Universität für Bodenkultur Wien

Master Thesis

Biodiversity and Growth Rates of Natural Forests in the Amhara Region of Ethiopia

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Thesis submitted in partial fulfilment of the requirement for the degree of MSc Forest Sciences

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Vienna (BOKU), October 2015

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Acknowledgment

Thanks to God Almighty for the completion of this master's thesis. Foremost, I would like to express my deep gratitude to my supervisor, Univ. Prof. Dipl. Ing. Dr. Hubert Hasenauer for his continuous and unreserved support in keeping me on the track from the begging of data collection to the final full writes up. I am also grateful to Dipl.-Ing. Dr. Christopher Thurnher, for his patient explanation of statistical tools and his constant technical support. Thanks also go to Mr. Lukas Wojtosiszyn for his checking and managing quality in laboratory analysis of tee ring.

A very special thanks goes to Univ.Prof. Ph.D. Dr. Douglas L. Godbold for creating financial support to study at BOKU. Special thanks are given to the Institute of Silviculture and the Institute of Forest Ecology for building my theoretical and practical knowledge. I express my warm thanks to Ms. Lanz Eva and Ms. Gubo Sigrid for their support. In addition, I appreciate the Mountain Forestry graduate master students of 2013-2014.

I would like to thank you SARC, and ARARI for in giving me the chance to pursue my MSc and providing necessary vehicles for data collection. I would like to thank my colleagues Derbe wudu, Andualem Ayalew and Tigabu Aregawi who devoted their time in supporting data collection and covering my research activity when I was studying. During the period of two years, many friends helped to color my life; I have to acknowledge all Ethiopian colleagues, Tesfaye Teklehaymanot, Sibhatu Abera, Hadera Kahsay, Beyene Belay, Kibruyisfa Sisay, Gezehegn Getachewand Hodaddis Kasahun for their assistances in various aspects.

I would also like to thank my parents Gebrehana Habtie and Zaid haile for the support they provided me through my entire life and in particular, I must acknowledge all my sisters and best friend for whose encouragement.

Last but not least, I would like to thank the Austrian government and people for the financial assistance and their hospitality. I would also like to thank Oead for frequent and consistent support and follow up.

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 indirekt 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 groundling 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

This study has two major objectives: (1) to study tree and shrub diversity, composition, population structure, and regeneration states of four selected natural forest of Amhara region (2) to estimate and compare the growth rate of natural forest and plantation forests of Gelawdiwos natural and plantation forest and Metema natural forest. The study was conducted in the Amhara region. The data was collected using a circular plot area of 0.03ha and 0.07ha depending on the size of forest coverage. The species diversity, richness, and relative distribution were analyzed using Shannon - wiener, Simpson, and Evenness diversity indices. Sorensen's similarity coefficient was utilized to distinguish the similarity and dissimilarity among the study forests. Accordingly, in total 123 trees and shrubs species were identified in four study areas. The highest number of species identified in a study area was 47 species found in both Injibara and Tara Gedam. The overall diversity results across the study areas show that Tara Gedam forest has the highest diversity of the studied forests. Gelawdiwos, Injibara and Tara Gedam have shown a similarity in diversity which may be due to the geographical proximity and climatic zone similarity of the forests. In terms of density and basal area, Gelawdiwos forest has shown a higher stem number and basal area per hectare than other forests. However, Tara Gedam forests have shown a lower number of trees than other forests which indicates that the forest is highly disturbed. The result of the periodic increment shows that there is significant difference between the growth rate of Gelawdiwos and Metema natural forest, as well as between Gelawdiwos plantation forest and Metema natural forest. However, there is no significant difference between Gelawdiwos natural and plantation forest. According to the cross dating result, it is possible to estimate the growth rate of trees in Ethiopia, particularly the area having unimodal precipitation. However, this study conducted in specific area, therefore, further studies important in different part of Ethiopia to get better understanding on tree growth rate.

Keywords: diversity, gamma, similarity, regeneration, IVI, cross dating, growth rate, and PBAI

Zusammenfassung

Für diese Arbeit sind zwei Hauptziele definiert, (1) die Untersuchung der Baum – und Strauchvielfalt, Zusammensetzung, Populationsstruktur sowie des Regenerationsstatus von vier ausgewählten Waldgebieten der Amhara – Region und (2) eine Schätzung und ein Vergleich der Zuwachsraten zwischen naturbelassenen Wäldern und angelegten Wäldern in Gelawdiwos und Metema. Die Studie wurde in vier verschiedenen Gebieten der Amhara – Region durchgeführt. Die Daten wurden in einem Gebiet von 0,03 ha und 0,07 ha in Kreisflächen gesammelt – die Größe der gewählten Fläche war abhängig vom jeweiligen Baumbestand. Zur Analyse der Artenvielfalt, des Artenreichtums und der relativen Verteilung wurden Shannon Wiener-, Simpson- und Evenness – Diversitätsindizes herangezogen. Der Sorenson´ Ähnlichkeitskoeffizient wurde verwendet um die Ähnlichkeit bzw. Unterschiedlichkeit zwischen den Versuchsgebieten festzuhalten. Demnach konnten in den vier Studiengebieten insgesamt 123 Baum- und Straucharten identifiziert werden. Die höchste Zahl der vorkommenden Arten, 47, wurden in Injibara sowie in Tara Gedam gefunden. Die Gesamtergebnisse bezüglich Diversität zeigen, dass das Waldgebiet in Tara Gedam die höchste Artenvielfalt aufweist. Gelawdiwos, Injibara und Tara Gedam zeigten ein ähnliches Artenvorkommen, dies mag sowohl auf die geographische Nähe als auch auf ähnliche klimatische Bedingungen zurückzuführen sein. Gemessen an Dichte und Grundfläche weist der Wald in Gelawdiwos eine höhere Stammzahl pro Hektar als andere Waldflächen auf. In Tara Gedam wurde eine geringere Anzahl an Bäumen als in den Vergleichsgebieten festgestellt. Diese Tatsache lässt darauf schließen, dass der Wald stark gestört wurde. Das Ergebnis des periodischen Wachstums zeigt einen signifikanten Unterschied zwischen der Zuwachsrate in Gelawdiwos und Metema (naturbelassener Wald), ebenso zwischen dem angelegten Waldstück in Gelawdiwos und dem natürlichen Waldgebiet in Metema. Es gibt jedoch keinen signifikanten Unterschied zwischen dem naturbelassenen und dem angelegten Wald in Gelawdiwos. Nach dem Cross-Dating Ergebnis ist es möglich, die Wachstumsrate von Bäumen in Äthiopien, in der Region mit unimodalen Regenfällen, abzuschätzen. Um ein besseres Verständnis auf Baumwachstumsraten in anderen Regionen Äthiopiens zu erlangen sind weitere Studien wichtig.

Schlüsselwörter: Diversität, Gamma, Ähnlichkeit, Regeneration, IVI, Wachstumsrate, PBAI

1. INTRODUCTION

Ethiopia has an enormous richness of biological resources because of the variability of topography, soil and climate. The altitude of the country ranges from 110m below sea level, at the sink of kobar in the Afar region, to 4620 meters above sea level at the highest mountain, at Ras Dejen (Gurmessa et al., 2013). The altitudinal variability leads to the creation of different climatic regions as well as different soil types. These different topographic and climatic conditions gave rise to the development of a wide variety of flora and fauna. According to the IBC (Institute of Biodiversity Conservation) 2008 report, the estimated number of plant species in Ethiopia is between 6, 000-7,000, of which 780- 840 (12-13%) species are considered to be endemic in the country (Senbeta and Teketay, 2001).

However, these resources, including forests, are being destroyed at a threatening rate due to several factors. The main factors for the destruction of natural forests are the expansion of agricultural land and human settlement, a rise in land grabbing by global investors, and over-exploitation of resources for various purposes such as firewood, coal, construction materials, and timber (Zegeye et al., 2011). These factors are mainly caused by rapid population growth, weak government policy on forest management and policy, and lack of knowledge of forest management. Accordingly, Amhara Region has become one of the severely environmentally degraded parts of Ethiopia. (Zegeye et al., 2011). Currently, the remaining forest is mainly limited to areas around churches and other protected or inaccessible areas (Wassie et al., 2005). For instance, we studied forest Gelawdiwos, Injibara, Metema, and Tara Gedam are among the remnant forest.

In an effort to alleviate such losses, due attention is given to sustainable forest management. According to Boon, sustainability is development or use that meets the needs of the present without compromising the ability of future generations to meet their own needs (Boon, 1966). Thus, the main purpose of forest management is to prevent or stop further environmental degradation, in particular deforestation (Bellefontaine et al., 2000). In order to develop a sound sustainable management system it is fundamental to understand the diversity and dynamics of the forest. Important elements in this regard are knowledge of species diversity, composition structures, distribution, and growth rate of a given forest.

In Ethiopia, different biodiversity studies have been conducted to update the knowledge of plant diversity in the country. Some methods and techniques are effective, while others do not have detailed explanations and lack consistency. For instance, certain studies conducted in similar place have given different results due to the application of different sampling methods and techniques.

Ethiopia has very limited experience in estimating the rate of growth forest. These growth rate estimations were conducted by using data from satellite imagery and data from repeated measurements (permanent plot). Estimation of growth rate through satellite images was conducted by comparing the consecutive periods of above ground biomass data and converting a change of the two consecutive periods by applying a default conversion factor, a formula developed by IPCC-GPG (Intergovernmental Panel on Climate Change - Good Practice Guidance) 2003 (Takano et al., 2010). However, the results does not correspond and probably under estimate the existing growth rate (Yitebitu et al., 2010). For instance, the Belete Gera forest growth rate calculated by JICA (Japan International Cooperation Agency) was three times higher than the national stand growth rate estimated by the satellite image (Yitebitu et al., 2010). This information shows that the result of growth estimation varies by the method of estimation employed.

The second method of estimation is repeated measurement from permanent plot. This methods was unusual and only applied in a few plantations and natural forests by forest enterprises and research institutes (Bekele, 2000; Yitebitu et al., 2010).

Another method used to estimate forest growth rate is with dendrochronology, the analysis of tree rings. The word comes from the Greek word, Dendron mean tree while Chronology is the study of time. According to Fritts and Swetnaw, the discipline is most appropriately characterized as the systematic use of tree rings; “cross dating", a procedure that uses variability of ring characteristics to establish the exact year in which each ring was formed (Fritts and Swetnam, 1989). Dendrochronology has been applied in temperate and boreal regions, but has not been widely applied to tropical forests due to the assumption that all tropical trees lack annual rings (Worbes et al., 2003).

However, in arid and semi-arid regions of the tropics, where moisture is the limiting factor, annual rings may be apparent due to variation in precipitation between the rainy and dry seasons

(T. H G Wils et al., 2011; Worbes et al., 2003). In the dry season latewood forms due to gradual declination of the growth unit until cambial dormancy, this latewood which differs structurally from the early wood of the previous growing season (Worbes et al., 2003).

Therefore, successful cross dating studies have reported that for many species of tropical trees with a distinct and predictable dry season annual rings are visible (Eshete and Ståhl, 1999; T. H G Wils et al., 2011; Tommy H G Wils et al., 2011; Worbes et al., 2003). For instance, the result of cross dating research conducted in Ethiopia revealed that dendrochronology can be applied successfully in the region experiencing unimodal rainfall regime (T. H G Wils et al., 2011). Figure 1, below, shows a unimodal rainfall pattern in the western Amhara region(Open Street Map project, 2015).

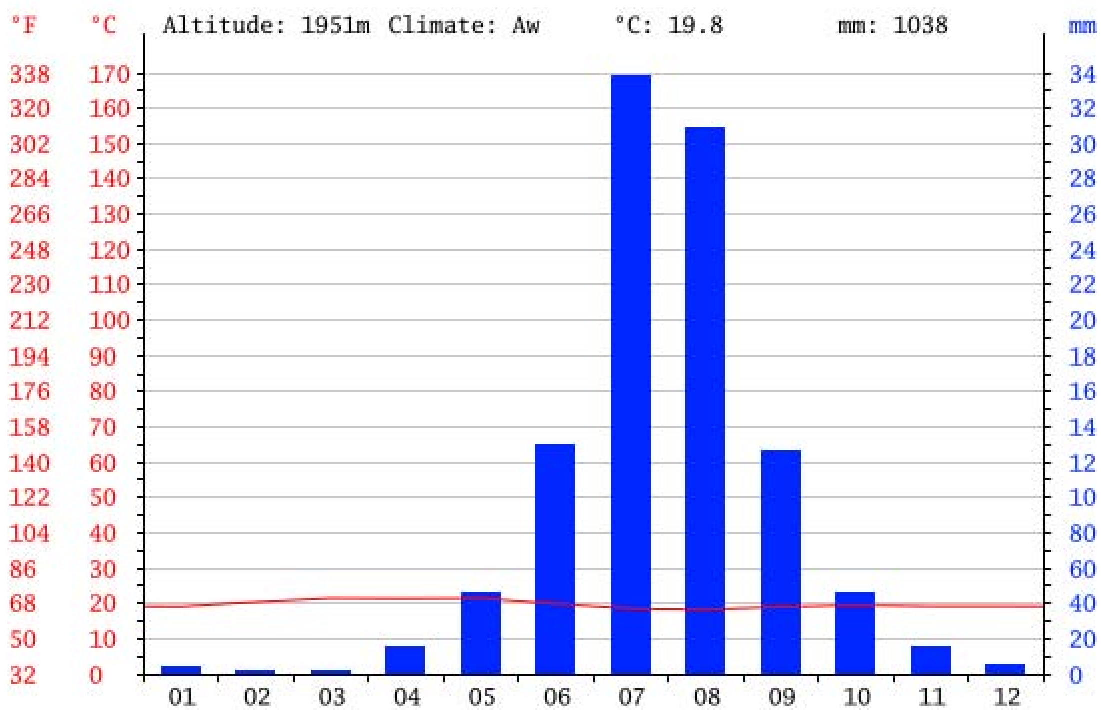

Figure 1: Typical climatic precipitation diagram from western Amhara region (Addis Zemen)

In Ethiopia, most cross dating studies focus on tree ring validation for a few trees and single tree base growth rate estimation. However, there is no published information that estimates the growth rate at forest stand level. Therefore, the findings of this study open the possibility to a broader application of forest growth analysis in natural and plantation forests of Ethiopia.

