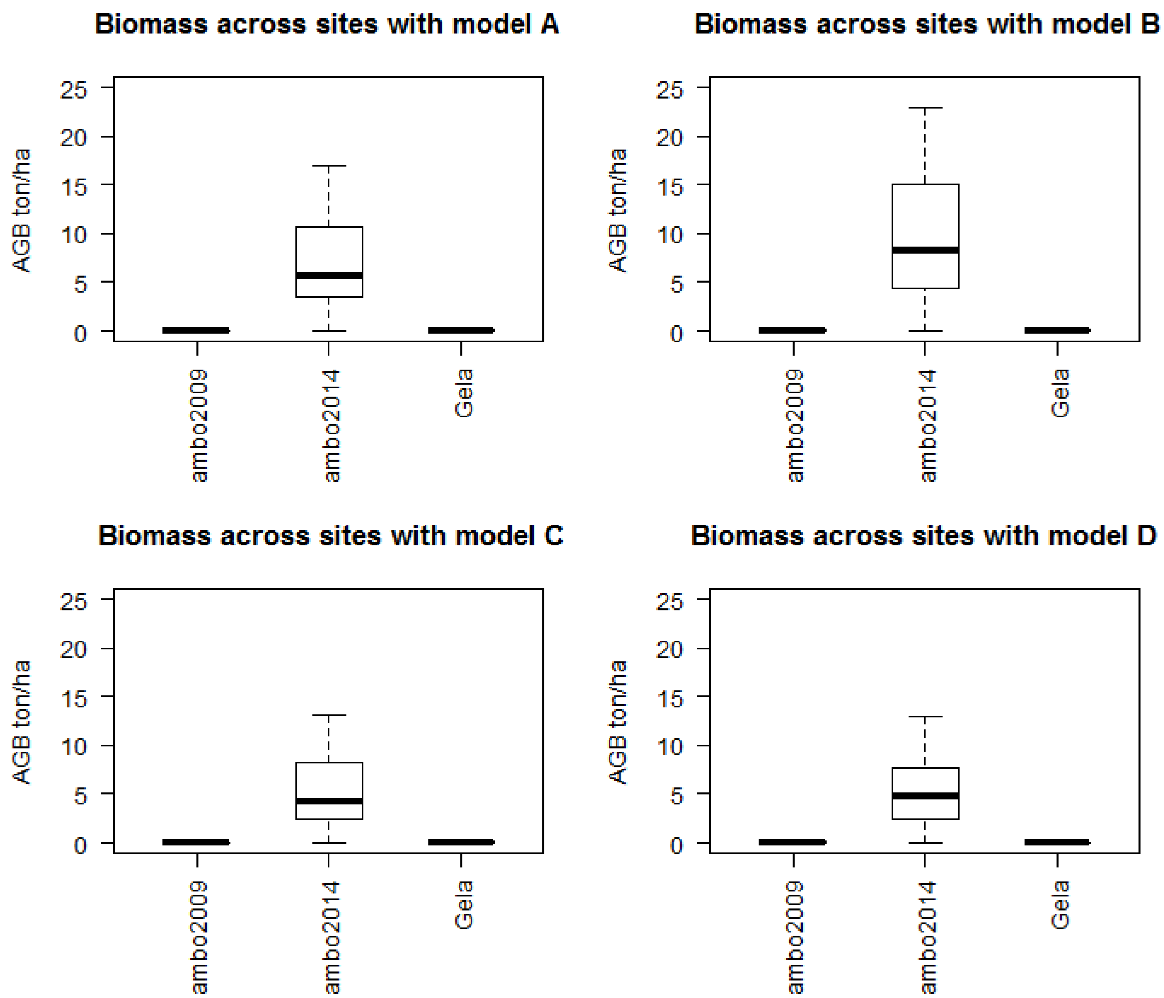


Figure 10: The correlation of estimated biomass and diameter of family species

5.1.3 Comparing above ground biomass using different models



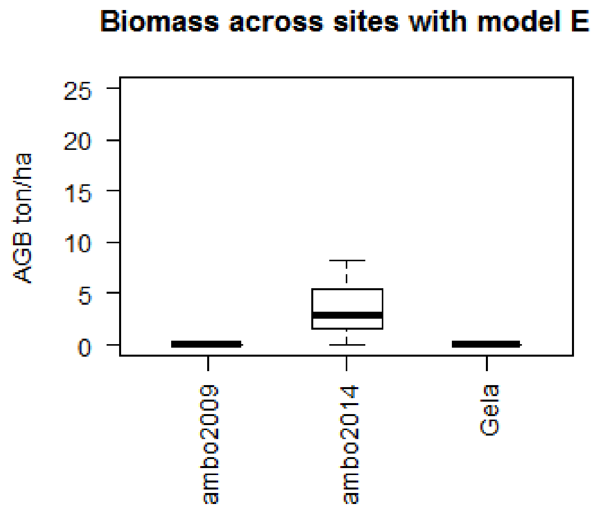


Figure 11: Biomass estimations and comparisons for each study site using five methods.

The box plot analysis results revealed that, the highest biomass for Ambober, 2014 was obtained by equation or model B. Equation A, C and D results showed similar biomass, but the lowest biomass was obtained from equation E (Figure 11). In both cases, Ambober, 2009 and Gelawdiows all models showed that the estimated biomass was not significantly different between the models and the sites (Figure 11).

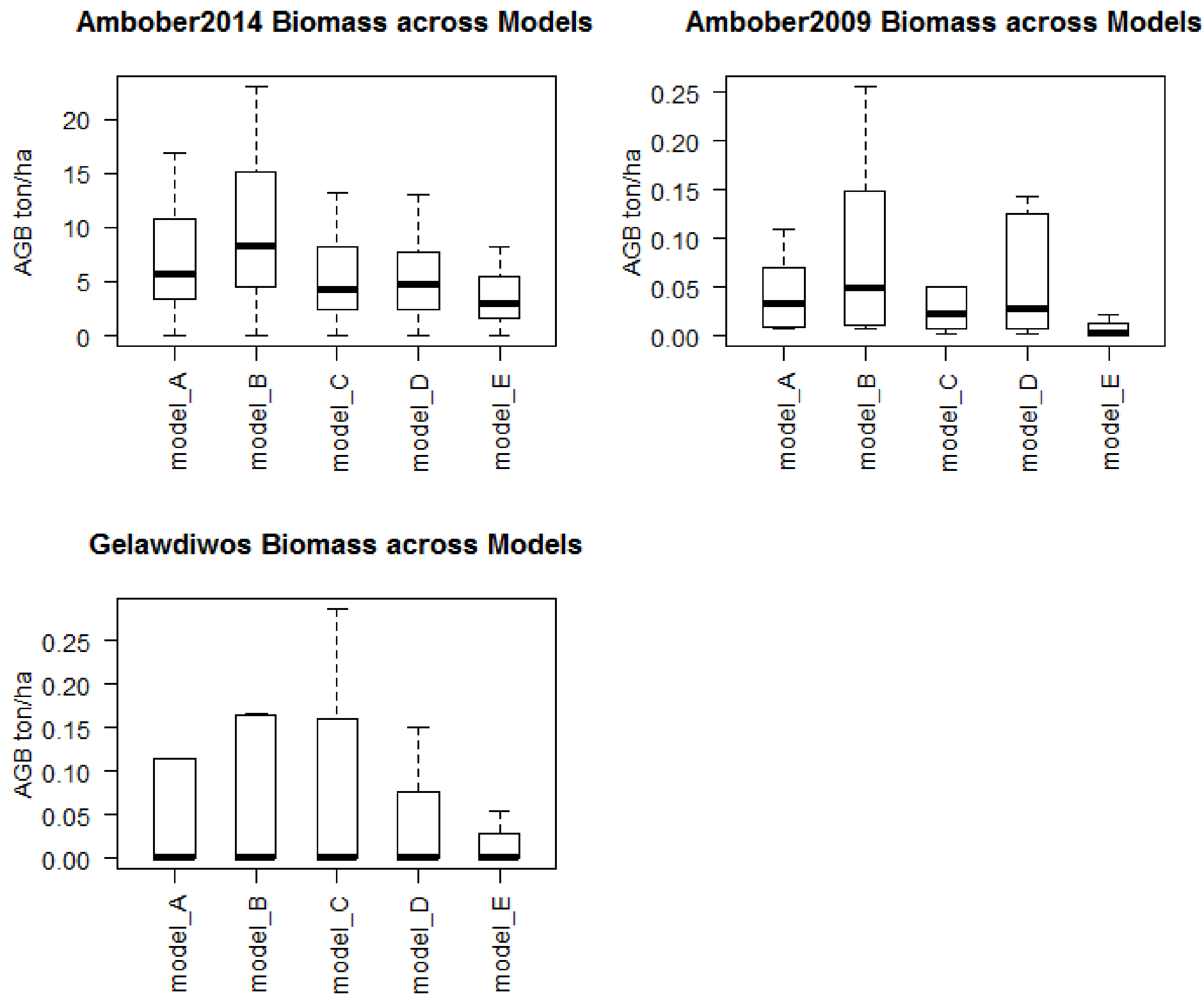


Figure 12: Comparison of biomass ton/ha each site with different models

The above ground biomass ton per ha of each study sites was calculated with five different equations/models. The boxplots (Figure 12) for each model showed the highest, median and lowest biomass values. In Ambober, 2014, the results showed that model B has the highest value and model E gave the lowest result compared to the other models.

In Ambober, 2014 study site, model B (10.01ton/ha) showed the highest result, model/equation A (7.22 ton/ha) followed. Model C and D had similar results (5.58 and 5.65 ton/ha) and model E (3.85 ton/ha) the lowest result compared to other models (Table 4 and Figure 12).

In Ambober, 2009 model B (0.09 ton/ha) showed the highest result, model/equation D (0.06 ton/ha) followed. Model A and C had similar result (0.04 and 0.04 ton/ha) and model E (0.007 ton/ha) had the lowest result compared to other models (Table 4 and Figure 12).

In Gelawdiows study site, model B (0.28 ton/ha) showed the highest result, model/equation A (0.20 ton/ha) followed. Model C and D had similar results (0.14 and 0.14 ton/ha) and model E (0.06 ton/ha) had the lowest result compared to other models in all study sites (Table 4 and Figure12).

Generally, model B gave higher estimates of AGB ton/ha compared to other models. Model E gave the lowest estimate for estimate above ground biomass (ton/ha) across all study sites (Figure 12).

At 95% family-wise confidence level, in Ambober, 2014 site, there was a not significant difference biomass ton/ha between model A and B (p=0.13), A and C (p=0.67),A and D (p=0.64), E and D (p=0.59) and E and C (p=0.55).However, E and A (p=0.04), E and B (p=0.000), D and B (p=0.002) and C and B (p=0.002) have strong significant difference (Table 4).