The studies were conducted in Amhara region on Gelawdiwos, Injibara, Metema and Tara Gedam natural forest and Gelawdiwos plantation forest. In the Amhara region, the study of natural forest biodiversity is not a new trend. Several forest biodiversity studies were conducted in a specific remnant natural forest of the region, but as described above, the forest growth rate has not been studied. Specifically, of our forest sites, diversity had been studied in Gelawdiwos, Metema and Tara Gedam but not in Injibara. For instance, the Gelawdiwos church forest has previously been studied before 10 years (Wassie et al., 2005). In particular the diversity of Metema church forest has not studied, but diversity and species distribution have been reported for the dry land of northwestern Amhara region(Mulat, 2013; Wale et al., 2012). In addition, the diversity and population structure of Tara Gedam has also been reported several times but the result of the studies were lacking consistency even if the study was conducted in similar periods (Gedefaw and Soromessa, 2014; Zegeye et al., 2011). Generally, there is no published study combining species diversity and growth rate of the forest at regional level.

Objectives and hypothesis

The main objective of this master thesis is to fill the existing knowledge gap, by providing current information about species diversity and growth rates of Amhara region forests. The specific objectives of the research are as follows:

- To investigate and document diversity, vegetation structure, composition, and natural regeneration status of four selected natural forests
- To distinguish the similarity and differences of four selected natural forests
- To estimate and compare the periodic basal area increment of selected natural and plantation forest of the Amhara region.

Hypothesis: The growth rate of plantation forest will be significantly greater than the growth rate of natural forest. Forests grow in similar agro ecology have similar tree and shrub species diversity.

2. DATA

2.1 Site description

The study was conducted in the Amhara region, which is located at 9°-14° N and 36°-40°E, in the northwest of Ethiopia. The region's area covers approximately 161,828.4 Sq.km. The topography of the region includes plains, valleys, plateaus, hills, and mountains. The altitude of the region ranges from 500 to 4620 meters high (ADS, 2012). The regions climatic zone changes greatly across the varying altitudes. Accordingly, the climate can be classified as such: dry and hot (Kola) tropical at ranges from 800-1830 masl, sub-tropical (Woina Dega) at ranges from 1830-2440 masl, temperate at ranges from 2440-3000 (Dega) masl, and alpine (Wurch) from 3000 masl (ADS, 2012).

The inventory in the four natural forests was carried out in the year 2014. These four forests were selected from the different agro-ecological zone, mainly based on altitudinal variations. Therefore, Gelawdiwos represents highland (Dega), Injibara and Tara Gedam represent midlevel (Woina Dega), and Metema (Metema) represents the lowland (kola) agro-ecological zone. Other than Injibara, the other three study sites belong to the Ethiopian Orthodox Tewahido church (EOTC) forests.

The four study area site descriptions are shown below in Table 1 while Figure 2 highlights their locations in the Amhara region.

Table 1: Site description and background information of the study sites

Region	Geographical location	Elevation (m a.s.l)	Mean annual Temperature (^{0}C)	Mean annual Rainfall (mm)	Soil type	Administrative Zone and woreda	Mean slope (^{0})	Area (ha)
Gelawdiwos	N11^{0}38’25” E:37^{0}48’55”	2466-2526	17	1200	Cambisols Andosols	South Gonder, Fogera	19	68
Injibara	N11^{0}0’05” E:36^{0}44’8”	2184-2231	15	2200	Acrisols	Awi, Injibara	19	553
Mahibere-Slase	N12^{0}32’20” E:36^{0}32’9”	835-880	19	965	Vertisols, Luvisols	North Gonder, Metema	16	1800
Tara Gedam	N12^{0}8’47” E:37^{0}44’45”	2200-2318	27	1000	Leptosol, Vertisol, Luvisol	South Gonder, Libokemkem	26	238

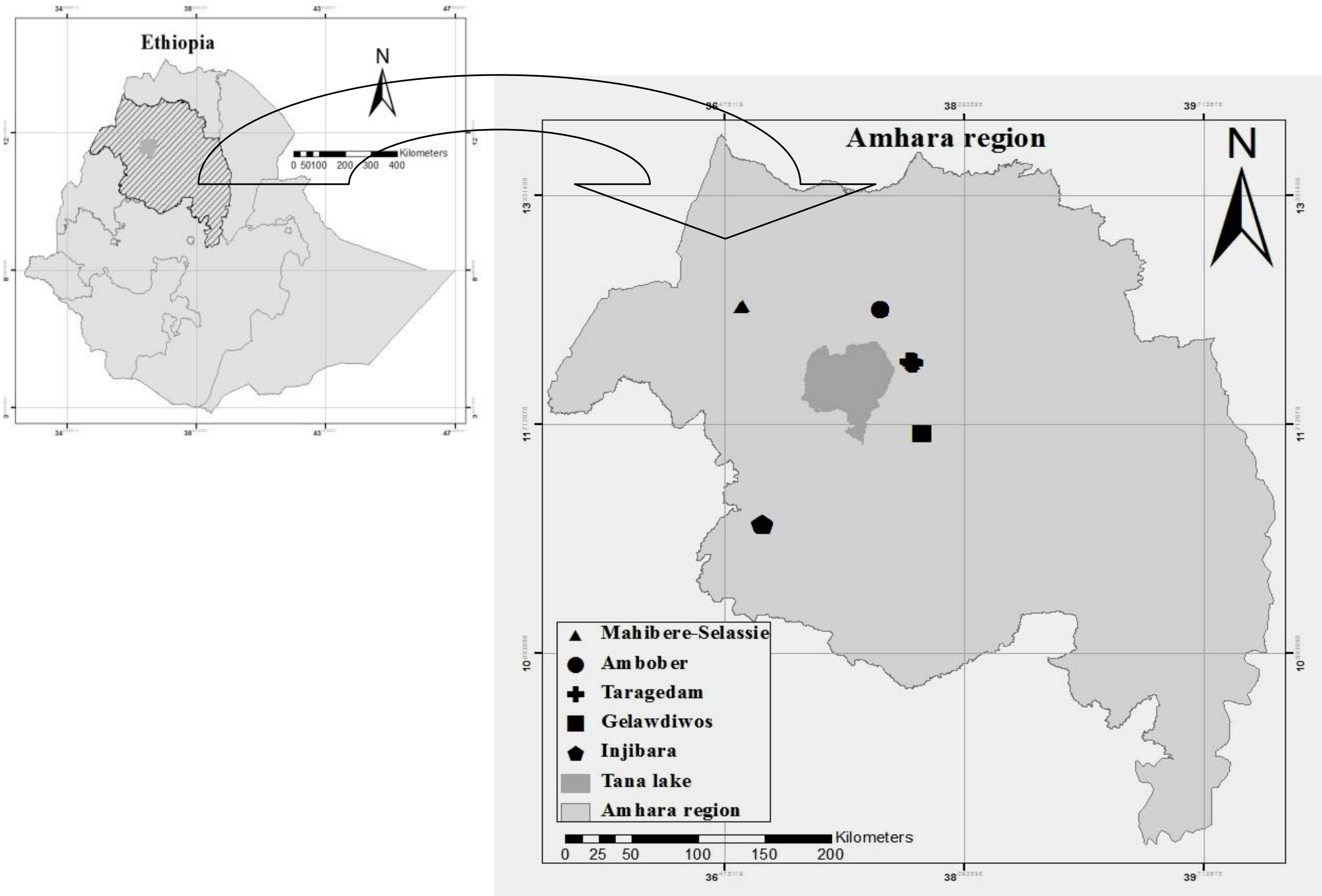

Figure 2: Location of Studies area across the Amhara region.

Figure 3: Gelawdiwos natural forest

Figure 4: Gelawdiwos plantation forest

Figure 5: Injibara natural forest

Figure 6: Metema dry land forest

Figure 7: Tara Gedam natural forest

2.2 Sample design

The sampling design used was systematic point sampling, which was adapted from the Austrian forest inventory design (Boon, 1966). The sample design of each natural forest consists of different number of plots depending on the size of the forest (Figure 4). The number of plots used in each forest was: Gelawdiwos 34, Injibara 63, Metema 21 and Tara Gedam 38. In addition, each sample was laid in different grid size depending on the area of the forest. The sample plots of Gelawdiwos, Injibara, Metema and Tara Gedam were located on the grid of 150m x 150m, 300m x 300m, 3000m x 3000m and 300m x 300m respectively.

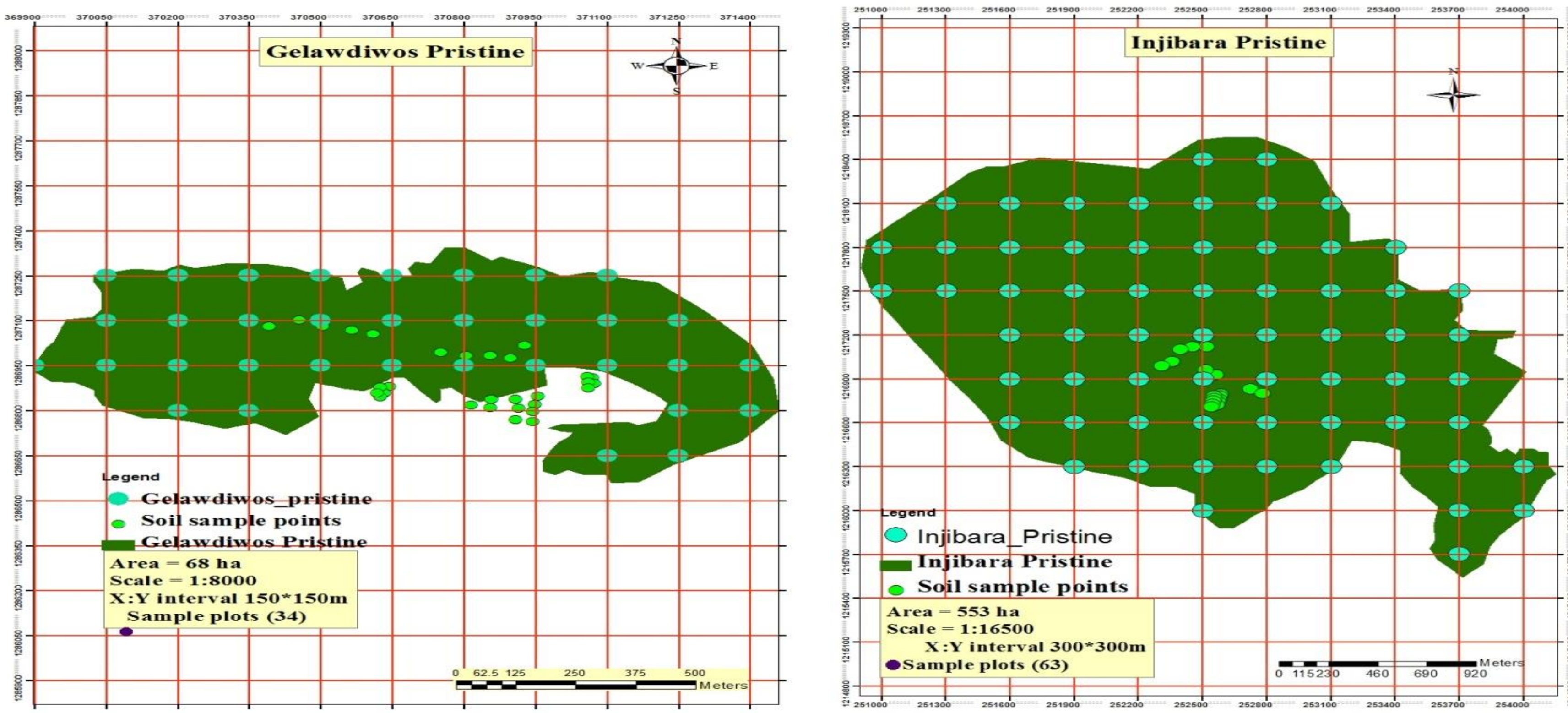

Figure 8: Sample plot distribution at Gelawdiwos and Injibara natural forest

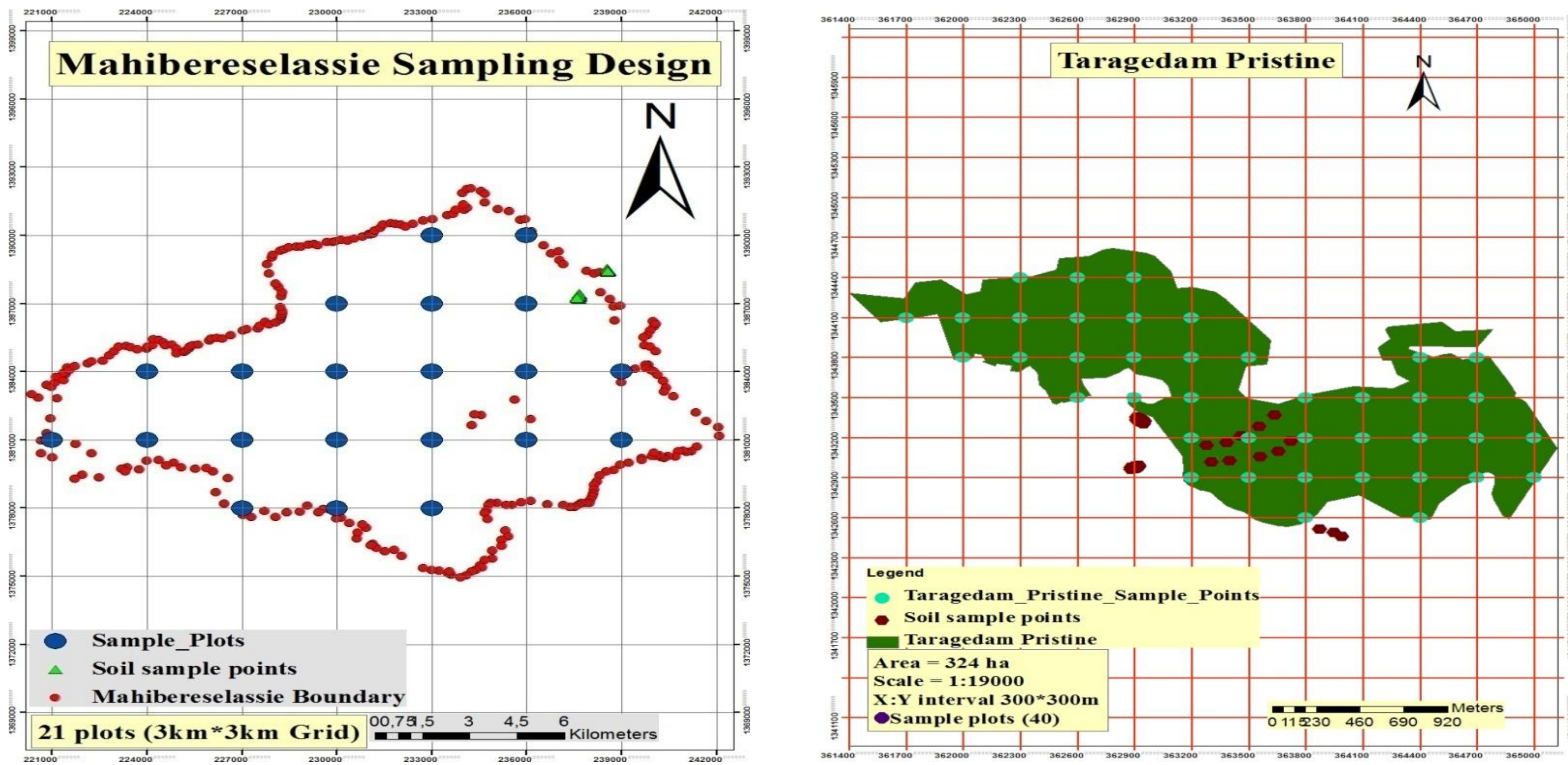

Figure 9: Sample plot distribution at Metema and Tara Gedam natural forest

2.2.1 Diversity

Circular plots with a radius of 10 m and an area 0.03 were used to Gelawdiwos and Tara Gedam and ha and 15 m with an area 0.07 ha were used to and Injibara and Metema, for a tree data DBH of 10 cm and above. Within the big circle, another radius of 5 m was used to collect sapling and shrub data (DBH below 10 cm and height above 1.5 m). Within the two circular plots, another rectangular cross 6m by 6m in length and 1m width plot were used for regeneration data (Figure 10). Tree data in the form of DBH, total height, height to live crown, crown width, azimuth, and horizontal distance from center from the plot were also recorded.