In Ambober, 2009 exclosure, between models almost all models has no significant difference biomass ton/ha (p=0.29<0.75<0.99) but between E and B models there was a significant difference (p=0.18) (Table 4). In Gelawdiows study site, between all models there was not a significant difference for biomass ton/ha (p=0.52<0.84<0.99) (Table 4). Between study sites, Ambober, 2014 had strong significant differences for biomass ton/ha from Ambober, 2009 and Gelawdiows (p=0.00).However, there was no significant different between Ambober, 2009 and Gelawdiows biomass ton/ha (p=0.99) (Figure 11 and Table 4).

Table 4: Anova analysis, statistics significant of between models, within and between study sites, Number of plots (N), A, B, C, D, E (models).

Sites		**Biomass ton/ha**				
		A	**B**	**C**	**D**	**E**
Ambober, 2014	42	7.224±5.703^{ab}	10.011±7.996^{a}	5.651±4.641^{be}	5.584±4.291^{be}	3.856±3.534^{e}
Ambober, 2009	14	0.041±0.033^{dc}	0.099±0.141^{c}	0.042±0.051^{dc}	0.062±0.074^{dc}	0.007±0.010^{d}
Gelawdiows	15	0.209±0.445^{dc}	0.289±0.624^{dc}	0.140±0.261^{dc}	0.142±0.320^{dc}	0.063±0.159^{dc}

In Ambober, 2014 area exclosure, per shrub/tree species above ground biomass obtained the highest estimate when using model B with a result of 0.36 ton/ha, the middle value that was obtained was from model A, C and D with a range of 0.20-0.26 ton/ha and the lowest value was from model E when 0.14 ton/ha was estimated. The total potential of biomass in Ambober, 2014 area exclosure (19 ha) was estimated in model B 190.22 tons, in model A, C and D it was 137.25-106.10 tons and 73.26 tons from model E (Table 5).

While in Ambober, 2009 area exclosure site, per shrub/tree species above ground biomass the highest was estimated in model B 0.006 ton/ha and followed model D 0.004 ton/ha , from model A and C was obtained the similar result 0.002 ton/ha and the lowest was estimated from model E 0.0005 ton/ha. The total potential of biomass in Ambober, 2009 area exclosure (19 ha) was obtained by model B 1.89 tons, using model D 1.19 tons, by model A and C 0.78 and 0.81 tons respectively and from model E 0.14 tons was obtained (Table 5).

In Gelawdiows area exclosure, per shrub/tree species estimation of biomass using model B was obtained 0.01 ton/ha which was followed by model A with 0.008 ton/ha, models C and D both resulted in 0.005 ton/ha. Using model E 0.002 ton/ha was estimated and the lowest compare with the other models. Finally, total estimated biomass from Gelawdiows area closure (15 ha) was obtained from using model B, giving a value of 4.34 tons. This was closely; followed by model A with a value of 3.14 tons, using model C and D similar result of 2.10 and 2.13 tons were recorded, respectively. Lastly model E estimated a value of 0.94 tons, which was the lowest compared with other models (Table 5).

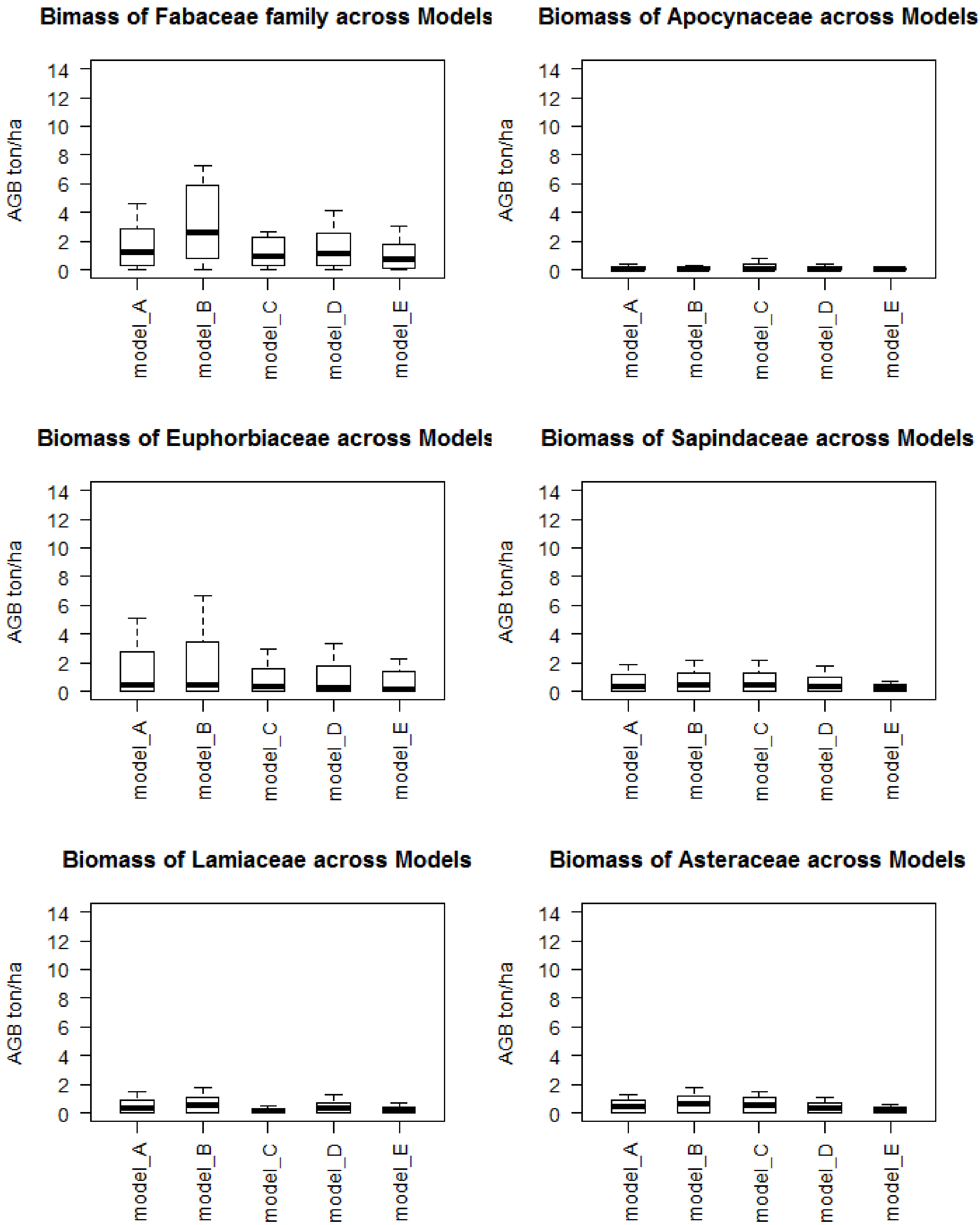
Table 5: Above ground biomass with different models (equation) of the study sites. Number of plots (N), A, B, C, D, E (models).

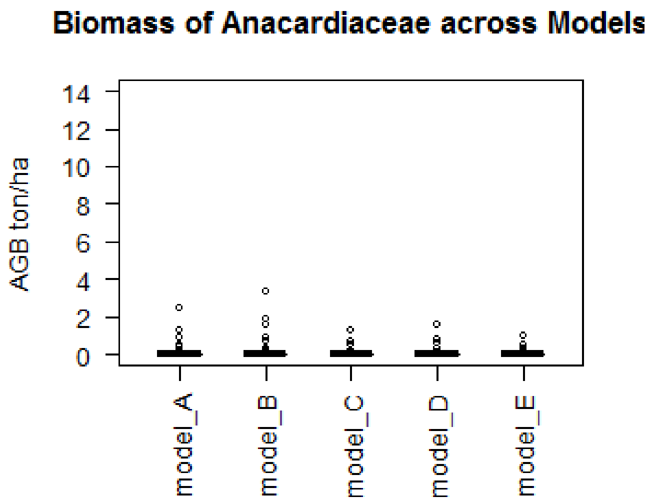
Site	N	Parameter	Biomass ton/ha				
			A	B	C	D	E
Ambober, 2014	42	Per shrub/tree	0.262	0.364	0.205	0.203	0.14
		Average/mean	7.224	10.011	5.651	5.584	3.856
		Total in the area	137.257	190.22	107.369	106.101	73.264
Ambober, 2009	14	Per shrub/tree	0.002	0.006	0.002	0.004	0.0005
		Average/mean	0.041	0.099	0.042	0.062	0.007
		Total in the area	0.784	1.897	0.812	1.192	0.147
Gelawdiows	15	Per shrub/tree	0.008	0.011	0.005	0.005	0.002
		Average/mean	0.209	0.289	0.140	0.142	0.063
		Total in the area	3.146	4.344	2.104	2.139	0.946

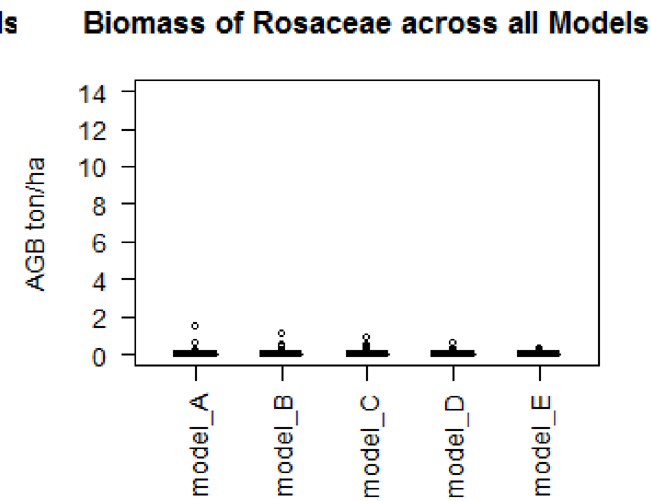
The five models or equations yielded significantly varied above ground biomass between the species families. The results in table 6 shows that the same family but different diameter require different models to estimate the biomass. For example to estimate biomass of *Sapindaceae* family in Ambober, 2014 using model A and B estimated high results, in the same family in Ambober, 2009 biomass calculated using models C and D obtained the highest results. However using model E the lowest biomass appeared across the family (Table 6). We observed the result that, the diameter is the main factor to select a model for biomass calculation for each species family.