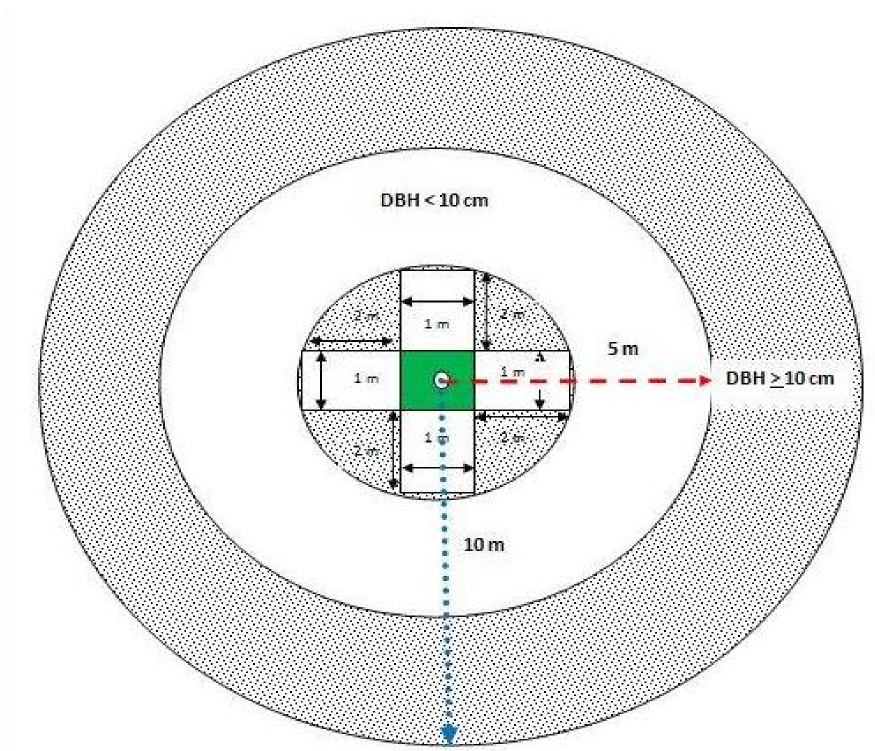

Figure 10. A schematic illustration of plot area

In the secondary plot, the data for saplings and shrubs that have DBH below 10 cm and height above 1.5 m were recorded. The data were taken by grouping the DBH class in the following range >4 cm, 5-6 cm and 7-9 cm, for each of these groupings one median height was recorded. In the last plot, the regeneration data was recorded. The data were recorded by counting and then grouping a sapling height below 50 cm and 50-130 cm. In these inventories, no herbaceous data were recorded. Apart from tree parameters information on topography, slope, aspect, liana load, disturbance in terms of grazing, cutting and other man-made activities were recorded.

Figure 11: Data collection of regenerated seedlings

Figure 12: Gelawdiwos data collection crew

2.2.2 Growth rate

The target trees were chosen from the main plots. For each tree species that is present in the main plot, the median of DBH trees was taken. However, the trees that have resin and very hard wood the increment core were not taken. The trees’ increment cores were taken at the breast height of the tree (1.3 meters above from the ground). After increment core samples were collected the samples were put in a tube and then in a paper bag which was labeled with tree information (tree and plot number and the name of tree species) (Figure 13).

Figure 13: Increment core data collection

2.3 Input data

2.3.1 Diversity

In total 1852 live and dead trees and shrubs were recorded in 170 main plots of which 1584 of the trees and shrubs were living. In Gelawdiwos, 341 trees and shrubs from 34 plots were recorded, 1042 in Injibara from 63 plots, and in Metema, 264 trees and shrubs from 21 plots Lastly, in Tara Gedam, 202 trees and shrubs from 52 plots were recorded.

The mean DBH of Gelawdiwos, Injibara, Metema and Tara Gedam were 22 cm, 22 cm, 19 cm and 21 cm respectively (Table 5).

In Gelawdiwos, the highest mean tree density was recorded at 308ha-1. In Tara Gedam, the mean tree density of 129ha-1 was the lowest recorded. In Injibara, the highest number of sapling per hectare was recorded at 3273 ha-1, this indicates that the forest is vulnerable to selective cutting and poachers. In Metema, the lowest mean number of sapling and seedlings were recorded (667 ha-1 and 655 ha-1, respectively). These low values are due to the elongated dry season and a harsh environment which negatively impact seedling and sampling survival (Figure 6).

In Gelawdiwos and Metema, the highest and the lowest basal area were recorded respectively. In Injibara, the highest number of mean dead trees per hectare was recorded. However, the greatest number of dead trees per hectare was obtained from Tara Gedam. As shown in Table 3, the lowest number of dead trees and shrubs was found in Gelawdiwos and Injibara. This indicates that these forests are in a relatively undisturbed condition.

Table 2: Mean, Minimum (min), Max (max) and standard deviation (Sd) of DBH, Density and Basal area of the forests

	Gelawdiwos (n=34)				Injibara (n=63)				Metema (n=21)				Tara Gedam (n=51)			
	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Mean tree DBH(cm)	22	108	10	17	22	143	10	17	19	50	10	8	21	114	10	13
Trees (Nha^{-1})	308	859	0	198	190	509	0	128	173	410	0	100	129	541	0	133
Sapling(Nha^{-1})	2404	11592	0	3291	1663	12537	0	2892	667	7412	0	3483	3273	16305	0	3870
Seedling(Nha^{-1})	8566	178333	0	48285	19841	98372	0	32805	655	35784	0	8579	1974	31667	0	7840
Basal Area (m^2ha^{-1})	20.05	59.5	1.3	14.54	12.25	53.57	0	10.45	6.61	12.45	0	3.3	6.68	58	0	9.5
Dead Trees (Nha^{-1})	11	95	0	22	35	240	0	52	5	28	0	9	14	318	0	51

2.3.2 Growth rate

This study estimated the growth rate of trees in natural and plantation forests in two regions. To do this, 326 increment core samples were collected. 118 core samples from Glawdiwos forest, 178 core samples from Mahibere, and 30 core samples from the plantation forest were collected (Table 3).

Table 3.Number of core by the region.

	Region	Number of species	Total core increment
1	Gelawdiwos	30	326
2	Metema	29	178
3	Gelawdiwos plantation forest	6	30
Sum		**65**	**326**

Plantation forest density

In total 358 trees with a DBH > 10 cm were counted. The average density of the forest was 570 tree per ha. The maximum density was 1814 trees per hectare. This indicates that forest is very thick and unmanaged. The forest is comprised of the following six species *Acacia decurrens, Croton acrostachyus, Eucalyptus globulus, Albizia gummifera, Eucalyptus camaldulensis,* and *Cupressus lusitanica.* The forest is dominated by *Cupressus lusitanica,* which covers 418.58 h^{-1} and shares 74% of total trees per hectare. *Eucalyptus globulus* comprises the second largest portion with120.96 h^{-1} and shares 21% of total trees per hectare. The remaining four tree species only made up 5% (Table 4).

Table 4: Contribution of species for density

species	Density (h^{-1})
Acacia decurrens	11.14
Croton acrostachyus	4.77
Eucalyptus globulus	7.96
Albizia gummifera	120.96
Eucalyptus camaldulensis	6.37
Cupressus lusitanica	418.58
Sum	570

3. METHOD

3.1 Diversity

By using fixed area-sampling techniques it was possible to calculate basal area, number of trees, and mean DBH, for each of the regions(Boon, 1966). Tree species in the forest were analyzed and for each plot mean, minimum and maximum DBH were also calculated.

Each region's species diversity was assessed at gamma diversity (diversity of species at region level) and alpha (species diversity at sample unit level) diversity level. The diversity of the regions was calculated using Shannon, Simpson and Evenness diversity indices. To assess the similarity and dissimilarity between the regions, Sorensen's similarity was applied.

Shannon - Wiener diversity index is the most accepted measure of biodiversity since it accounts for biodiversity and evenness and it is not affected by the sample size (Krebs, 2014). Shannon-Wiener diversity index was calculated as follows.

$$\boldsymbol{H' = -\sum_{i=0}^{s} Pi \ln Pi} \qquad 1$$

Equation 1: Shannon - Wiener diversity index

Where,

H' = Shannon diversity index,

S= the number of species,

P*i*= the proportion of individuals or the abundance of the *i* th species expressed as a proportion of total cover

Ln = log base n

Evenness (Equitability)

"Species evenness is a measure of the relative aboundance of the different species making up the richness of an area". Species evenness can be mathematically described as follow:

$$J = \frac{H'}{ln\ s} \qquad 2$$

Equation 2: Shannon Evenness index

Where,

J = Evenness,

H'= Shannon-Wiener diversity index and

S = the number of species.

Simpson Index

Simpson's Diversity Index is used to determine diversity and it considers the number of species present as well as the relative abundance of each species (Centre, 2013)

$$\mathbf{D} = \frac{1}{\sum_{i=1}^{s} Pi^2} \qquad 3$$

Equation 3: Simpson index

Where,

D = Simpson diversity index

P*i*= the proportion of individuals or the abundance of the *i* th species expressed as a proportion of total cover

Sorensen's

Sorensen's similarity index is used to measure the similarity in species composition of the four natural forests. It is described using the following formula (Kent and Coker, 1992).

$$SS = \frac{2a}{2a+b+c} \qquad 4$$

Equation 4: Sorensen's similarity coefficient

Where,

SS= Sorensen's similarity coefficient

a = Number of species common to both samples;

b = Number of species in sample 1;

c = Number of species in sample 2

Important Value Index (IVI)

Importance value index (IVI) was computed by summing up relative frequency (RF), relative density (RD), and relative dominance (RDO) values. It is described using the following formula.

$$\boldsymbol{IVI_I = \left[\frac{B_i}{\sum_j^n \mathrm{B_j}} x100\right] + \left[\frac{n_i}{\sum_j^n \mathrm{n_j}} x100\right] + \left[\frac{f_i}{\sum_j^n \mathrm{f_j}} x100\right]} \qquad \mathbf{5}$$

Equation 5: Important value index

Where:

- IVI_i= the Importance Value Index (IVI) of the i^{th} species
- n_i= the number of individuals of the i^{th}
- species; n_j = the sum of individual trees of all species
- Bi= the basal area of the i^{th}
- species; B_j= the total basal area (m^2) of all specie
- f_i= the absolute frequency of the i^{th}
- species; f_j = the total sum of the absolute frequencies of all species

Statistical tests were conducted using R software and Microsoft Excel.

3.2 Growth rate

The laboratory work started by immersing the core sample into one spun soda solution containing water for ten minutes, to increase the workability of the core increment (Figure 14).Next, the moist samples were put on an increment core holder which is used to handle the core and assemble broken core samples (Figure 15). After the core sample is inserted into the core holder the blade slices the core to make the tree rings visible and to smoothe sample. If the core was still not visible at this stage, the core was brushed with 10% sodium hydroxide (NaOH) solution to enhance visibility.

Figure 14: Increment core soak in water.

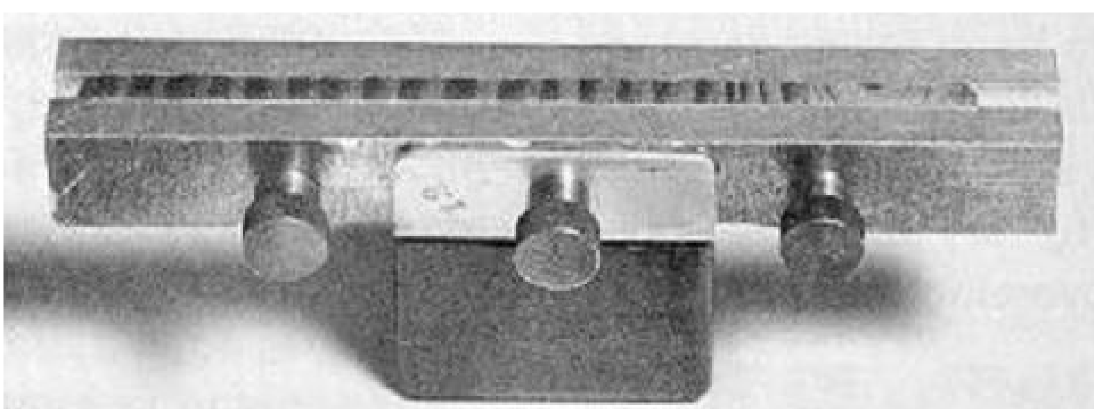

Figure 15: Increment core holder.

After the samples were prepared increment growth measuring was conducted by using a increment core measuring device called a traversing micrometer (Robert and Maeglin, 1979) (Figure 16). The traversing micrometer measures radial dimensions by traversing across increment cores with a scale of magnification of 1/100mm. The device has the following advantage: the size of the sample is independent from the device's magnification, the scale readings are direct readings of actual measurements and are independent of magnification, and if the sample is broken it is possible to measures by skipping the broken part.

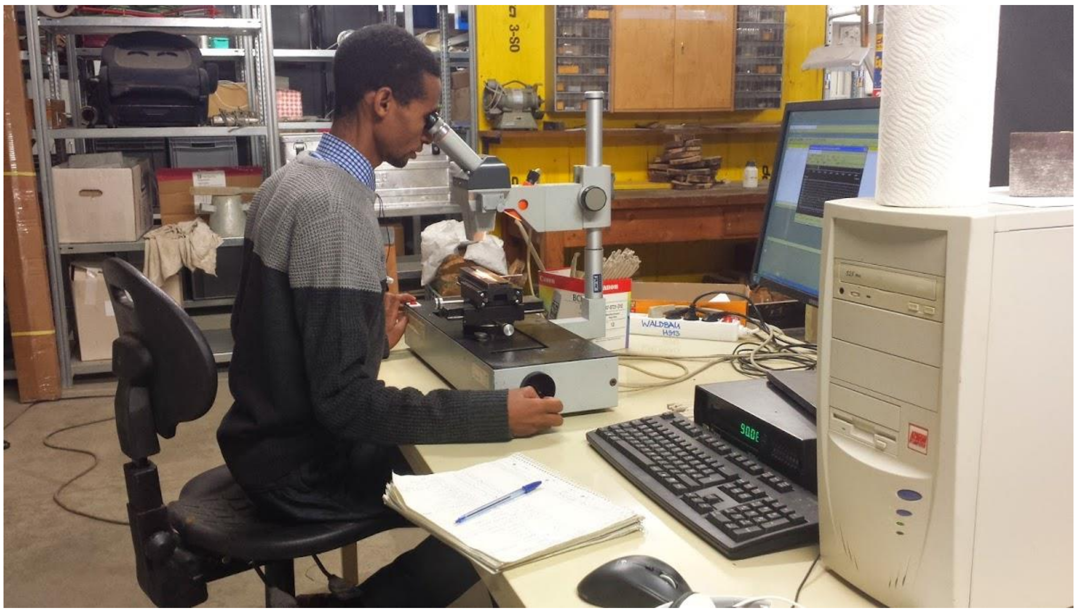

Figure 16.Increment measuring device traversing micrometer.

Subsequently, the data of measured increment cores was transferred to the computer using TSAP software(TSAP-Win^{TM}, 2014). The TSAP software was also used for the graphics analysis.

The ring widths were measured at the radial direction and the results were compared statistically using the tree ring program TSAP and were also visually compared by analyzing the print outsof the ring curves. This procedure, known as cross dating, is usually applied in dendro-chronological science in order to detect missing rings (Worbes et al., 2003). By using this procedure the tree ring curves of all samples were corrected, whereby missing rings were included and false rings were excluded (D.W et al., 1999).

The objective of this study was to investigate the two consecutive periodic increments of the forest. Accordingly, the analyses were conducted as the following procedure:

- Arrange the same species together in the plot (each plot had one tree core increment sample),
- Estimate periodic radii growth by summing up the first five year rings (2014-2010 and 2009- 2005) for each trees with increment core data,
- Calculate the diameter growth of the tree sample by multiplying the periodic radial growth by 2
- Calculate the proportional growth between the periods for each sample that have tree ring data
- Calculate periodic growth, for those trees without increment core data at plot level by using mean proportional growth of the same species with increment core data available in all forests.
- Calculate diameter increments for those trees without increment core data by multiplying median proportional growth of all species that were taken increment core.

After all the diameter increments were taken basal area increment calculated as follows:

$$\mathrm{DBH}_{2014} - \mathrm{D}_{\mathrm{inc1}}. = \mathrm{DBH}_{2009} \quad \textbf{6}$$

$$\mathrm{DBH}_{2009} - \mathrm{D}_{\mathrm{inc2}}. = \mathrm{DBH}_{2005} \quad \textbf{7}$$

$$\mathrm{Ba}_{2014} = \pi \frac{\mathrm{DBH}_{2014}{}^{2}}{4} \quad \textbf{8}$$

$$\mathrm{Ba}_{2009} = \pi \frac{\mathrm{DBH}_{2009}{}^{2}}{4} \quad \textbf{9}$$

$$\mathrm{Ba}_{2005} = \pi \frac{\mathrm{DBH}_{2005}{}^{2}}{4} \quad \textbf{10}$$

$$\mathrm{Ba}_{2014} - \mathrm{Ba}_{2009} = \mathrm{Ba}_{\mathrm{inc1}} \quad \textbf{11}$$

$$\mathrm{Ba}_{2009} - \mathrm{Ba}_{2005} = \mathrm{Ba}_{\mathrm{inc2}} \quad \textbf{12}$$

Finally, basal area increment per hectare was calculated:

$$\mathrm{Ba}_{\mathrm{in1\ or\ in2}} * \mathrm{N} * \mathrm{F} = \mathrm{Ba}_{\mathrm{inc1\ or\ in2}} \qquad \mathbf{13}$$

Where:

- $DBH_{2014,}$ $DBH_{2009}$and DBH_{2005} are diameter at breast height at the year 2014, 2009, and 2005 respectively,
- D_{inc1} and D_{inc2} is diameter increment between the years 2010-2014 and 2009-2005 respectively
- $Ba_{2014,}$ Ba_{2009} and Ba_{2005} are basal area at the year 2014, 2009, and 2005 respectively,
- Ba_{inc1} and Ba_{inc2} is basal area increment between the years 2010-2014 and 2009-2005 respectively
- N is factor of representative tree,
- F is the frequency of the tree,

4. RESULT

The results have been presented in line with diversity and annual growth, based on the objectives of the study. Firstly, the diversity part is presented in terms of different diversity indices and by including the tree and shrub composition as well as the population structure. Secondly, the result of increment core is presented in terms of periodic increment of the tree.

4.1 Diversity

4.1.1 Tree and shrub species composition

In total, 124 tree and shrub species were identified in the four study areas. Among them Tara Gedam and Injibara encompassed the largest number of species, which was 47 for each site. In Gelawdiwos and Metema, 42 and 36 species were found, respectively (appendix 1).

In Gelawdiwos' main plot, 30 tree species were identified. In the second plot, 33 sapling or shrub species were identified while in the regeneration plot, 23 tree or shrub seedling species were identified. Therefore, in total, in the Gelawdiwos study area 42 species were identified.

As displayed in the chart below (Figure 17, a), from the species obtained in Gelawdiwos, 36% of species were found in the form of a tree, sapling, and seedling. The 19% of the species were found in the form of tree and sapling. Overall, the species were found in the form of a tree, sapling, and seedling in the share of 12%, 14%, and 5% respectively. However, some species in sapling and seedling level have a shrub habit throughout their lifetime, and some species are also found in both the tree and shrub life form depending on environmental conditions. To avoid this confusion, shrubs found in maturing stages were considered saplings. Therefore, the data presented as a sapling and seedling includes the shrub species.

In the Injibara main plot, 36 tree species were identified. In the second plot, 28 sapling or shrub species were identified and in the regeneration plot 26 tree or shrub seedling species were identified. Consequently, the total number of species identified in Injibara was 47.

Results from Injibara showed that 28% of species were found in the form of tree, sapling, and seedling. Furthermore, 26% species of were found in the form of tree only which means they have not been replacing saplings and seedlings. The species were found in the form of seedling and sapling accounted for 2% and 8%, respectively.

In Metema main plot, 30 tree or shrub species were identified. In the second plot, 14 sapling species were identified. Lastly, in the regeneration plot 6 tree or shrub seedling species were identified. Therefore, in a total of 36 species were identified in the Metema area.

In Metema 50% of the species were found in the form of tree only which indicates that most of the species have not been replaced. The species found in the form of tree, sapling and seedling covered 6%. Accordingly, the Metema forests exhibit a regeneration problem. Additionally in this location, tree and sapling vegetation forms covered 26% of the area.

In Tara Gedam main plot, 17 tree species were identified. In the second plot, 21 sapling species were identified. Lastly, in the regeneration plot, 12 tree or shrub seedling species were identified. Therefore, in total 47 species were identified in Tara Gedam.

As shown in Figure 17 below, in Tara Gedam most of the species were found in the form of sapling (45%) only. In addition, 19% of species were found at seedling and sapling stage while 6% of species where found in tree form (Figure 17, d). In general, Tara Gedam forest was considered to be in the early stage of succession which may be due to the disturbance of the forest.

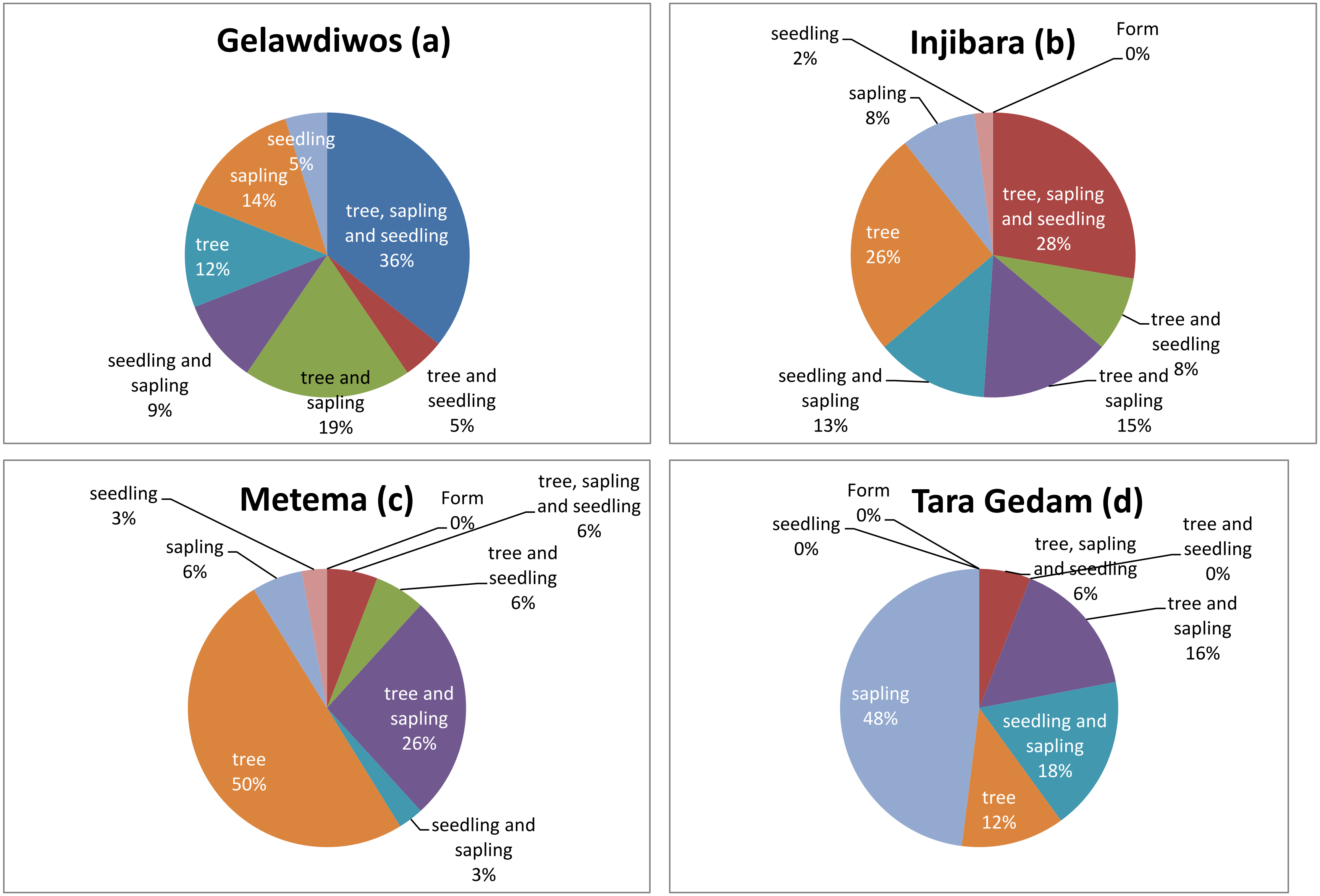

Figure 17: The distribution of tree, sapling and seedling.

4.1.2 Species diversity across the region

1. Gamma diversity (Overall diversity)

Gamma diversity shows the diversity of tree, sapling and seedling at the regional level. The result shows that in both Shannon and Simpson diversity indices, the Metema forest has the highest species diversity. The lowest diversity was found in Injibara (Table 5). In addition, the Evenness index indicates that Metema forests are more evenly distributed than other forest sites. Again, Injibara forest was most unevenly distributed forest.

Table 5: Gamma diversity across the region

Region	Shannon(H')	Simpson(D)	Evenness(J)
Gelawdiwos	2.95	13.93	0.79
Injibara	2.91	11.78	0.74
Metema	3.00	13.97	0.85
Tara Gedam	3.17	16.24	0.81

2. **Alpha diversity**

Alpha diversity is shows the diversity of individual at sample unit. Therefore, the following diversity indices results, presented below, consider the diversity of tree, sapling and at plot level (Table 6 and Figure 18, 19, 20 and 21).

Tree diversity

The result shows, at 95% confidence interval, that the Shannon and Simpson diversity indices of Metema forest are significantly high in terms of tree species diversity. However, Tara Gedam forest has significantly low species diversity compared to others. With the Shannon index there is no significant difference in tree diversity between Gelawdiwos and Metema and also between Gelawdiwos and Injibara. However, in Simpson index, there is significant difference between Metema and Gelawdiwos but no significant difference between Gelawdiwos and Injibara.

Additionally, based on evenness index, Metema natural forest species have significantly less distribution within the whole forest (0.26). Gelawdiwos (0.82) tree species are significantly evenly distributed throughout the forest. Relatively, Injibara (0.69) and Tara Gedam (0.46) forests tree species are also significantly distributed through the forest (Table 6 and Figure 18).

Sapling diversity

Shannon diversity index shows that there is no significant difference among the sapling of Gelawdiwos (1.14) and Injibara (0.99).While, Tara Gedam sapling has higher diversity than the others (1.33). In contrast, Metema (0.48) saplings are significantly lower in species diversity than the others. Similarly, in Simpson index, Tara Gedam (3.53) forest saplings have higher species diversity compared to the others, but Metema (1.66) forest has lesser diversity.

Based on the measure of evenness, there is no significant difference among the forests. However, in Tara Gedam a higher evenness value was recorded than in the Injibara forest. According to the below box plot, Gelawdiwos, Injibara and Tara Gedam have similar distribution of values while Metema sapling diversity distribution is different. (Table 6 and Figure 19).

Seedling Diversity

In seedling level the Shannon diversity index shows that there is no significant difference among the four forests (Table 6) but Injibara forest seedlings have higher diversity than the others. In contrast, the Metema seedlings have the lowest species diversity. Moreover, as shown in the box plot below, the Shannon diversity index values within the samples shown less variability (Figure 20).

Furthermore, at 95% confidence interval, the Simpson index shows there is no significant difference among the forest seedlings. Injibara recorded the highest value for seedling diversity while Metema had the lowest. According to the value of evenness index, there is no significant difference amongst seedling distribution through the whole forests. However, seedlings of Metema were less evenly distributed throughout the forest. As shown in box plot, the evenness index value within sample of Injibara and Tara Gedam showed big variability in contrast to Metema forest which yielded narrow variability.