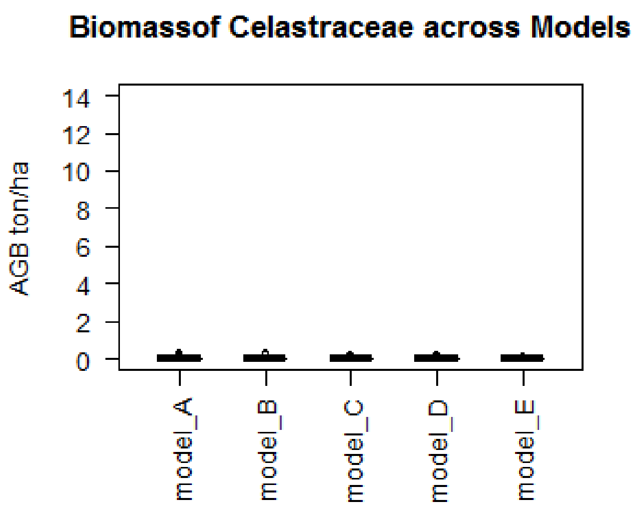
Table 6: Average biomass of each species family with five models of the study sites, Number of plots (N) and A, B, C, D, E (five models).

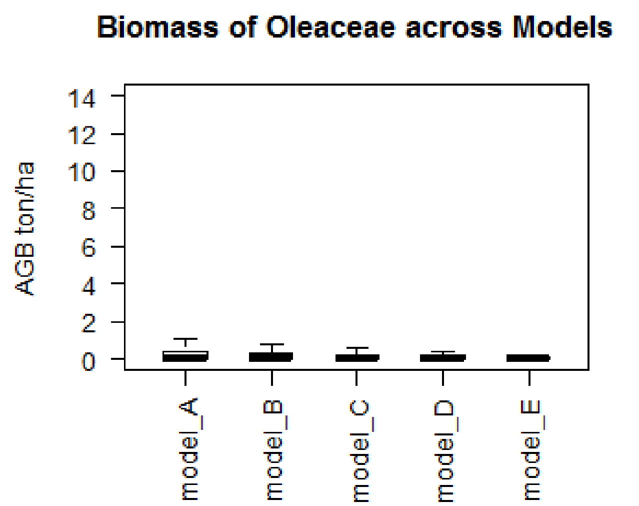
Sites	N	Family	Average biomass ton/ha A	B	C	D	E
Ambober, 2014	42	Fabaceae	1.796	3.539	1.279	1.613	1.052
		Apocynaceae	0.244	0.182	0.397	0.213	0.105
		Euphorbiaceae	1.983	2.40	1.167	1.226	1.186
		Sapindaceae	0.874	0.968	0.964	0.794	0.453
		Lamiaceae	0.683	0.853	0.245	0.585	0.308
		Anacardiaceae	0.142	0.222	0.073	0.094	0.050
		Rosaceae	0.092	0.069	0.057	0.038	0.020
		Asteraceae	0.805	1.141	1.036	0.677	0.459
		Celastraceae	0.046	0.066	0.04	0.044	0.028
		Oleaceae	0.329	0.293	0.193	0.157	0.109
		Primulaceae	0.016	0.011	0.015	0.008	0.004
		Polygonaceae	0.107	0.14	0.073	0.06	0.033
		Malvaceae	0.015	0.014	0.016	0.008	0.003
		Combretaceae	0.029	0.025	0.033	0.019	0.011
		Hypericaceae	0.01	0.02	0.011	0.008	0.003
Ambober, 2009	14	Sapindaceae	0.01	0.011	0.019	0.019	0.003
		lamiaceae	0.006	0.011	0.004	0.018	0.002
		Asteraceae	0.006	0.012	0.008	0.011	0.002
		Euphorbiaceae	0.01	0.01	0.008	0.005	0.001
		Anacardiaceae	0.008	0.055	0.002	0.009	0.001
		Celastraceae	0.001	0.001	0.001	0.001	0.000
Gelawdiows	15	Melianthaceae	0.129	0.184	0.039	0.094	0.046
		Combretaceae	0.063	0.088	0.089	0.041	0.015
		Lamiaceae	0.003	0.002	0.000	0.001	0.000
		Euphorbiaceae	0.015	0.015	0.012	0.006	0.002

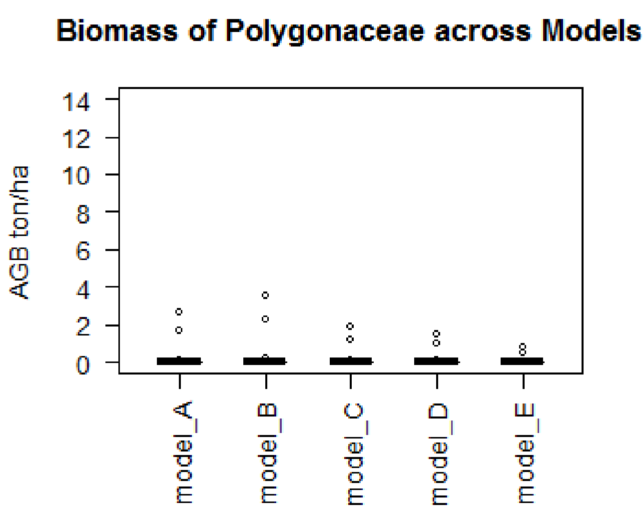

Bimass of Fabaceae family across Models
Biomass of Apocynaceae across Models
Biomass of Euphorbiaceae across Models
Biomass of Sapindaceae across Models
Biomass of Lamiaceae across Models
Biomass of Asteraceae across Models
AGB ton/ha
0 2 4 6 8 10 12 14
model_A
model_B
model_C
model_D
model_E

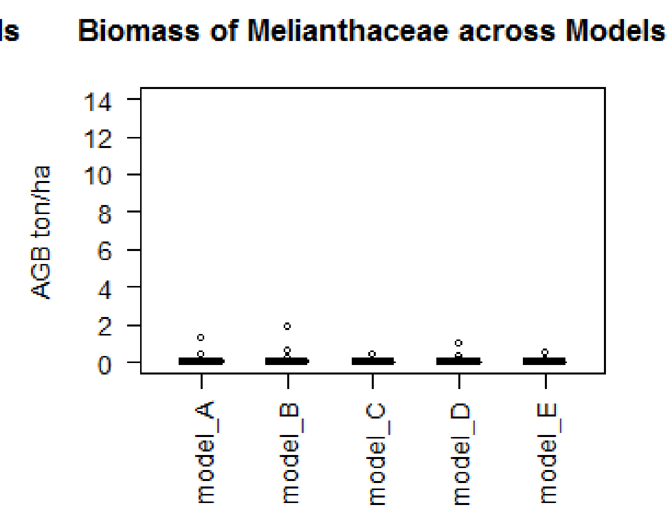

Biomass of Anacardiaceae across Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E


Biomass of Rosaceae across all Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E


Biomassof Celastraceae across Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E


Biomass of Oleaceae across Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E


Biomass of Polygonaceae across Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E


Biomass of Melianthaceae across Models
AGB ton/ha
0
2
4
6
8
10
12
14
model_A
model_B
model_C
model_D
model_E

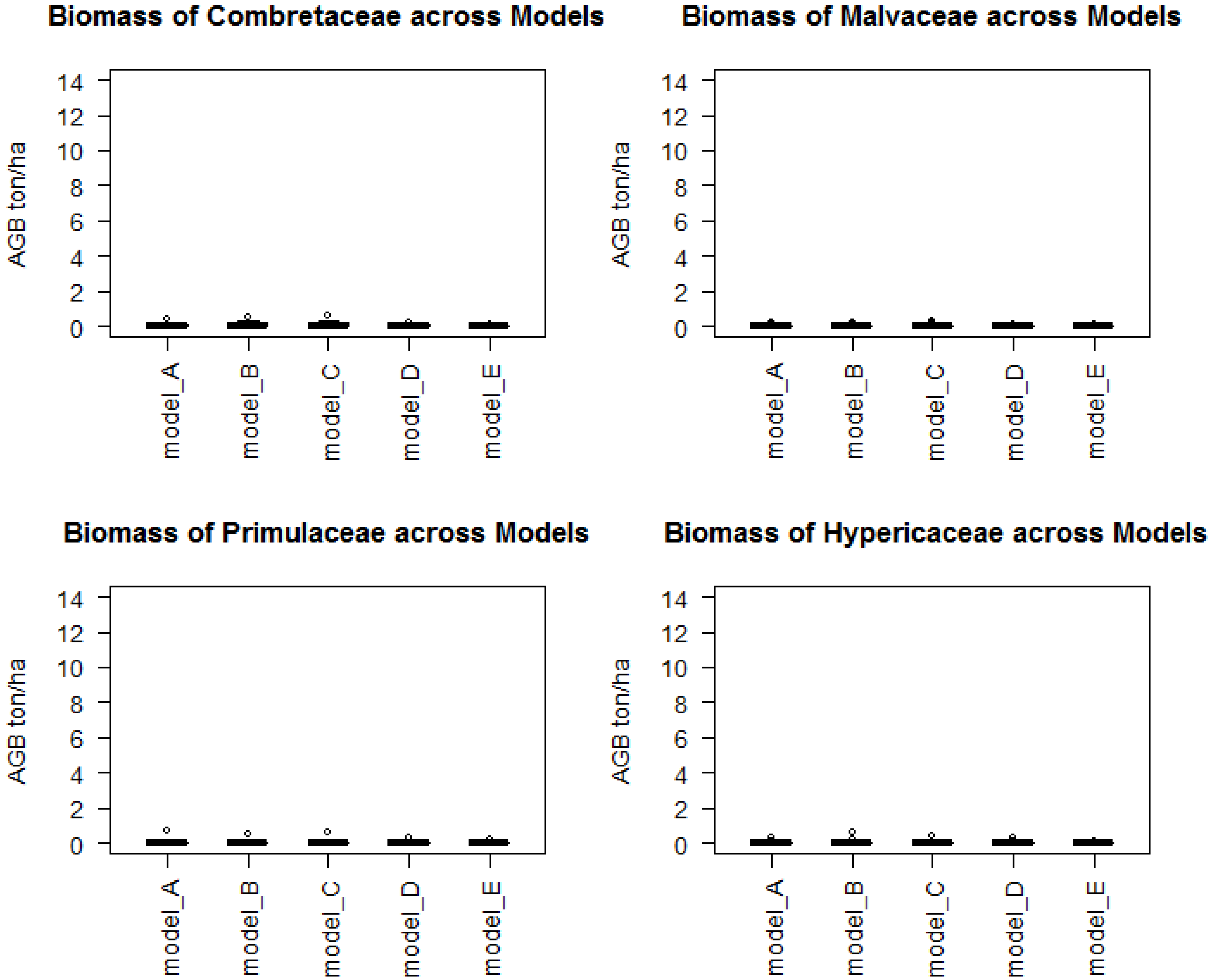


Figure 13: Comparison of species family biomass ton/ha with different model.

The figure above illustrates the biomass of different shrub/tree families of with different models. In the *Fabaceae* family, model/equation B had the highest performance; the other four models (A, C and D) all had a similar result. For *Apocynaceae*, all models gave a very similar result. However for *Euphorbiaceae* family model B showed the highest biomass value, followed by model A whereas model C, D and E showed similar values. For *Sapindaceae* and *Asteraceae* family using model A, B, C, and D similar biomass values were estimated whereas using model

E, the lowest value was obtained compared to with other models. For *Anacardiaceae, Rosaceae, Celastraceae, Oleaceae, Polygonaceae,* and *Melianthaceae* all models have similar result (Figure 13).