Table 6: Diversity and Evenness of tree, sapling and seedling in different indices

		Gelawdiwos	Injibara	Metema	Tara Gedam
Shannon Index	Trees	1.21±0.50^{ab}	1.06±0.59^{bd}	1.55±0.43^{a}	0.49±0.48^{c}
	Saplings	1.14±0.52^{a}	0.99±0.43^{ba}	0.48±0.44^{db}	1.33±0.57^{a}
	Seedlings	0.58±0.40^{c}	0.74±0.57^{bc}	0.18±0.44^{dc}	0.47±041^{c}
Simpsons Index	Trees	3.31±1.36^{a}	2.92±1.32^{ca}	4.49±1.69^{d}	1.66±0.81^{b}
	Saplings	2.87±1.45^{ac}	2.55±0.98^{c}	1.66±0.71^{dc}	3.54±1.81^{a}
	Seedlings	1.69±0.81^{b}	2.14±1.12^{cb}	1.33±0.81^{b}	1.63±0.63^{b}
Evenness	Trees	0.82±0.24^{a}	0.69±0.33^{ca}	0.26±0.40^{d}	0.46±0.42^{a}
	Saplings	0.70±0.20^{abc}	0.74±0.22^{c}	0.51±0.45^{dc}	0.71±0.23^{ac}
	Seedlings	0.51±0.28^{b}	0.55±0.37^{cb}	0.16±0.40^{b}	0.55±043^{ab}

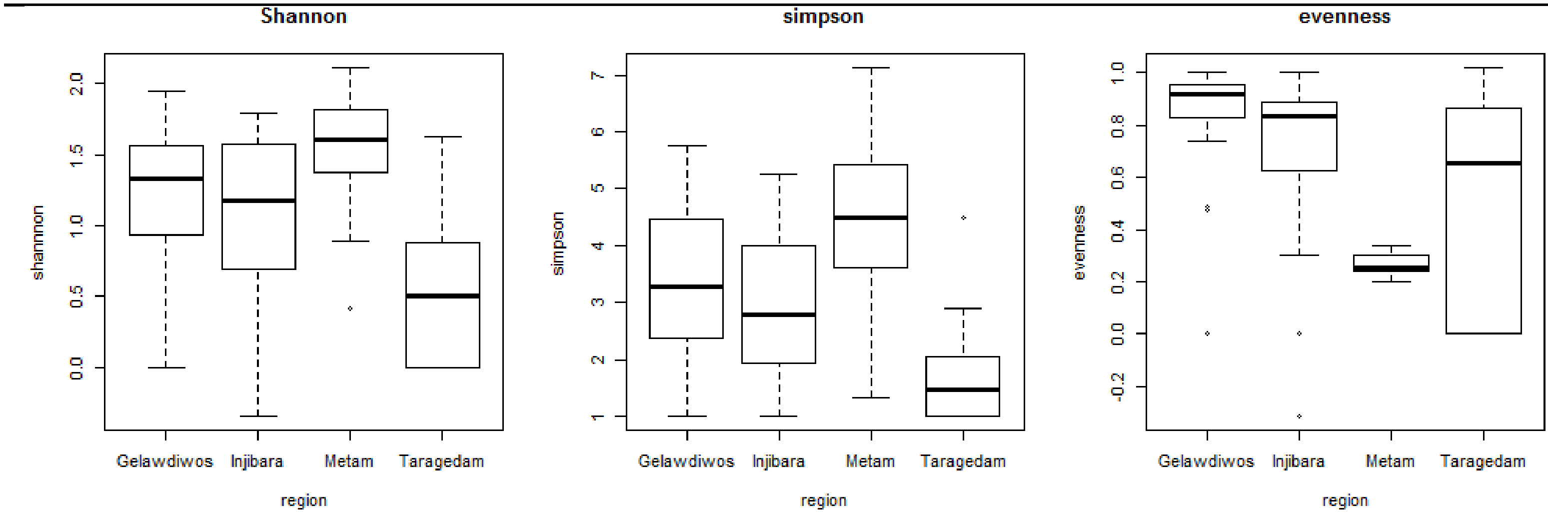

Figure 18: Shannon, Simpson and evenness values of the tree species across the region

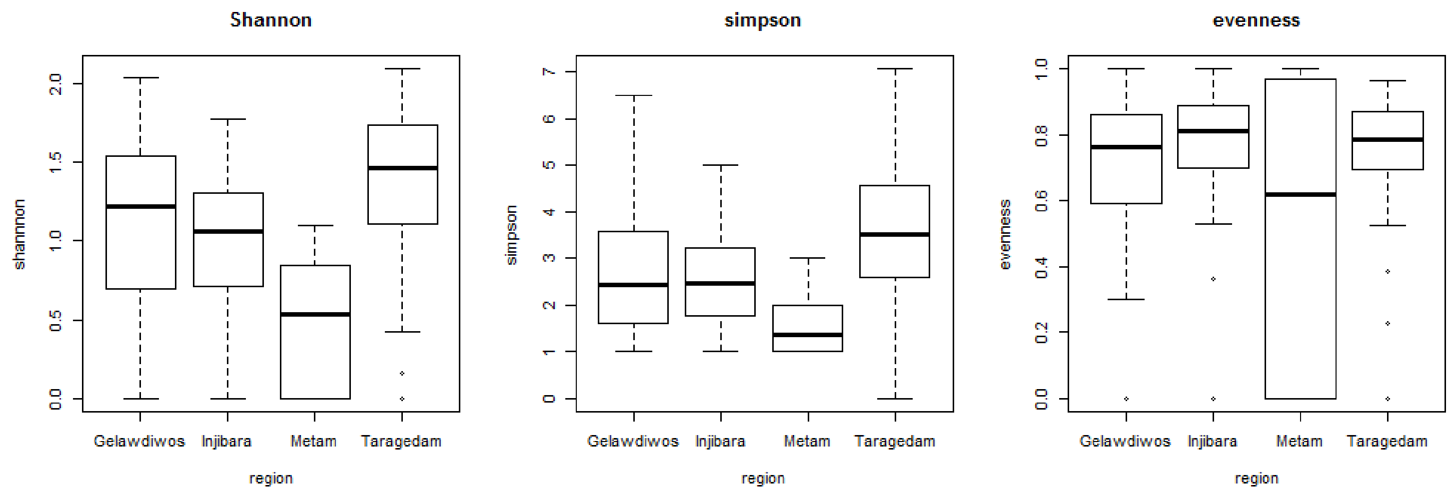

Figure 19: Shannon, Simpson and evenness values of the saplings across the region

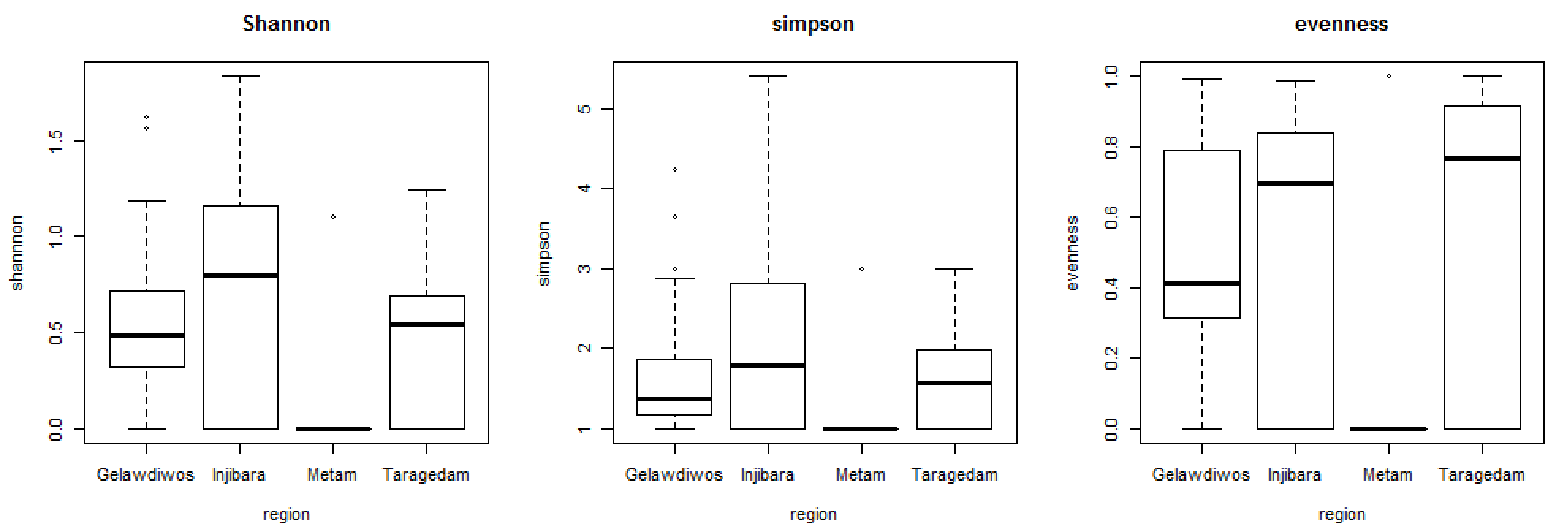

Figure 20: Shannon, Simpson and evenness values of the seedling across the region

4.1.3 Species diversity within the region

Gelawdiwos

According to the Shannon index value, there is no significant difference between tree and sapling species diversity. Moreover, the box plot shows the similarity of tree and sapling species diversity where 50 % their diversity value lies between the interval 1.2-1.5 (Table 6, Figure 21). However, seedling diversity significantly differs from tree and sapling diversity and two outliers are observed in the diversity values (Figure 21).

Likewise, in Simpson diversity index there is no significant difference between tree and saplings but seedling diversity exhibits significant difference from tree and sapling diversity (Table 6). The box plot below shows that seedlings have three outlier values (Figure 21).

The evenness index value shows that trees and saplings are similarly distributed within the Gelawdiwos forest. In addition, saplings and seedlings have no significant difference in the distribution through the forest but there is significant difference between tree and seedling distribution (Table 6 and Figure 21).

Injibara

The Shannon index and Simpson index show that there is no significant difference in species diversity among tree, saplings, and seedlings. Moreover, evenness index shows that there is no significant difference in the distribution of trees, saplings, and seedlings (Table 5). The box plot shows there is wide range of evenness value with in seedlings and the outliers are observed within trees and saplings (Figure 22).

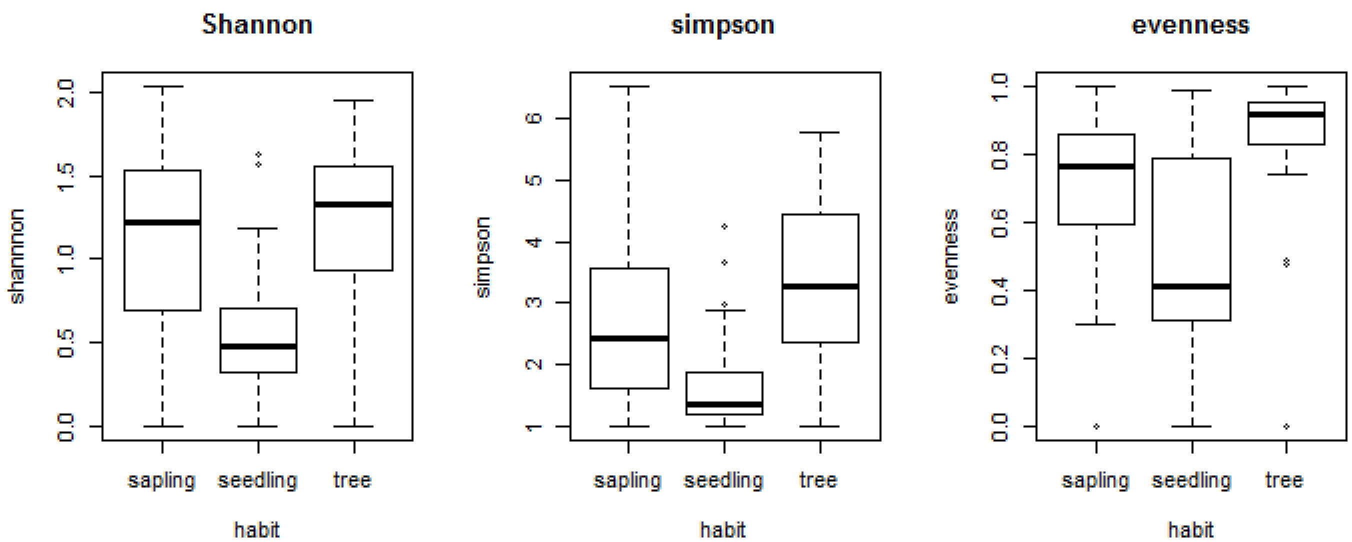

Figure 21: Gelawdiwos forest diversity of tree, sapling and seedling

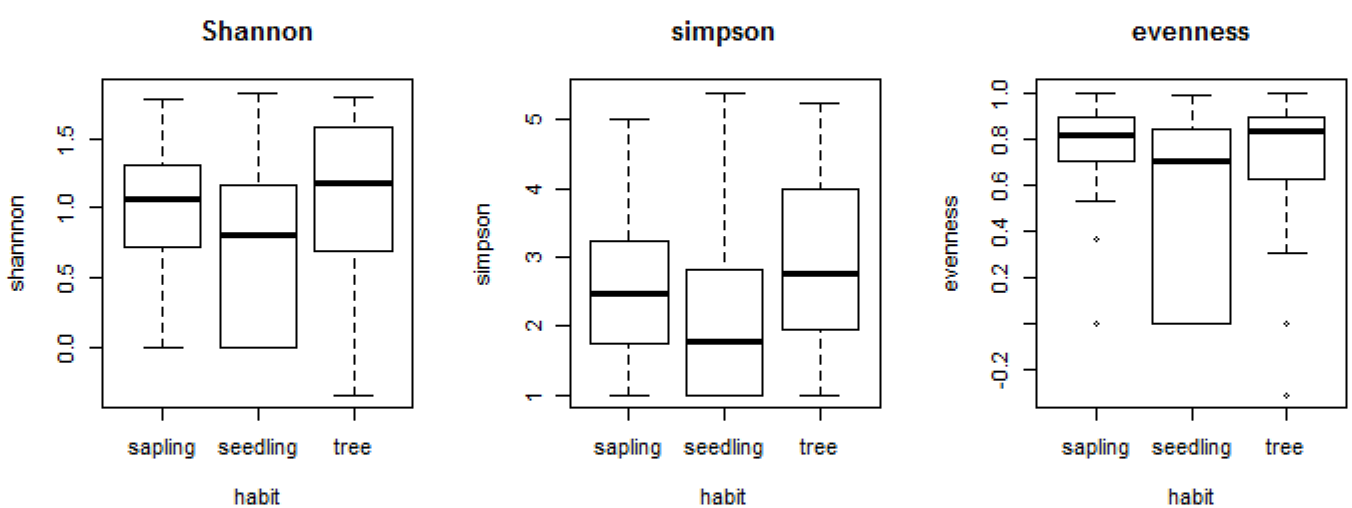

Figure 22: Gelawdiwos forest diversity of tree, sapling and seedling

Metema

According to, Shannon and Simpson indices, at a 95% confidence interval, there is significant difference between tree and sapling, and tree and seedling species diversity. However, there is no significant difference between seedling and sapling diversity. The Shannon and Simpson box plot shows that there is different distribution among the diversity value of tree, sapling and seedling and that seedling diversity values are similar. However, the sapling diversity values have wider variability.