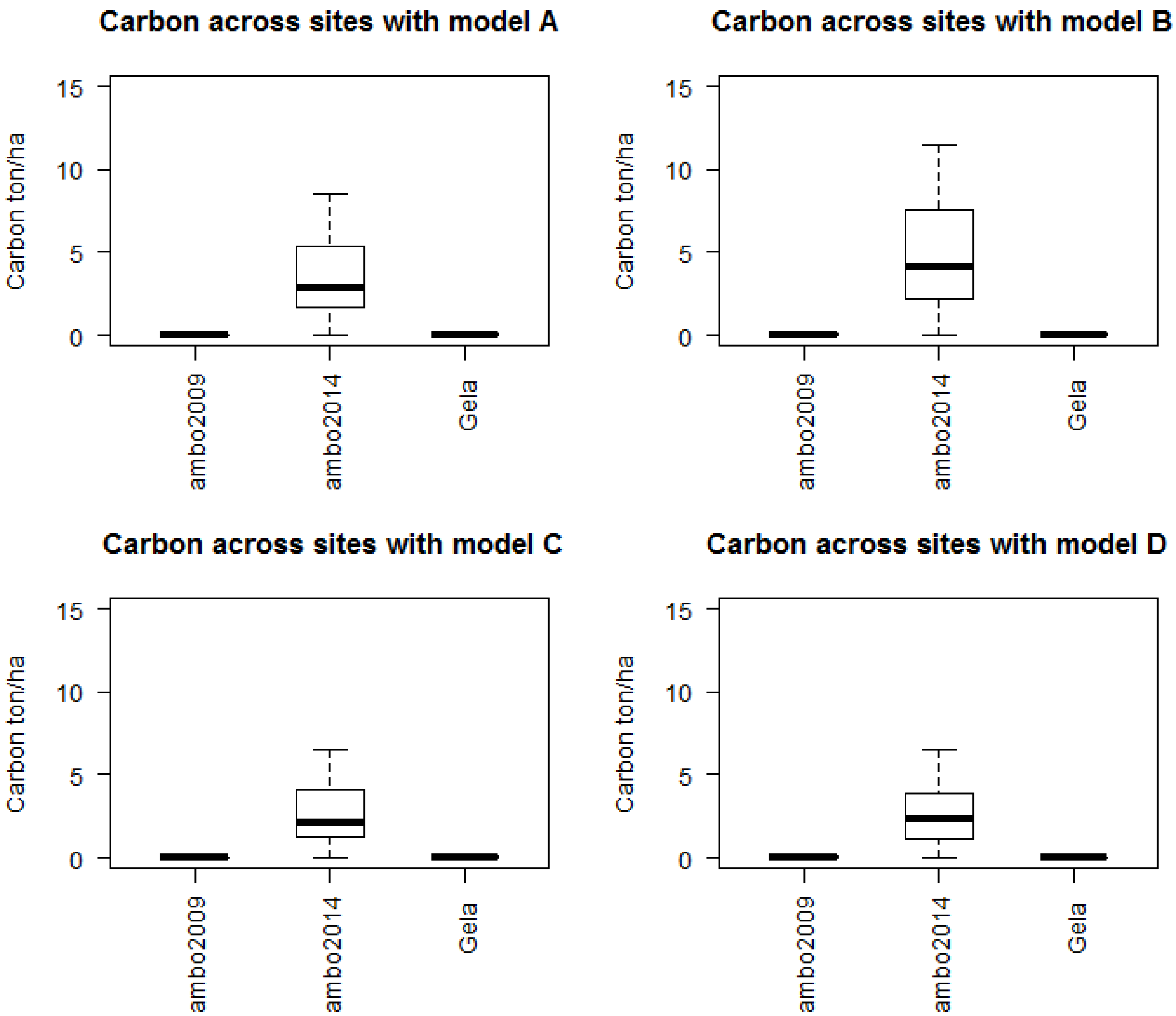
5.1.4 Estimation of carbon stock

In Table 7, the result of the carbon stock estimation by the five models/equations the study site is shown. Using the five models, carbon storage per shrub/tree, mean and total storage of the area were calculated at each study site.

In Ambober, 2014 area exclosure higher carbon stock were estimated per shrub/tree species as well as mean and total storage (Table 7). The total potential of carbon storage in Ambober, 2014 exclosure area (19 ha) was obtained by model B at 95.11 tons, followed using model A with a value of 68.6 tons, models C and D has similar results of 53.68 and 53.05 tons, respectively and the lowest estimated value was by model E with 36.63 tons of carbon. In Gelawdiows exclosure (15 ha) by model B, 2.17 tons of carbon were obtained, using model A, 1.57 tons was obtained, whereas models C and D has similar results of 1.05 and 1.06 tons and using model E gave the lowest of 0.47 tons. As a final point in Ambober, 2009 (19 ha) study site the lowest carbon stock was estimated in all models compared with other study sites.

Table 7: Estimation of carbon stock each study area with different models, Number of sample plot (N), A, B, C, D, E (five models).

			Carbon stock ton/ha				
Site	**N**	**Parameter**	**A**	**B**	**C**	**D**	**E**
Ambober, 2014	42	Per Shrub/tree	0.131	0.182	0.102	0.101	0.07
		Average/mean	3.612	5.005	2.825	2.792	1.928
		Total in the area	68.628	95.11	53.684	53.05	36.632
Ambober, 2009	14	Per Shrub/tree	0.001	0.003	0.001	0.002	0.0002
		Average/Mean	0.02	0.049	0.021	0.031	0.003
		Total in the area	0.392	0.948	0.406	0.596	0.073
Gelawdiows	15	Per Shrub/tree	0.004	0.005	0.002	0.002	0.001
		Average/mean	0.104	0.144	0.07	0.071	0.031
		Total in the area	1.573	2.172	1.052	1.069	0.473


Carbon across sites with model A
Carbon across sites with model B
Carbon across sites with model C
Carbon across sites with model D
Carbon ton/ha
0
5
10
15
ambo2009
ambo2014
Gela

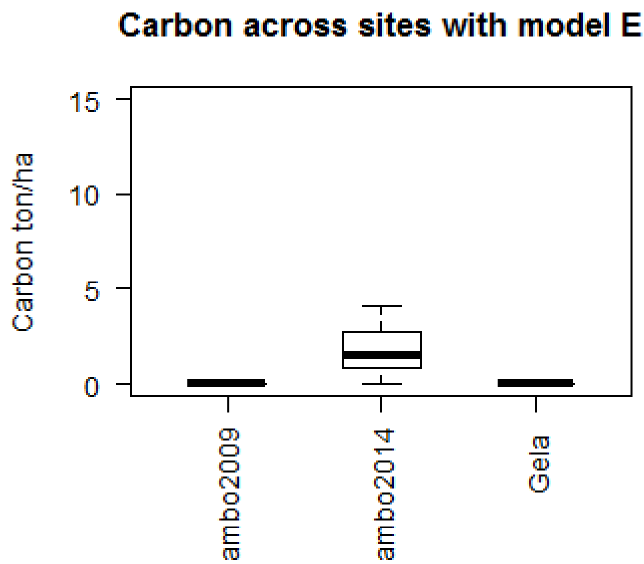


Figure 14: Comparison of carbon ton/ha of study sites with different models

The box plot analysis result revealed that Ambober, 2014 exclosure showed higher carbon stock estimation in all models compared to Ambober, (Figure 14). However, the estimated carbon from Ambober, 2009 and Gelawdiows was shown to be similar in all models (Figure 14).

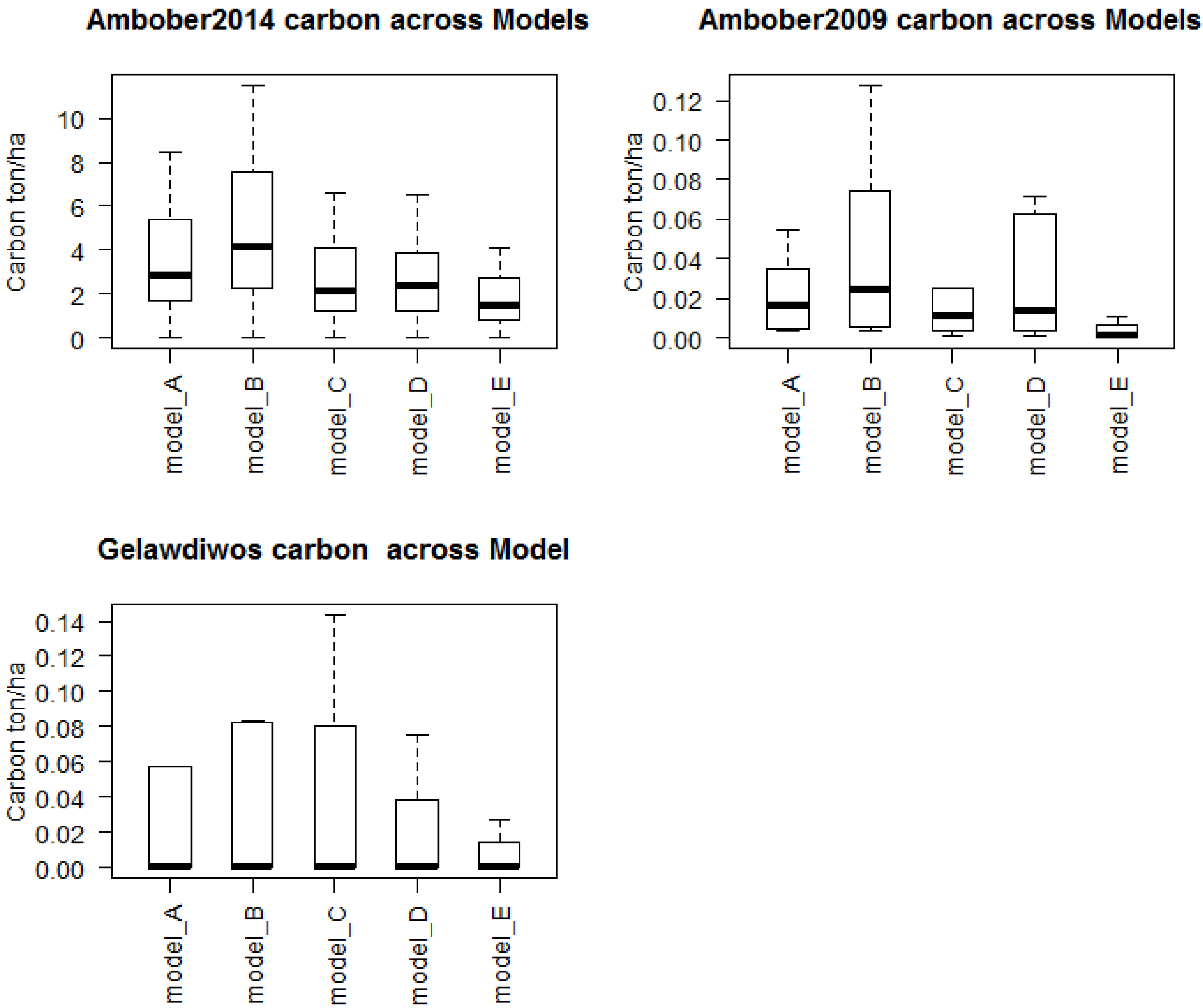


Figure 15: Comparison of carbon ton/ha each site with different models

In Ambober, 2014 study site, the calculated mean carbon using model B (5.00 ton/ha) gave the highest result and this was followed by model A (3.61 ton/ha). Model C and D (2.82 and 2.79 ton/ha) had similar results and using model E (1.92 ton/ha) gave the lowest estimated carbon (Figure 15).

As the result showed, in Ambober, 2009 model B (0.04 ton/ha) obtained the highest result for mean carbon, model D (0.03 ton/ha) was next. Model A and C (0.02 and 0.02 ton/ha) had similar results and model E (0.003 ton/ha) gave the lowest value for carbon compared to other models

(Table 7 and Figure 15).The mean carbon stock calculated in Gelawdiows study site, using model B (0.144 ton/ha) showed the highest result, model A (0.104 ton/ha) followed. Models C and D had similar results (0.071 and 0.071 ton/ha) and model E (0.031 ton/ha) was the lowest compared to other models in all study sites (Table 7 and Figure 15). In general, for the five models, B model showed the highest result and model E had the lowest result for mean carbon ton/ha in all study sites.

5.1.5 Estimations of biomass change

As the result showed, the mean biomass increment (change) in Ambober area exclosure within 5 years using the model B 11.25 ton/ha gave the highest estimate and using model E 4.78 ton/ha was obtained, which was the lowest estimate.

The total increment biomass in Ambober area closure within 5 years was estimated using the various models. Model B gave a result of 213.75 tons, while model A delivered a value of 160.17 tons, models C and D were 122.93 tons and 120.65 tons, respectively and the lowest value was given with model E at 84.74 tons. Annual increment of biomass in Ambober area exclosure was estimated and the highest resulting value was 2.25 ton/ha (model B) and 0.96 ton/ha was the lowest (E model) (Table 8).

Table 8: Biomass increment within 5 years in Ambober area exclosure study site. A, B, C, D, E (Five models), Number of sample plot (N), Standard Deviation (SD).

	Biomass ton/ha											
Model	**Ambober, 2014**			**Ambober, 2014**			**Ambober, 2009**			**Biomass increment in Ambober**		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
A	42	7.22	5.70	14	8.47	6.34	14	0.04	0.03	14	8.43	6.34
B	42	10.01	8.00	14	11.35	9.23	14	0.10	0.14	14	11.25	9.24
C	42	5.65	4.64	14	6.51	4.44	14	0.04	0.05	14	6.47	4.41
D	42	5.58	4.29	14	6.41	4.73	14	0.06	0.07	14	6.35	4.70
E	42	3.86	3.53	14	4.79	4.47	14	0.01	0.01	14	4.78	4.46

As the results indicated, biomass /carbon stock Ambober, 2014 (after enclosed) has a strong significant difference from Ambober, 2009 (before enclosure). The results showed that among models there was no significant difference except between model B and E (have significant difference) before and after the enclosure of the site (Table 9).

Table 9: Welch two sample t-test analysis statistics significant biomass increment within 5 years in Ambober area closure study site. Number of plots (N), A, B, C, D, E (Five Models).

		Biomass ton/ha	
Model	**N**	**Ambober, 2014**	**Ambober, 2009**
A	14	8.47 ± 6.34^{ab}	0.04 ± 0.03^{cd}
B	14	11.35 ± 9.23^{a}	0.10 ± 0.14^{d}
C	14	6.51 ± 4.44^{ab}	0.04 ± 0.05^{cd}
D	14	6.41 ± 4.73^{ab}	0.06 ± 0.07^{cd}
E	14	4.79 ± 4.47^{b}	0.01 ± 0.07^{c}

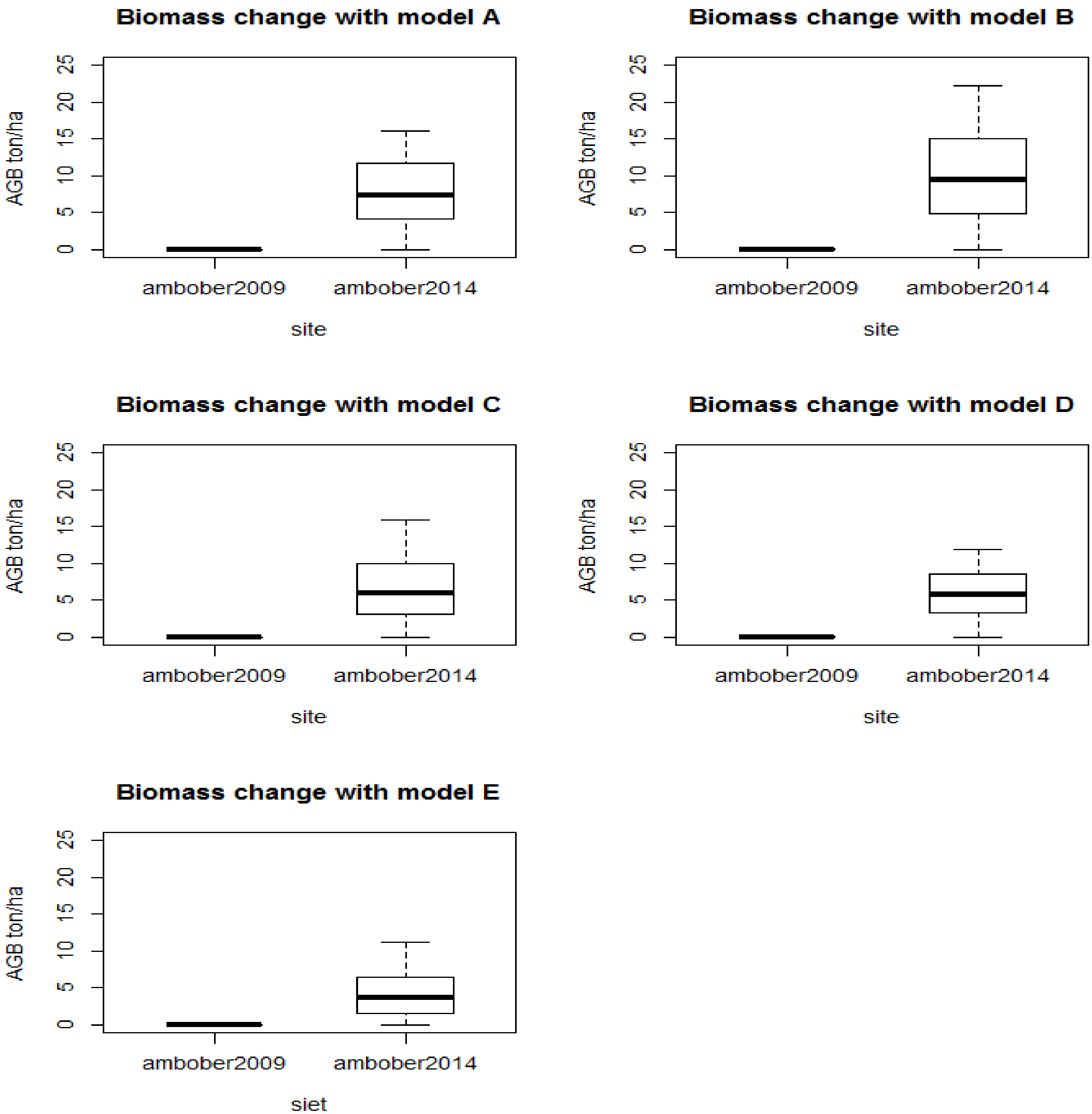


Figure 16: Comparison of Biomass increment in Ambober area closure within 5 years.

In Figure 16 the results showed that, Ambober area exclosure had a strong biomass change or increment within 5 years. Between Ambober, 2009 and Ambober, 2014 there was a big difference biomass ton/ha. However, between models the method using models A, C, D showed very similar results. Whereas using model B showed the highest values and model E gave the lowest value in Ambober, 2009 (before enclosure) and Ambober, 2014 (after enclosure) (Figure 16).

5.2 Diversity

5.2.1 Species diversity and composition

A total of 37 species and 16 families were recorded across the study sites. In Ambober exclosure 33 species were identified and in Gelawdiows exclosure 4 species were recorded (Table 2).

In Ambober exclosure *Calpurnia aurea (Fabaceae family)* contributed the greatest number of species and *Bersama abyssinica (Melianthaceae)* in Gelawdiows exclosure. During the beginning of area exclosure (Ambober, 2009) *Otostegia integrifolia (lamiacea family)* was the dominant species. The exclosure was dominated by shrubs, herbaceous species and less by trees. Furthermore, the number of shrubs and tree species increasing with increase the exclosure age.

The two area closures namely Ambober and Gelawdiows have significantly different tree and shrub species composition. In comparing the shrub/tree diversity and total number of Ambober in two different season (2009 and 2014) there is a clear difference in species and tree composition.

The Shannon-Wiener diversity index, Simpson-index and evenness were computed to analyze diversity and composition of shrub/tree species in the exclosure.

Table 10: Overall diversity of the study sites.

Site	Shannon index(H')	Simpson index(D)	Evenness(E)
Ambober, 2014	2.726	0.906	0.738
Ambober, 2009	1.597	0.751	0.891
Gelawdiows	1.157	0.526	0.526

Amobober, 2014 (after exclosure) had highly significant differences from Ambober, 2009 (before exclosure) and Gelawdiows exclosure in terms of species diversity, evenness and similarity. Among Ambober (before exclosure) and Gelawdiows exclosure there was no significant difference (Table 10 and 11).

Table 11: Mean values, standard deviation and statistical significance of the study area.