In evenness index, there is significant difference in species distributions between tree and seedling, as well as between sapling and seedling. In contrast, there is no significant difference in species distribution between trees and saplings (Table 6). Nevertheless, as we have seen in the box plot there is a very wide difference from the maximum to the minimum values and in the first quartile and the third quartile of evenness value (Figure 23).

Tara Gedam

Based on Shannon and Simpson indices there is significant difference between sapling and tree and between sapling and seedling species diversity but there is no significant difference between tree and seedling diversity (Table 6). Evidently, as shown below, 50% of values are similarly distributed at 0.5 in the Shannon index and at 0.8 in the Simpson index results (Figure 24).

Despite this, evenness indices show that there is no significant difference in distribution of trees, saplings, and seedlings. As we have seen in the box plot, 50% of trees, sapling and seedling values lie at an evenness value of 0.8. However, trees and seedlings have shown a wider range (Figure 24).

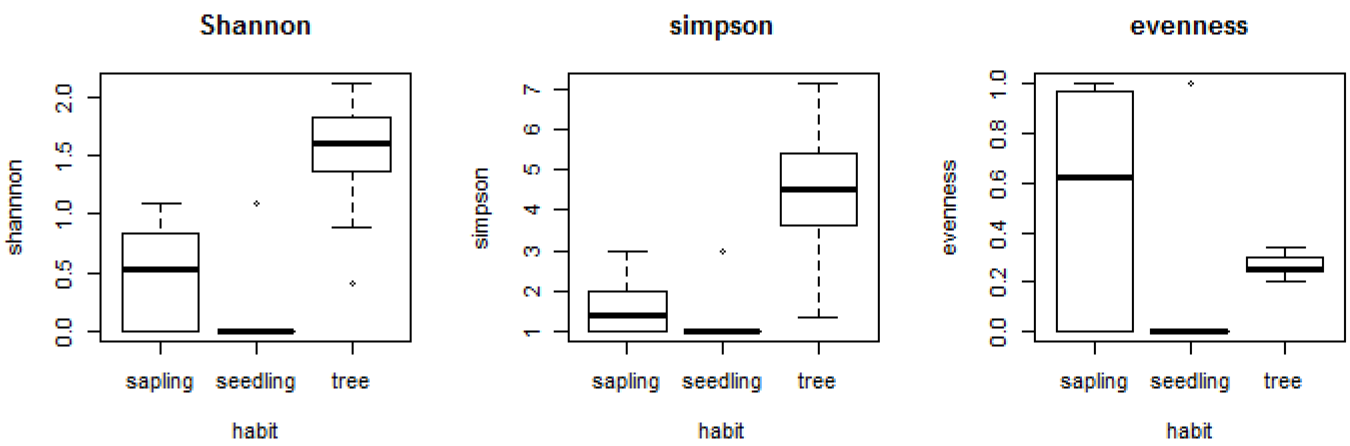

Figure 23: Metema forest diversity of tree, sapling and seedlings

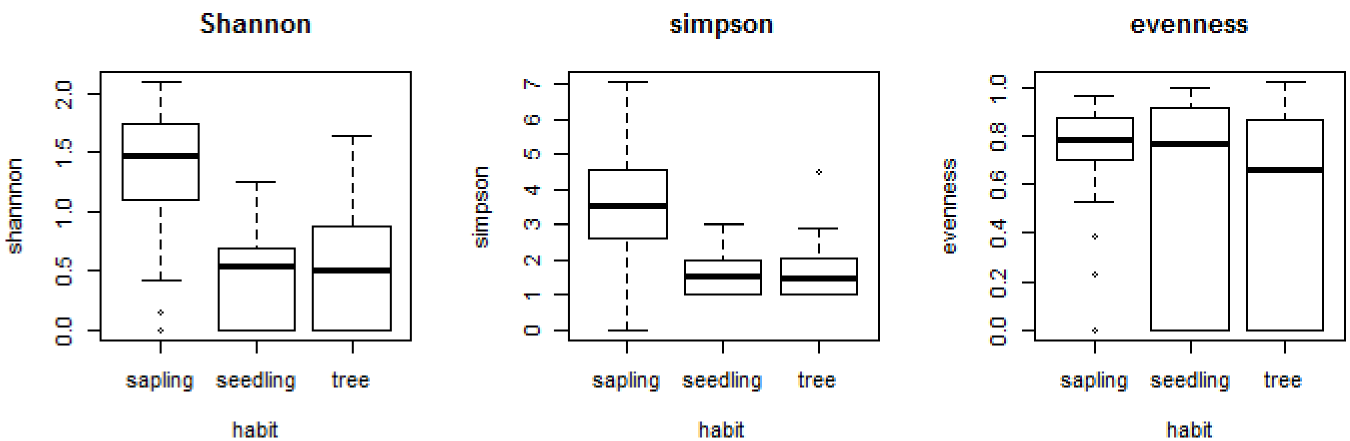

Figure 24: Tara Gedam forest diversity of tree, sapling and seedlings

4.1.4 Similarity

Sorensen similarity coefficient was used to determine the similarity among forest regions. If the Sorensen coefficient value is one then it indicates that the two forests being compared are identical. However, if the Sorensen coefficient value is zero then they are completely different. Accordingly, the highest similarity coefficient (0.46) was observed between Gelawdiwos and Injibara. In contrast, the lowest similarity coefficient (0.4) was found between the forest of Tara Gedam and Metema. Gelawdiwos forest has shown the highest similarity with the other forests. However, Metema showed the least similarity in terms of species composition with other forests (Table 7).

Table 7: The Sorensen similarity coefficient among the regions

	Gelawdiwos	Injibara	Metema	Tara Gedam
Gelawdiwos	***	**0.35**	**0.053**	**0.46**
Injibara	***	***	**0.071**	**0.34**
Metema	***	***	***	**0.04**
Tara Gedam	***	***	***	***

4.1.5 Density and Basal area

A total number of 1852 tree and shrubs were recorded in 170 plots. In Gelawdiwos, 341 trees and shrubs from 34 plots were recorded. In Injibara, there were 1042 trees and shrubs on 63 plots. In Metema, 264 trees and shrubs were recorded on 21 plots. Lastly, in Tara Gedam, 202 trees and shrubs were recorded on 52 plots.

For the mean diameter at breast height (DBH), there is no significant difference across the regions. The mean DBH of Gelawdiwos, Injibara, Metema and Tara Gedam were 22 cm, 22 cm, 19 cm, and 21 cm, respectively (Table 8).

Table 8. Mean DBH, density and basal area across the region

		Gelawdiwos	Injibara	Metema	Tara Gedam
Mean	**Tree**	22.41±17.46[a]	22.65±17.46[a]	19.86±8.49[a]	21.76±13.33[a]
DBH (cm)	**Dead Tree**	30.41±16.76	22.88±18.07	23.57±13.75	22.3±8.91
Density	**Trees**	307±201[a]	190±129[b]	173±103[b]	129±135[b]
(h^{-1})	**Sapling**	2404±2125[a]	1663±1820[a]	667±859[b]	3273±3132[a]
	Seedling	8566±9707[ab]	19841±38789[a]	655±1226[b]	1974±4002[b]
	Dead Trees	11.24±22.01[b]	34.59±47.20[a]	4.7±9.31[b]	14.69±50.63[b]
Basal Area	**Tree**	20.00±14.73[a]	12.25±10.49[b]	6.61±3.46[b]	6.81±10.76[b]
(m^2ha^{-1})					

The box plot in the Figure 19 shows that, there are a large number of DBH outliers, recorded in Gelawdiwos and Injibara, while in Tara Gedam and Metema, a small number of outliers were recorded (Figure 25). The maximum DBH from all forests was recorded in Injibara, which was 143 cm *(Ekebergia capensis)*and the maximum DBH recorded for the others are, 108 cm (*Ekebergia capensis)* in Gelawdiwos, 114 cm *(Schefflera abyssinica)* in Tara Gedam and 50 cm *(Terminalia laxiflora)*in Metema.

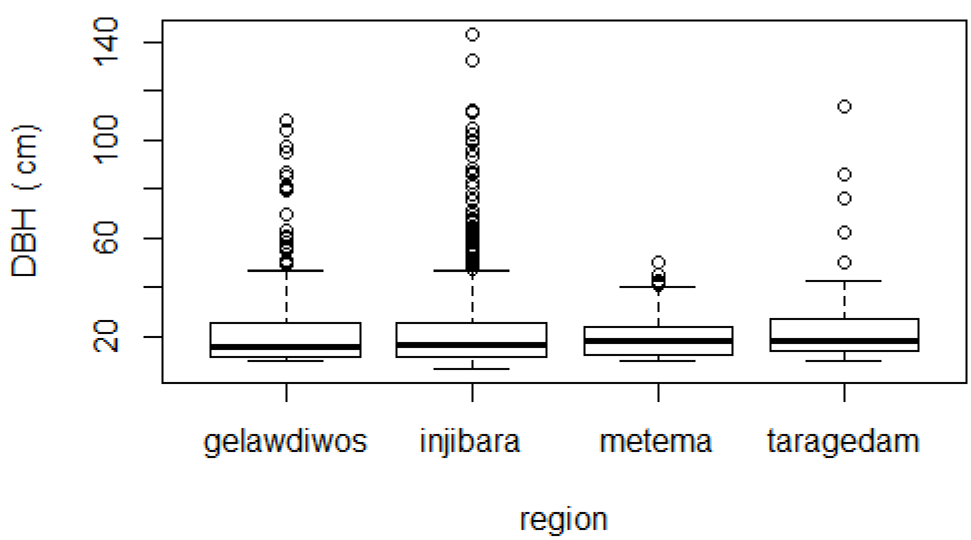

Figure 25: DBH distribution across the region

During the inventory, dead tree trunks or stumps were also recorded. The result shows that the maximum mean diameters of dead trees were found in Gelawdiwos and the minimum mean diameters were recorded in Tara Gedam (22 cm) (Table 7).

The density of trees per hectare in the region shows significant difference, especially between Gelawdiwos (307 per ha) and other forests. The lowest density of trees per hectare was found in Tara Gedam (129 per ha). There is no significant difference between Injibara and Metema, where 190 and 173 trees per hectare have been found, respectively. The box plot shows, there are outliers in Gelawdiwos, Metema and Tara Gedam (Table 8 and Figure 26).

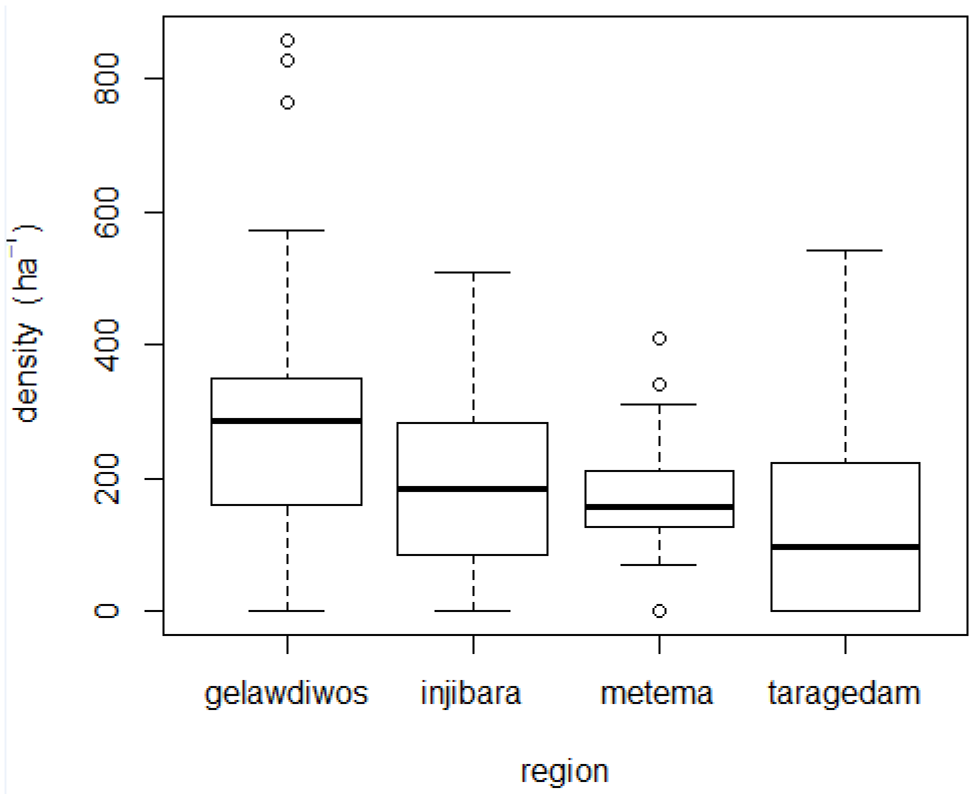

Figure 26: Number of tree per hectare across the region

The density of saplings and shrubs shows that there are no significant differences among Gelawdiwos (2464 ha^{-1}), Injibara (1663 ha^{-1}), and Tara Gedam (3273 ha^{-1}). However, Metema (667 ha^{-1}) was significantly different from the others (Table 8).

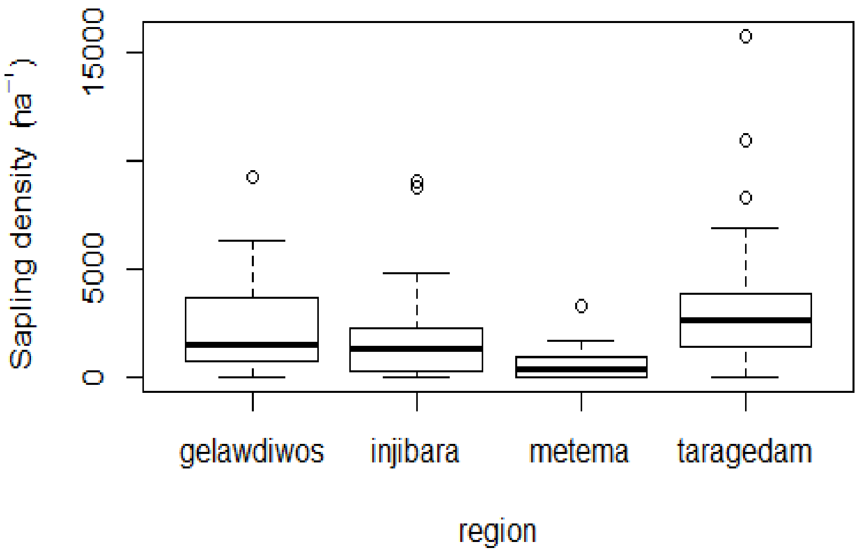

Figure 27: Density of sapling per hectare across the region

The above figure shows that there are outliers in Tara Gedam and Injibara. Despite this, the Tara Gedam the density values were concentrated on the first quartile, which illustrated that they are far away from upper boundary (Figure 27).