Index	habit	Ambober, 2009	Ambober, 2014	Gelawdiows
Shannon	shrub	0.05± 0.18 ^{b}	1.40 ± 0.48 ^{a}	0.30 ± 0.39 ^{bc}
	seedling	-	1.64 ± 0.61^{a}	0.43 ± 0.44**b**
Simpson	shrub	0.07 ± 0.17^{b}	0.67 ± 0.17^{ad}	0.20±0.25^{b}
	seedling	-	0.74 ± 0.14b^{ba}	0.25 ± 0.26^{dc}
Evenness	shrub	0.01 ± 0.06^{b}	0.45 ± 0.17^{ac}	0.23± 0.37^{b}
	seedling	-	0.58 ± 0.22^{a}	0.15± 0.18^{b}

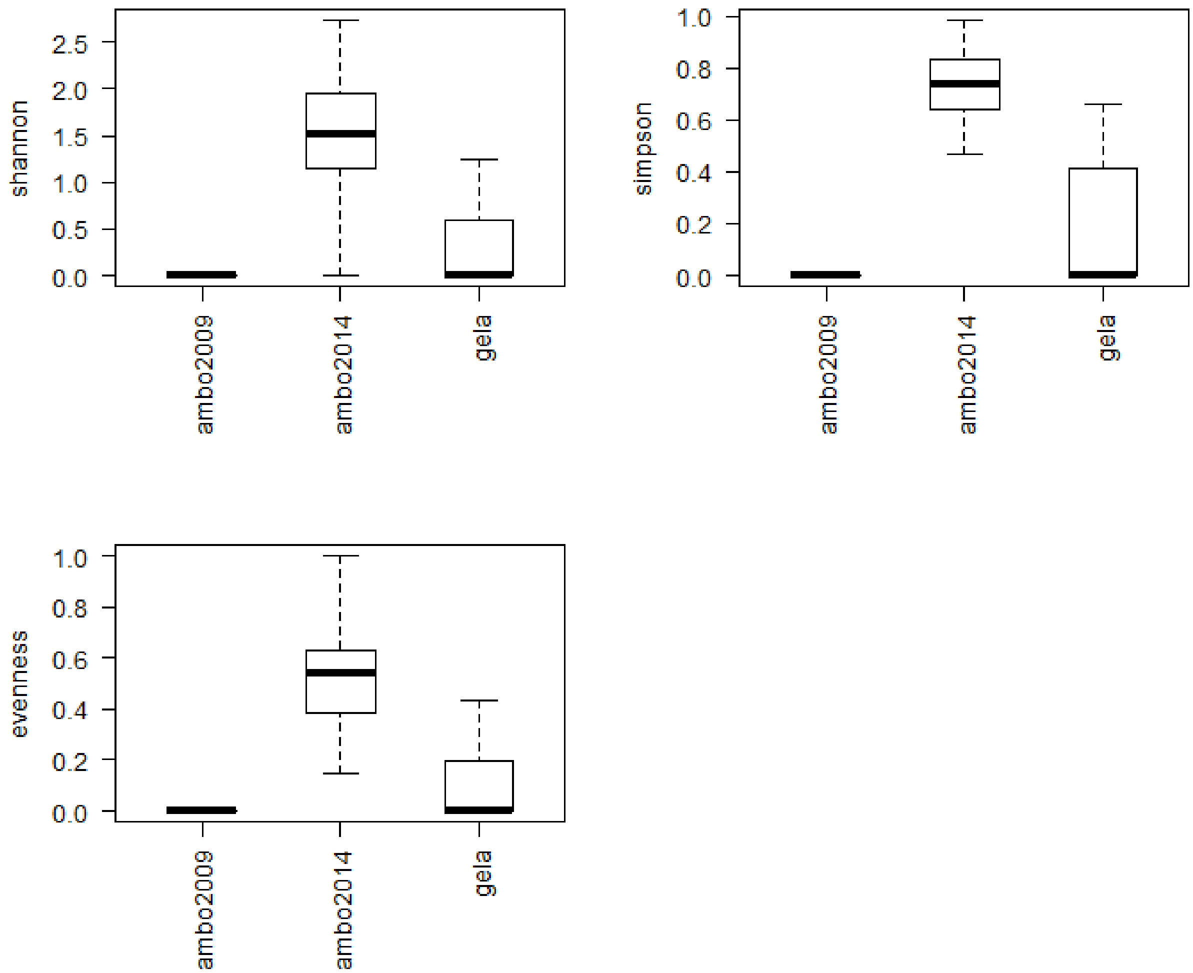


Figure 17: Species composition of across study sites

As the results showed, in Amobober, 2014 (after exclosure) 5 years old, there was highly significant differences from Ambober, 2009 (before exclosure) and Gelawdiows exclosure 2 years old, with Shannon index, Simpson and evenness of the species. However between Ambober, 2009 and Gelawdiows there was no significant difference (Table 11 and Figure 17).

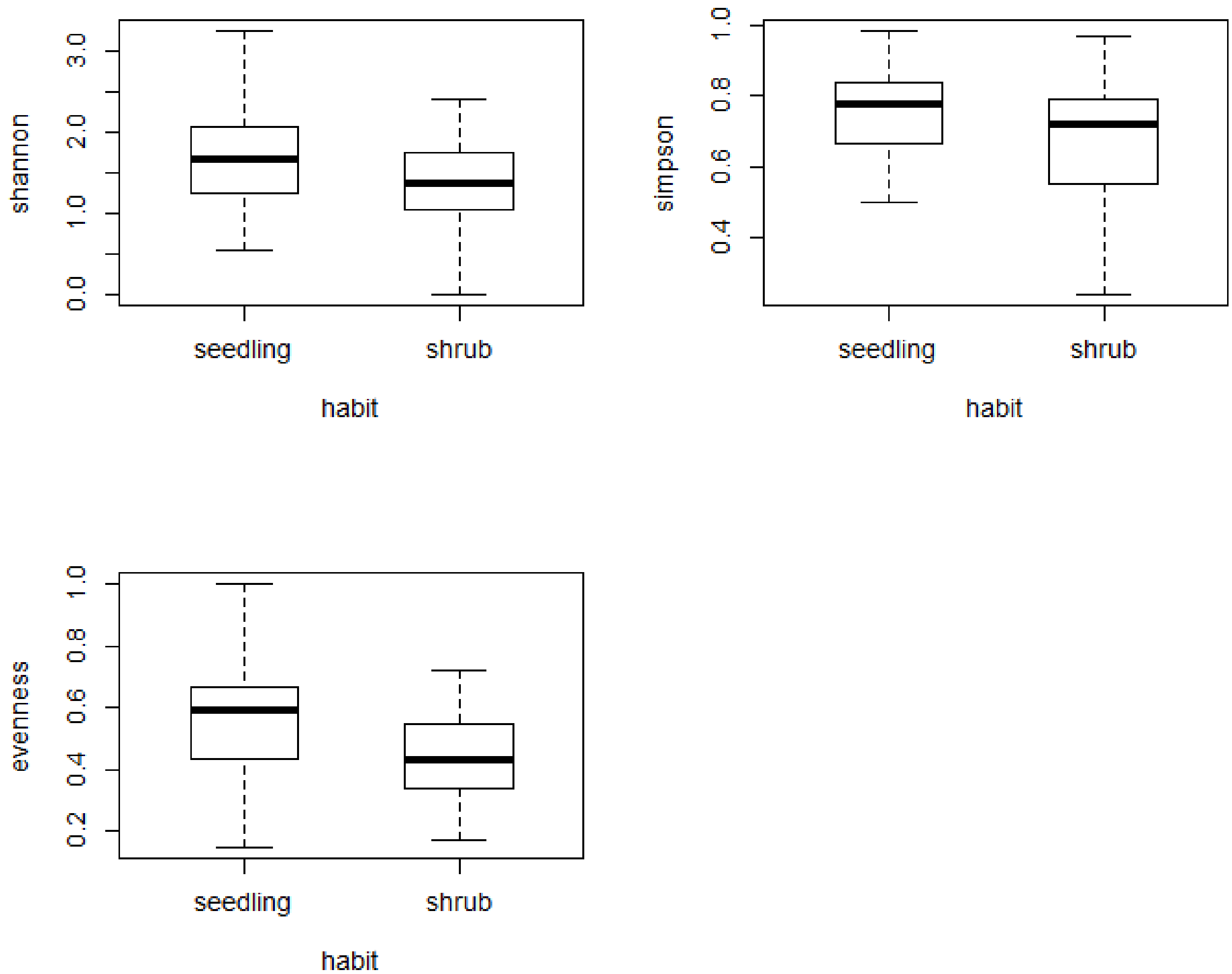


Figure 18: Species composition of Ambober, 2014 area exclosure.

According to the analysis result in Ambober, 2014 the Shannon index and Simpson index show that there is no significant difference in species diversity among shrubs and seedlings. Additionally, the evenness index shows that there is no significant difference in the distribution of shrubs and seedlings (Table 11 and Figure 18).