The plants with diameters below 4 cm and heights below 1.3 meters were considered to be seedlings. In Injibara, the highest mean density of seedlings per hectare was recorded (19841 ha^{-1}). According to the statistical analysis result, at 95% confidence interval there are significant differences between Injibara and the other forests (Table 8).

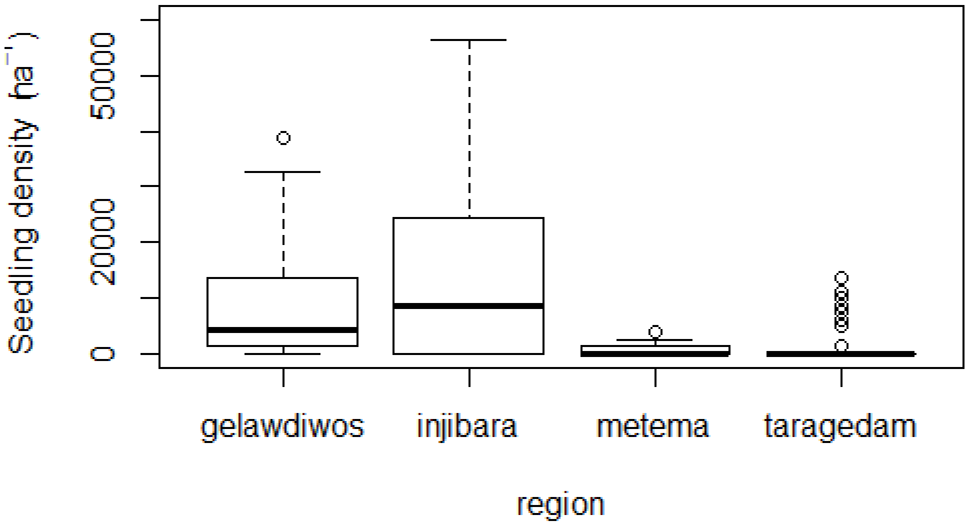

Figure 28: Density of seedling per hectare across the region

As we have seen from the below figure, there are outliers in Metema and Tara Gedam (Figure 29). The highest number of dead trees per hectare was found in Injibara (34 tree per ha) and the lowest were found in Metema (4 tree per ha). Hence, there is a significant difference among Injibara and others, but there is no significant difference among Gelawdiwos, Metema, and Tara Gedam (Table 8). The figure below shows that dead tree outliers were observed in all forests that the studies were conducted in (Figure 29).

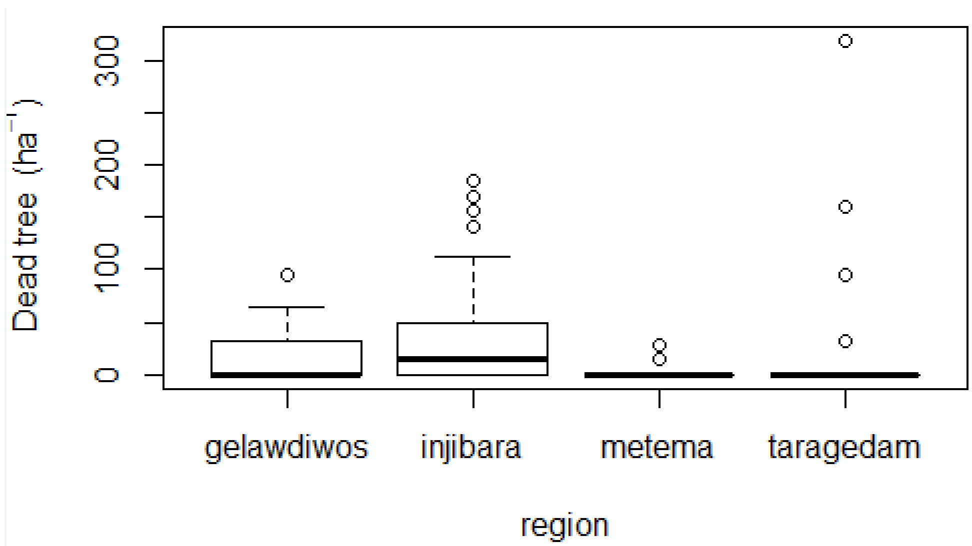

Figure 29: Density of dead tree per hectare across the region

According to, the result of basal area there is a significant difference between Gelawdiwos ($20m^2ha^{-1}$) and others. Statistically at a 95% confidence interval, there is no significant basal area difference between the remaining forests. However, the greatest difference was observed between Injibara ($12.25m^2ha^{-1}$) and Metema ($6.61m^2ha^{-1}$), and Injibara and Tara Gedam ($6.81m^2ha^{-1}$).

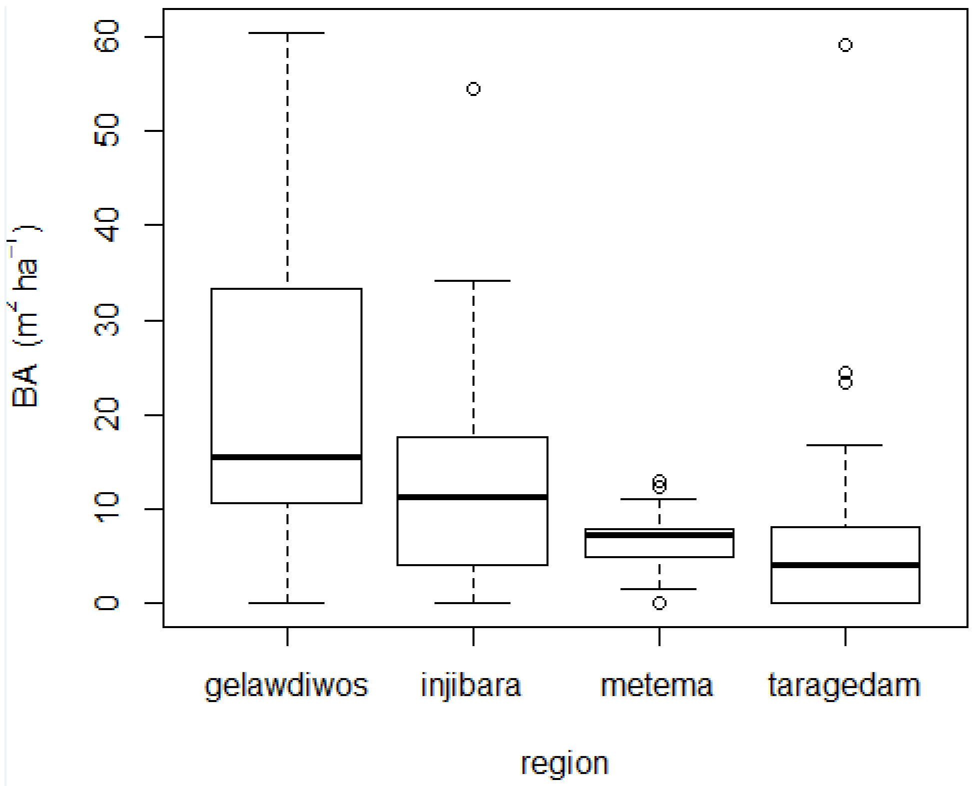

Figure 30: Basal area per hectare across the region

4.1.6 Diameter distribution

The diameter distributions were manipulated by separating trees from seedlings and saplings due to the number of saplings and seedlings being significantly higher. Under these circumstances, the results were described.

As shown in the figure below (Figure 31), in Injibara and Gelawdiwos the number of seedlings was much greater than the number of saplings. In Injibara the seedlings cover 95% and in Gelawdiwos the saplings cover 75%. This indicates that there is a replacement of trees following removal is occurring. In Metema and Tara Gedam, there was no difference between the number of seedlings and saplings. Moreover, the Tara Gedam saplings number was lower than the seedlings. This indicates that there has been poor regeneration.

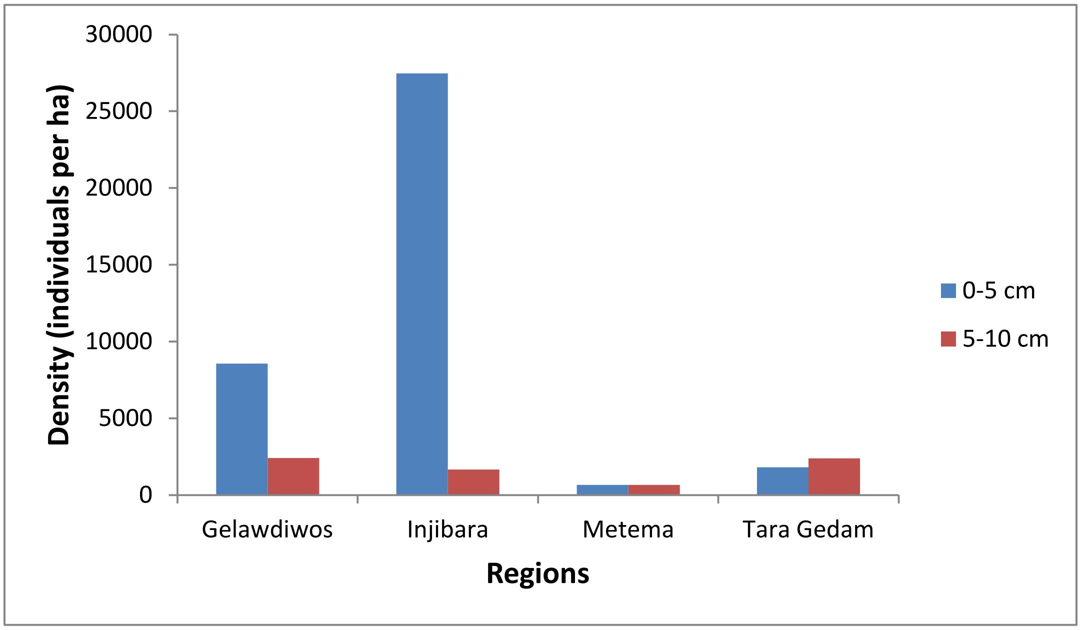

Figure 31: Density of sapling and seedling across the region

The diameters at breast height distribution in the region's forests were classified into eleven diameter classes conventionally (Figure 32). However, Metema region diameter class comprises five classes because the maximum diameter at breast height was 50 cm, whereas the maximum DBH of Gelawdiwos, Injibara and Tara Gedam were 108 cm, 143 cm, 50 cm and 114 cm, respectively.

As presented in below figure, the distribution pattern of the entire region was an inverted J-shape. This showed that the species frequencies were highest in lower diameter classes and decreased gradually towards the highest classes.

As we have seen in the Figure 24, about 82 %, on average in the entire region, individuals were found to be in the first class (DBH < 20 cm). The remaining nine classes together account for 18 % of total standing tree individuals.

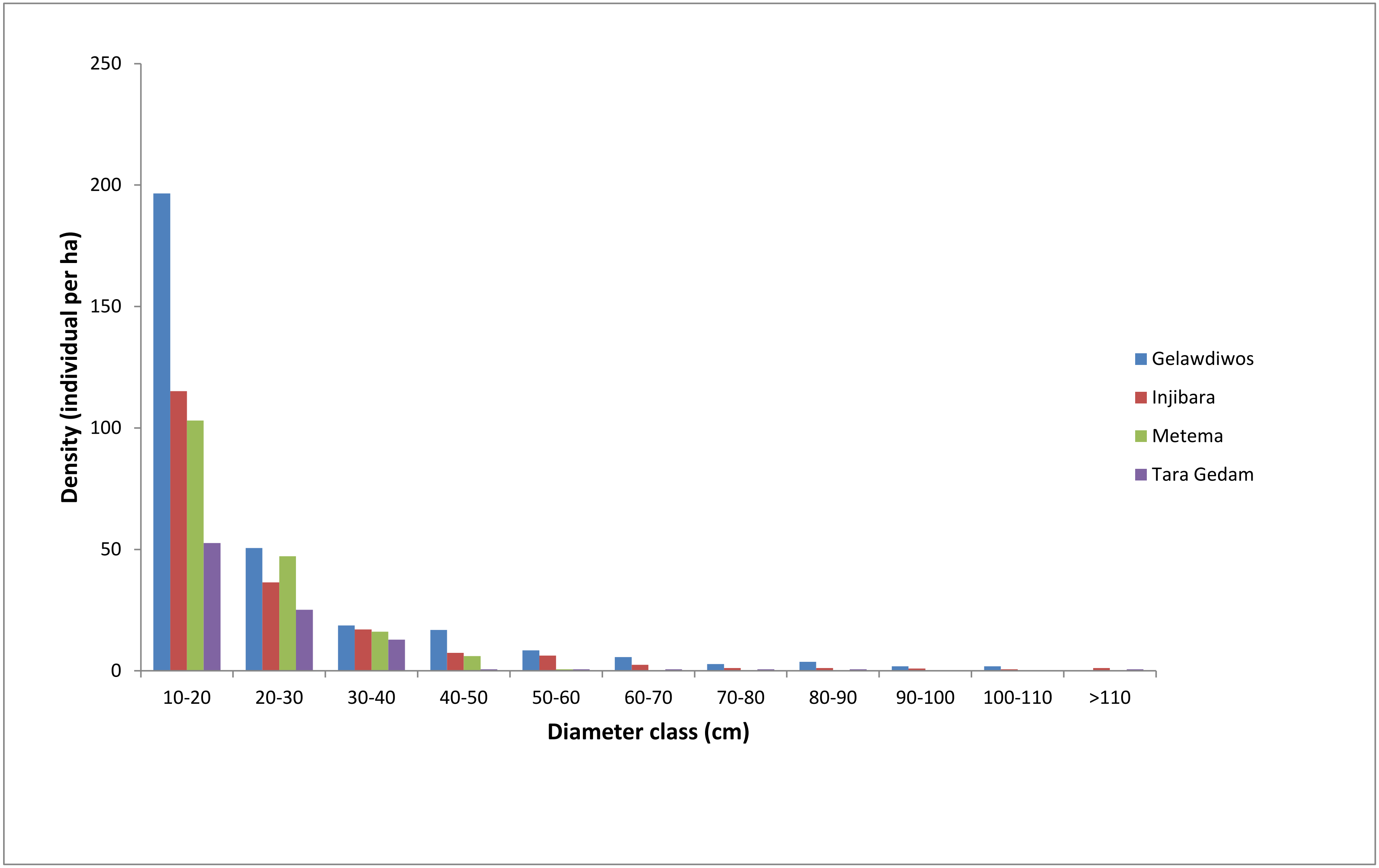

Figure 32.Diameter distribution across the region.