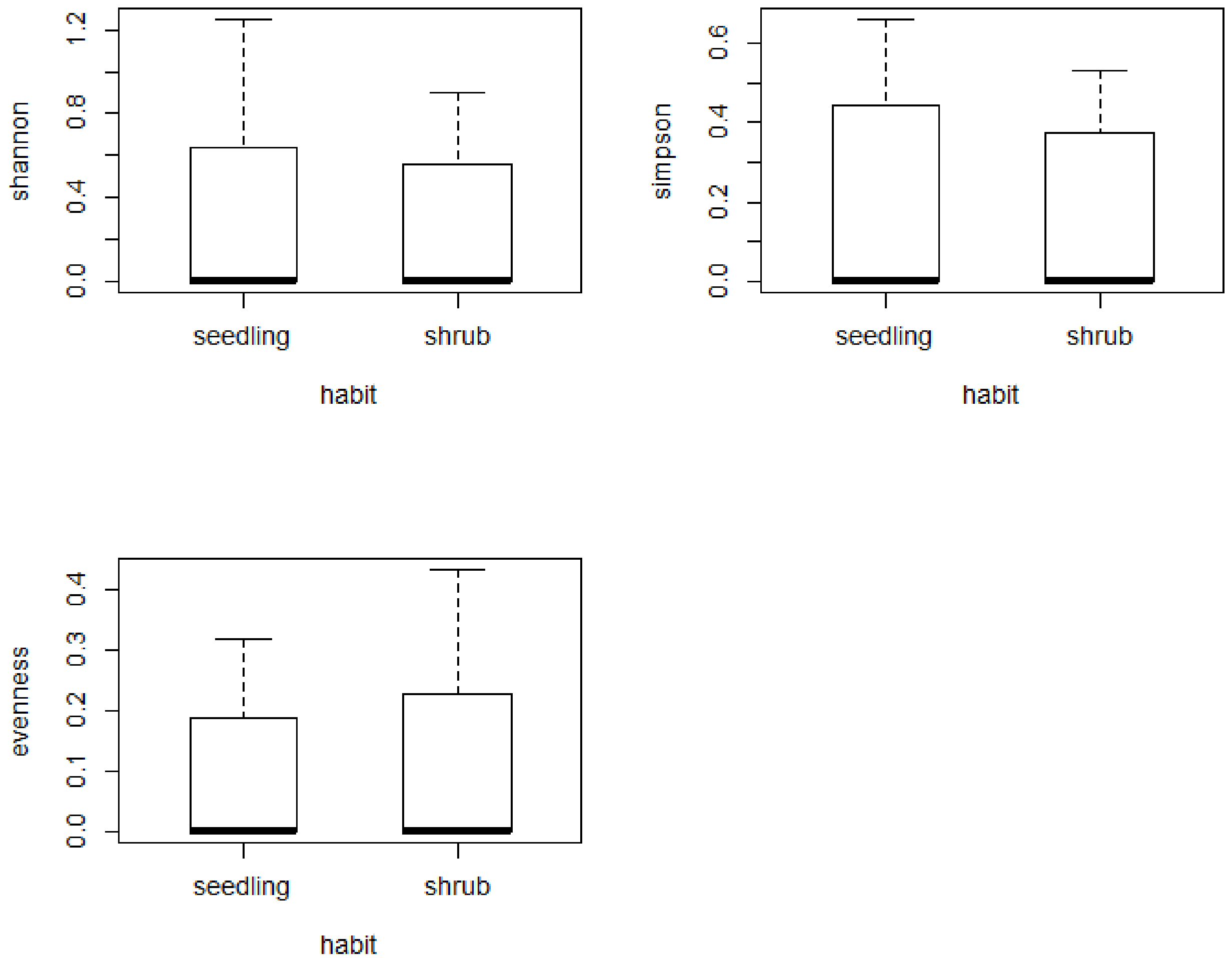


Figure 19: Species composition of Gelawdiows

According to the Shannon index value, there is no significant difference between the shrubs and the seedling species diversity. Moreover, the box plot shows the similarity of the shrubs and seedlings diversity. Similarly, in Simpson diversity index there is no significant difference between shrubs and seedlings. The evenness index value shows that shrubs and seedlings are similarly distributed within the Gelawdiows exclosure (Table 11 and Figure 19).

6. DISCUSSIONS

6.1 Biomass

6.1.1 Shrub/tree characteristics

Communal forestlands are poor in there forest species composition, aboveground biomass storage and other forest ecosystem services due to frequent free grazing and human interference (Mekuria, 2013). Area exclosure is an important method to restore and rehabilitate the degraded grazing land and hill sides, to increase fertility and productivity of the soil in Ethiopia (Tefera et al., 2005; Ajit Kumar Banerjee, 1989). Ambober and Gelawdiows are the areas where this study took place and are the two out of many area exclosure found in the Amhara region. The study showed that the numbers of shrub/tree species in these area exclosure were low at larger diameter classes and there were higher numbers of shrub/tree species at lower diameter classes (Figure 8). This result might be due to its early stage of rehabilitation.

Plant species richness, diversity and above ground biomass increased with increasing age of the exclosure. The younger area exclosure (Gelawdiows) was dominated by grass and the old area exclosure (Ambober, 2014) was dominated by shrubs and trees. This shows the great contributions of exclosure to increasing the biomass accumulation and carbon stock potential of the area (Mekuria, 2013).In our investigation, there was a strong increase of plant species, diversity, biomass and carbon stock during the last five years Ambober, 2014 enclosed area compared to Gelawdiows two years enclosed area and Ambober, 2009 the beginning of the area closure establishment (Table 5 and Figure 11).

The study result showed that the small number of trees/shrub with bigger diameter contributed more to above ground biomass than many tree/shrub individuals with smaller diameter (Figure 10). This implies that trees with smaller diameter have lower carbon sequestrating ability in compare with the larger diameter tree. Similar findings were reported by Brown et al., 1989, Chaturvedi et al., 2012, K. Giday et al., 2013 and Bekele, 2014. However, due to their fast growing rate young trees can have greater carbon sequestration potential than the older ones (Losi et al., 2003).

The average biomass in Ambober, 2014 was (3.85-10.01 ton/ha), which was higher than in Ambober, 2009 (0.007-0.099 ton/ha) and Gelawdiows (0.063-0.289 ton/ha). The variation is perhaps due to the considerable difference in the presence age of the exclosure and densities of the shrubs/trees. Hence, the density was 3501 shrub/tree per ha in Ambober, 2014, 2913 shrub/tree per ha in Ambober, 2009 and 220 shrub/tree per ha in Gelawdiows exclosure sites.

It is possible to suggest that the more protected bush lands could enhance the ecosystem and have high biomass or carbon stock. However in Ambober, 2009 there were higher densities than Gelawdiows but Gelawdiows had higher biomass because in Ambober, 2009 the shrubs/trees have smaller RCD measurements. Therefore, RCD and age of the exclosure were perhaps the main reasons for variation biomass of measured between the exclosure sites.

6.1.2 Above ground biomass and carbon stock estimation

To estimate above ground biomass of shrubs/trees allometric equation were selected from different literatures using family and agro-ecology data of the shrubs /trees and comparing the equations, From 57 plots 37 species were obtained and the species were grouped in to 16 families. From the literature, 5 different equations were selected and again compared to each other based on correlation of biomass and RCD.

Three factors determined the equations selected for this study. Firstly, the selected equations were developed for shrub and tree species and this study is also involves shrubs and the small trees. Secondly, to estimate the biomass, the following measurements were used: diameter at stump height (DSH), Diameter at 30 cm (D_{30}) and Diameter at 40 cm (d_{40}): this study also measured diameter. The third reason was that some of the equations were developed for area exclosure and the sites of this study were also at area exclosures.

A,B,C equations were developed by Guy Parent (2000) for woody biomass inventory for some tree and shrub species in Dry Kolla, Moist Wet kolla, Moist Weyna Dega and Dry Weyna Dega agro-ecological zone of Ethiopia and by (Cleemput et al., 2013), Biomass estimation techniques for exclosure in semi-arid area north Ethiopia (Table 1).

D equation was developed by (Negash et al., 2013b). This allometric equations was for estimating above ground biomass of coffee Arabica L. grown in the rift valley escarpment of Ethiopia. E equation was developed by (K. Giday et al., 2013), for woody biomass functions for

Acacia Abyssinica trees and shrubs and for implications of provision of ecosystem services in community management exclosure in Tigray, Ethiopia (Table 1).

In general, most of the equations were developed for small tree and shrub species biomass calculation. Diameter is calibrated at stump height and the equations also utilized 5, 10 and 11 years area closure sites (Giday et al. and Cleemput et al., 2013). This is the reason to select the equations/models from those studies to use in our study to estimate the biomass and carbon stock.

Using the five equations or models to estimating biomass or carbon stock from the different age of the area exclosure study sites exhibited different results. Above ground biomass from the total area of 19 ha Ambober, 2014 area exclosure using model B gave a value of 190.11 tons which was the highest estimate. The second highest estimate was from model A at 137 tons, the middle estimate were 107.36 and 106.10 tons from by models C and D, respectively and the lowest estimated value was from model E at 73.26 tons within 5 years enclosed area.

In Ambober, 2009 from the total area of 19 ha, data measured at the beginning of area exclosure establishment was 0.14-1.89 tons of biomass. The estimated biomass and from the total area 15 ha Gelawdiows area exclosure was 0.94-4.34 tons within 2 years enclosed with different five models

The results show that different ages of the area exclosure have different biomass amounts. Ambober, 2014 (five years age) and Ambober 2009 (during beginning of the area exclosure establishment) are similar sites and have similar total area but the difference is the age of the site. For this reason Ambober, 2014 had the highest estimated biomass. Gelawdiows (two years age) had the second highest biomass estimate followed and the lowest estimated biomass was from Ambober, 2009 in all models (Figure 11, Table 5). The study by Mekuria, (2013) investigated similar results from area exclosures in the low lands of northern Tigray, Ethiopia.

Above ground biomass results reported by Mekuria (2013) were 0.448 ton/ha , Cleemput et al., (2013) reported 1.84 ton/ha while Ubuy et al., (2014) reported 2.0 ton/ha in 5, 10 and 11 years enclosure area in lowland and semi-arid area of north Ethiopia. Those investigation compared to our study result have significant difference. This means using models A, B, C ,D and E have high biomass obtained compared to Mekuria, (2013); Cleemput et al., (2013); Ubuy et al., (2014) their results of biomass investigations. By K Giday et al., (2013) studied enclosed wood Acacia and shrubs area for 11 years were estimated above ground biomass to be 25.4 ton /ha. Whereas, from our study, 5 years enclosed area estimated 10.01 ton/ha using model B. Model A gave a result of 7.22 ton/ha as estimation. Model C gave a result of 5.65 while model D result was 5.58 ton/ha estimated and the lowest estimated value was 3.85 ton/ha.

Moreover, the variation of above ground biomass between the exclosure sites was dependent on stand structure, species composition, topography, altitude and the main reason was the age of enclosed of the area and the RCD (big or small) of the shrub/tree.

6.1.3 Comparing of species family biomass with different models

Figure 10 illustrated how different above ground diameter measurements affect the biomass of a shrub/tree. In the *Fabaceae* family, the five allometric equations showed different biomass values in relation to diameter. Equation B showed the highest /sharp biomass value and this value followed by equation A, whereas equation C showed the lowest result. However, the biomass result of equation D and E were found to be the mean of the five allometric equations. Similarly, for *Euphorbiacea*, *Lameaceae*, *and Anacardiacea* families, equation B showed highest /sharp biomass value and was followed in second by equation A, whereas equation C showed the lowest result. Still equations D and E were found to be the mean the five allometric equations.

For *Asteraceae* family equations C and B showed high performance compared to the other equations, equation A has showed middle performance, and equations E and D were lower.

For *Apocynaceae* and *sapindaceae* families all 5 methods showed similar results regarding the shrubs/trees with a small dimeter (RCD). With an increasing diameter, the deviation between the results of each method as well as the deviation between the different methods enlarged.

Generally, almost all families, equation E showed the lowest value at small diameter classes of family shrub/tree species, however for all families the diameter of the species increased at the same time the above ground biomass also increased.

6.2 Diversity

6.2.1 Species diversity and composition

Shrub/tree species composition of vegetation might be showed as species abundance, richness and life form (Tefera et al., 2005). In this study, a total of 37 shrub/tree species, excluding herbs and climbers, were identified in Ambober and Gelawdiows study site. These species represent 16 families. Among them, the highest numbers of species were found at Ambober study site. In Ambober, 2014, 33 number species was identified. However, before enclosure (Ambober, 2009) only 6 species was recorded.

The two area enclosures Ambober and Gelawdiows have significantly different tree and shrub species composition. In comparing the shrub/tree diversity and total number of Ambober in two different season of 2009 and 2014 there is a clear difference in species and tree composition.This indicated how much free grazing and human intervention influenced tree generation, species composition and richness of the area (Mekuria, 2013).

Species diversity measure indices show the diversity of an ecological community that includes both species richness and the evenness of species' abundances (Whittaker et al., 2005). The species diversity measures were analyzed by using Shannon and Simpson diversity indices and species distribution was also analyzed by an evenness index. Accordingly, in overall species diversity, Ambober had the highest species diversity in both indices and also in the evenness index.

7. CONCLUSION AND RECOMMENDATION

Through sustainable management of forests including restoration of degraded land by natural regeneration (area closure) and artificially (planting seedling) can be done to increase the biomass/carbon stock to capture and decrease the concentration of CO2.

At the beginning of the establishment of the exclosure shrub/tree plants were highly browsed low exhibiting species diversity and had small diameters. Our study result showed significant increases of the vegetation cover, composition and diversity of shrubs and trees of the area exclosure. Area exclosure is very important for restoration and to generate the indigenous tree species in the degraded land. In our study sites, we observed indigenous tree at seedling (regeneration) stage (Olea *europeana*, *Croton macrostachyus* and *Carissa spinarum*).

In this study of non-destructive methods and the parameter from forest inventory root collar diameter (RCD) was used for estimation of above ground biomass of shrub/tree in the area exclosure study sites. The estimation of biomass and carbon stocks can help with the future development of integrated planning for the area exclosure in the region. In this study, biomass was accumulated in the 19 ha area exclosure of Ambober, was 73.26-190.11 ton and within 5 years enclosed and in the 15 ha area exclosure of Gelawdiows 0.94-4.34 ton within 2 years enclosed.

This is the first study of, biomass /carbon stock of shrubs/trees species estimated in area closure in north Gonder, Amhara region. However, in Tigray region some biomass function/equation was developed, which estimated for woody tree and shrub species in area closures. It may be possible to use the developed allometric function (equation) with the similar site and stand characteristics but the validation is important. Further studies are needed to confirm our study or the five models we used and to predict above-ground biomass of shrub species for different age of area closure and agro-ecology in north Gonder, Amhara region.

8. REFERENCE

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12. LIST OF ABBREVIATIONS

ARARI	Amhara region agricultural research institute
A	Area
BT	Total above ground biomass
b1, b0	Coefficient
DSH	Diameter at Stump Height
D15	Diameter at 15cm
D30	Diameter at 30cm
^0C	Degree centigrade
DW	Dry weight
D40	Diameter at 40 cm
H	Height
Max.	Maximum
Min.	Minimum
Cm	Centimeter
m	Meter
mm	millimeter
masl	Meter above sea level
km	Kilometre
ha	hectare
RCD	Root Collar Diameter

TDW	Total dry weight
Totwt	Total dry weight
Y	Dry weight mass
N	number of plot
N/ha	number of stems per hectare
AGB	Above Ground Biomass
Ton/ha	ton per hectare

13. APPENDIX

Appendix 1: List of shrubs/trees species recorded in the study area.

No.	Local name	Scientific name	Family	Habit
1	Bazra girar	*Acacia abyssinica*	*Fabaceae*	tree
2	Mimosa	*Acacia decurence*	*Fabaceae*	tree
3	Akacha saligna	*Acacia saligna*	*Fabaceae*	tree
4	Kusheshile	*Acanthus sennii*	*Acanthaceae*	shrub
5	Embs	*Allophzlus abyssinicus*	*Sapindaceae*	tree
6	Azamir	*Bersama abyssinica*	*Melianthaceae*	tree
7	Yergib-ater	*Cajanus cajan*	*Fabaceae*	shrub
8	Digita	*Calpurnia aurea*	*Fabaceae*	shrub
9	Agam	*Carissa spinarum*	*Apocynaceae*	tree
10	Tree lucerne	*Chamaecztisus proliferus*	*Fabaceae*	shrub
11	Fiyelfeji	*Clutia abyssinica*	*Euphorbiaceae*	shrub
12	Avallo	*Combretum molle*	*Combretaceae*	tree
13	Bsana	*Croton macrostachyus*	*Euphorbiaceae*	tree
14	Kitkita	*Dodonaea angustifolia*	*Sapindaceae*	shrub
15	Kenteftefa	*Entada abyssinica*	*Fabaceae*	shrub
16	shibaha	*Ficus thonningii*	*Moraceae*	tree
17	Lenkotie	*Grewia ferruginea*	*Malvaceae*	tree
18	Amja	*Hypericum quartinianum*	*Hypericaceae*	shrub
19	Msrich	*Ilex mitis*	*Aquifoliaceae*	tree
20	Tembelel	*Jasminum abyssinicum*	*Oleaceae*	shrub
21	Atat	*Maytenus arbutifolia*	*Celastraceae*	shrub
22	Kechemo	*Myrsine africana*	*Primulaceae*	tree
23	Weyra	*Olea europeana*	*Oleaceae*	tree
24	Keret	*Osyris quadripartita*	*Lamiaceae*	shrub
25	Tinjut	*Otostegia integrifolia*	*Lamiaceae*	shrub
26	Endod	*Phytolacca dodecandra*	*Phytolaccaceae*	shrub
27	Checho	*Premna schimperi*	*Lamiaceae*	shrub

28	Embs	*Rhus glutinosa*	*Anacardiaceae*	tree
29	Kimo	*Rhus vulgaris*	*Anacardiaceae*	tree
30	Kega	*Rosa abyssinica*	*Rosaceae*	shrub
31	Embacho	*Rumex nervosus*	*Polygonaceae*	shrub
32	Kundo-berberie	*Schinus molle*	*Anacardiaceae*	tree
33	Serk-abeba	*Senna didymobotrya*	*Fabaceae*	shrub
34	Bisbisha	*Senna singueana*	*Fabaceae*	shrub
35	Didiya	*vernonia sp.*	*Asteraceae*	shrub

Appendix 2: Species family biomass with five equations across study site sample plot.

Species family	Models/Equations	Biomass(ton/ha)		
		Ambober,2014	Ambober,2009	Gelawdiows
Fabaceae	A;Y=(-0.5385*DSH)+ (0.5341*(DSH exp1.6))	1.796		
	B; Y=(0.9511*DSH)+ (0.0295*(DSH exp2.4))	3.539		
	C; Y=230.98*(D30^(1.47)	1.279		
	D; $Y=b1d^2_{40}$, b1(0.147)	1.613		
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	1.052		
Apocynaceae	A; Y=(0.0345*DSH)+ (0.0377*(DSH exp3.3))	0.244		
	B; Y=(0.1788*DSH)+ (0.0319*(DSH exp2.6))	0.182		
	C; Y=(0.3658*DSH) +(0.1144*(DSH exp2.2))	0.397		
	D; $Y=b1d^2_{40}$, b1(0.147)	0.213		
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.105		
Euphorbiaceae	A; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	1.983	0.01	0.015
	B; Y=(0.2972*DSH)+ (0.1588*(DSH exp2.2))	2.40	0.01	0.015
	C; Y=(0.3679*DSH)+ (0.0459*(DSH exp2.5))	1.167	0.008	0.012

	D; $Y=b1d^2_{40}$, b1(0.147)	1.226	0.005	0.006
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	1.186	0.001	0.002
Sapindaceae	A; Y=(0.3989*DSH)+ (0.0126*(DSH exp2.9))	0.874	0.01	
	B; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.968	0.011	
	C; Y=(0.2313*DSH)+ (0.1073*(DSH exp2.0))	0.964	0.019	
	D; $Y=b1d^2_{40}$, b1(0.147)	0.794	0.019	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.453	0.003	
Lamiaceae	A; Y=(0.3989*DSH)+ (0.0126*(DSH exp2.9))	0.683	0.006	0.003
	B; Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	0.853	0.011	0.002
	C; Y=45.80*(D30^(2.26))	0.245	0.004	0.000
	D; $Y=b1d^2_{40}$, b1(0.147)	0.585	0.018	0.001
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.308	0.002	0.000
Anacardiaceae	A; Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	0.142	0.008	
	B; Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	0.222	0.055	
	C; Y=(0.0884*DSH)+ (0.0331*(DSH exp2.8))	0.073	0.002	
	D; $Y=b1d^2_{40}$, b1(0.147)	0.094	0.009	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.050	0.001	
Rosaceae	A; Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	0.092		
	B; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	0.069		
	C; Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	0.057		

	D; $Y=b1d^2_{40}$, b1(0.147)	0.038	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.020	
Asteraceae	A; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.805	0.006
	B; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	1.141	0.012
	C; Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	1.036	0.008
	D; $Y=b1d^2_{40}$, b1(0.147)	0.677	0.011
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.459	0.002
Celastraceae	A; Y=(0.2685*DSH)+ (0.0492*(DSH exp2.3))	0.046	0.001
	B; Y=(0.1317*DSH)+ (0.1075*(DSH exp2.4))	0.066	0.001
	C; Y=(0.2451*DSH)+ (0.0271*(DSH exp2.6))	0.04	0.001
	D; $Y=b1d^2_{40}$, b1(0.147)	0.044	0.001
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.028	0.000
Oleaceae	A; Y=(0.6806*DSH)+ (0.0422*(DSH exp2.7))	0.329	
	B; Y=(0.1517*DSH)+ (0.1518*(DSH exp2.3))	0.293	
	C; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.193	
	D; $Y=b1d^2_{40}$, b1(0.147)	0.157	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.109	
Primulaceae	A; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	0.016	
	B; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.011	
	C; Y=(0.1517*DSH)+ (0.1518*(DSH exp2.3))	0.015	

	D; $Y=b1d^{2}_{40}$, b1(0.147)=	0.008	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.004	
Polygonaceae	A; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	0.107	
	B; Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	0.14	
	C; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.073	
	D; $Y=b1d^{2}_{40}$, b1(0.147)	0.06	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.033	
Malvaceae	A; Y=(0.5983*DSH)+ (0.0017*(DSH exp3.7))	0.015	
	B; Y=(0.1532*DSH)+ (0.2018*(DSH exp1.9))	0.014	
	C; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	0.016	
	D; $Y=b1d^{2}_{40}$, b1(0.147)	0.008	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.003	
Combretaceae	A; Y=(0.0922*DSH)+ (0.1540*(DSH exp2.2))	0.029	0.063
	B; Y=(0.1135*DSH)+ (0.1140*(DSH exp2.3))	0.025	0.088
	C; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))	0.033	0.089
	D; $Y=b1d^{2}_{40}$, b1(0.147)	0.019	0.041
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.011	0.015
Melianthaceae	A; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))		0.129
	B; Y=(0.3658*DSH)+ (0.1144*(DSH exp2.2))		0.184
	C;Y= (0.1189*DSH) +(0.0011*(DSH exp4.0))		0.039

	D; $Y=b1d^{2}_{40}$, b1(0.147)		0.094
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827		0.046
Hypericaceae	A; Y=(0.3197*DSH)+ (0.0383*(DSH exp2.6))	0.01	
	B; Y=(0.0038*DSH)+ (0.6092*(DSH exp1.5))	0.02	
	C; Y=(0.0281*DSH)+ (0.1505*(DSH exp2.3))	0.011	
	D; $Y=b1d^{2}_{40}$, b1(0.147)	0.008	
	E; lnTDW= b0 + b1lnDSH, b0= -3.514, b1=2.827	0.003	