4.1.7 Important value index (IVI) and population structure of dominant species

In this segment, the regions important value index (IVI) results were presented. Additionally, the population structures of the species with the highest IVI were also presented.

Gelawdiwos

Important value index (IVI) was calculated for all 30 tree and shrub species DBH >10 cm (Table 8 and Appendix 2). Among them *Chionanthus mildbraedii* was found to have the highest IVI (62.52%) followed by *Euphorbia abyssinica* (31.78%), *Albizia gummifera* (34.27%), *Croton macrostachyus* (21.93%), and lastly *Dovyalis abyssinica* (21.18%). The lowest five IVI values were found, in decreasing order, in the following tree and shrub species *Maytenus undata (1.67%)*, *Myrica salicifolia* (1.58%), *Rhus glutinosa*(1.40%), *Vernonia amygdalina* (1.19%) *and Allophylus abyssinicus* (1.17%).

Table 9: Importance value indices of woody species for Gelawdiwos (for the full list see the appendix 2)

Species	Relative basal area (%)	Relative Density	Relative Frequency (%)	IVI (%)	IVI rank
Chionanthus mildbraedii	38.59	11.96	11.97	62.52	1
Euphorbia abyssinica	9.41	15.34	7.04	31.79	2
Albizia gummifera	4.93	14.42	4.93	24.28	3
Croton macrostachyus	3.58	9.20	9.15	21.94	4
Dovyalis abyssinica	2.03	8.59	10.56	21.18	5
			.		
			.		
			.		
Allophylus abyssinicus	0.16	0.30	0.70	1.17	30
				300	

Based on IVI results the population structures of the five dominant species were presented in Figure 33 below. The population structure of selected species followed two general diameter distribution patterns. The first pattern was a bell shape which showed that the number of individual in the middle diameter classes is high while the number of individuals was low in lower and higher diameter classes. The second pattern was an irregular shape in which the number of individuals is distributed differently in almost all classes and there is an absence of individuals between diameter classes. Accordingly, the first dominant species *Chionanthus mildbraedii* (Wogeda) followed the bell shaped pattern. *Euphorbia abyssinica, Albizia gummifera,* and *Croton macrostachyus* were also found to have the bell shape distribution. While, *Dovyalis abyssinica* and *Ekebergia capensis* followed an irregular shape diameter distribution.

The tree species *Chionanthus mildbraedii* has been recorded in eleven diameter classes (Figure 30, a). The two middle DBH classes cover 41 % of the whole population. The younger and older population contributes 12% and 9% of the population. All of the *Albizia gummifera* population was found in the first four diameter classes and the middle class accounts for 75% of the population. The younger and older population covers 4% and 9% respectively.

Euphorbia abyssinica, Croton macrostachyus, and *Dovyalis abyssinica* populations have been found in the first six, five and four diameter classes respectively. However, the *Ekebergia capensis* population was found in six diameter classes in fragmented order (Figure 33, f).

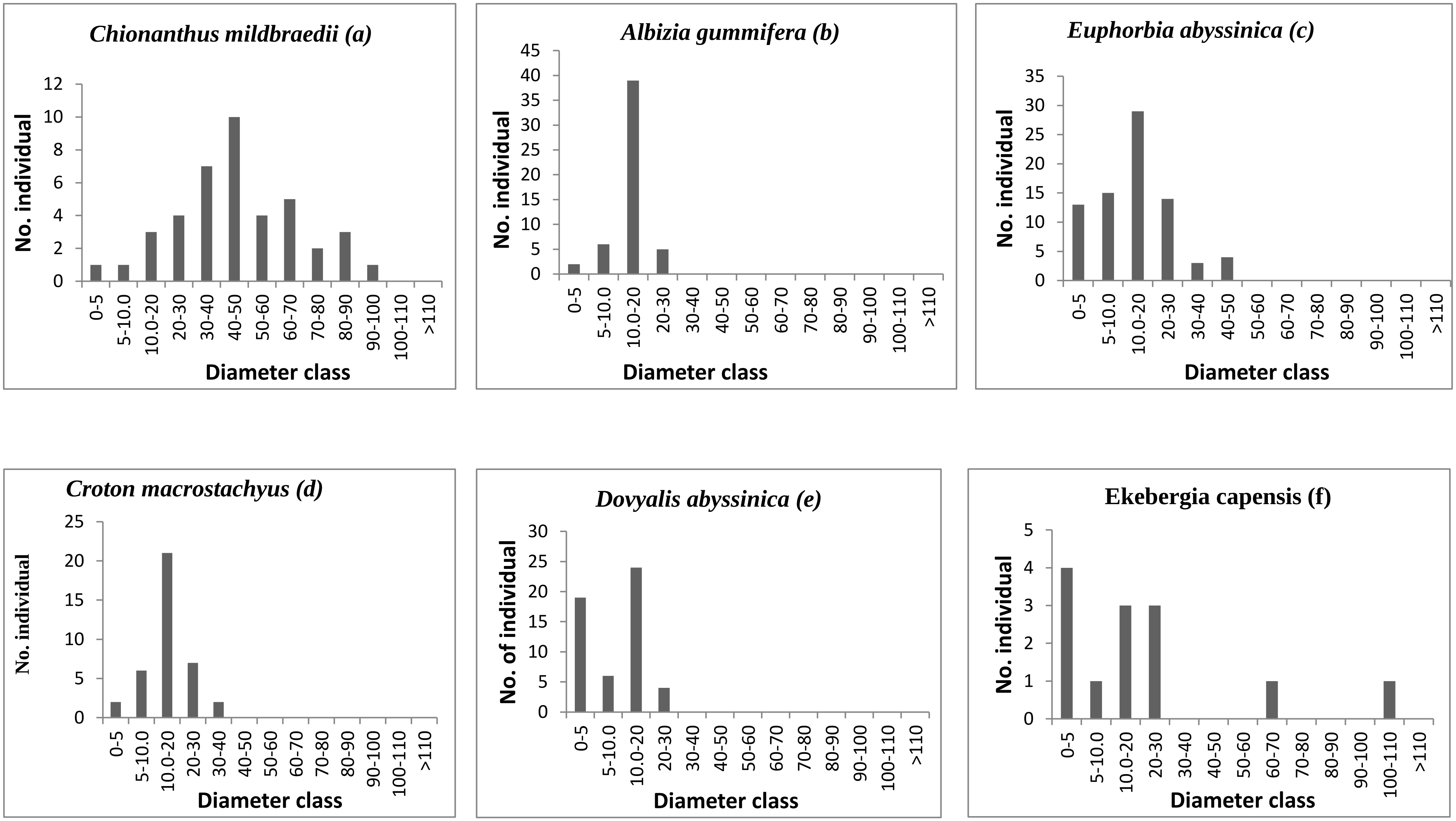

Figure 33. Diameter class frequency distribution of selected tree species on Gelawdiwos

Injibara

Important value index (IVI) was calculated for all 38 trees and shrub species DBH >10 cm (Table 9). Among them *Albizia gummifera*was were found to have the highest IVI (87%) followed by *Croton macrostachyus* (35.81%), *Prunus Africana* (28.88%), kenebela (21.77%) and Gimibilitini (18.58%). The least IVI result was found from O.europea species (0.52%).

Table 10: Importance value indices of woody species for Injibara (for the full list see the appendix 3)

Species	Relative basal area (%)	Relative Density	Relative Frequency (%)	IVI (%)	IVI rank
Albizia gummifera	36.45	30.45	20.08	86.98	1
Croton macrostachyus	8.25	13.39	14.17	35.82	2
Prunus Africana	15.64	4.97	8.27	28.88	3
Kenebela	2.68	11.61	7.48	21.77	4
Gimibilitini	2.88	7.82	7.87	18.58	5
			. . .		
Olea europaea	0.01	0.12	0.39	0.53 300	38

According to the IVI result of Injibara forest, five dominant species population structures were presented in the figure below (Figure 34). The population structure of selected species followed three general diameter distribution patterns. The first was a bell shape, indicating that the number of individuals present in the middle diameter classes is high, and at lower and higher diameter class the number of individuals is low. The second sample was irregularly shaped with a different distribution in almost all classes and absence of individuals between the diameters of the class. The third sample was an interrupted inverted J-shape which showed that the frequency of the species was highest in the lower diameter class and the number of individuals gradually reduced towards the higher diameter class.

Hence, *Albizia gummifera* and *Prunus Africana* followed an interrupted inverted J-shaped pattern. Gimibilitini and *Croton macrostachyus* were also found to have the bell shaped pattern. The Kenebela population pattern looks like an irregular shape. The first three dominant species population distribution runs into eight diameter class while the fourth and the fifth dominant species run only into the first four ordered diameter classes.

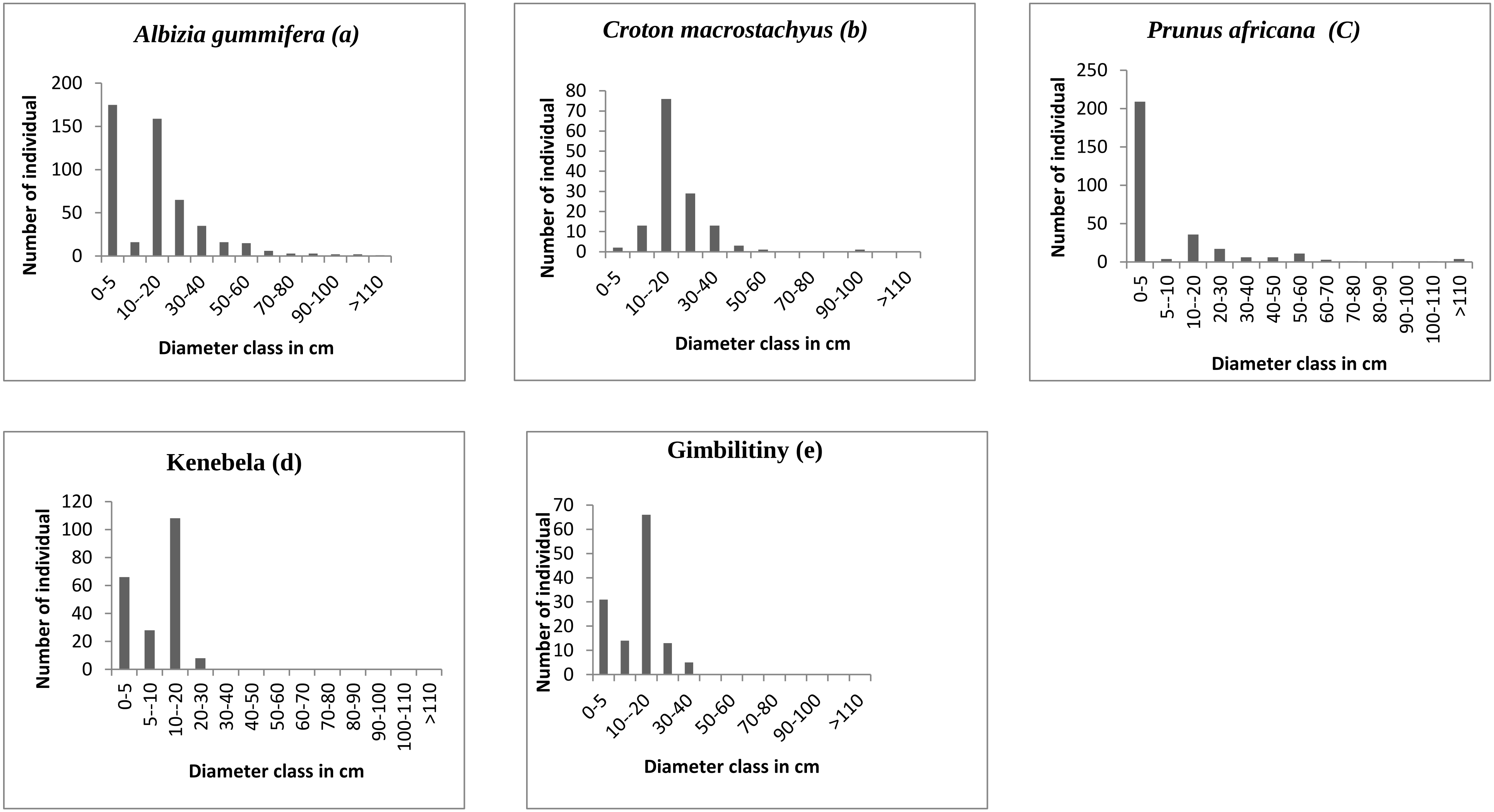

Figure 34: Diameter class frequency distribution of selected tree species on Injibara

Metema

Important value index (IVI) was calculated for all 30 tree and shrub species with DBH >10 cm (Table 10). Among them *Boswellia Papyrifera*was was found to have the highest IVI (33.22%) followed by *Sterculia setigeraI* (29.74%), *Terminalia laxiflora*(25%), Fola (20.86%) and *Pterocarpus lucens* (19.53%). The lowest IVI result was found from Dabda (1.52%) species.

Table 11: Importance value indices of woody species for Metema (for the full list see the appendix 4)

Species	Relative basal area (%)	Relative Density	Relative Frequency (%)	IVI (%)	IVI rank
Boswellia Papyrifera	13.33834	12.06226	7.826087	33.22668	1
Sterculia setigeraI	15.78434	7.003891	6.956522	29.74475	2
Terminalia laxiflora	13.45092	5.447471	6.086957	24.98535	3
Fola	4.868653	8.171206	7.826087	20.86595	4
Pterocarpus lucens	7.69494	5.447471	6.086957	19.22937	5
			. . .		
Dabda	0.270203	0.389105	0.869565	1.528873	30
				300	

The population structure of three dominant tree and shrub species in Metema forest followed a general diameter distribution patterns. *Boswellia Papyrifera,* Fola and *Pterocarpus lucens* shows the bell shaped distribution pattern. The second dominant species *Sterculia setigeraI* followed an interrupted inverted J shaped pattern, whereas the third dominant species *Terminalia laxiflora* had an irregular shaped distribution pattern.

As we have seen in the diameter distribution graph, except the species Fola, all of the first five dominant species did not have a sapling and seedling stage. The species *Boswellia Papyrifera* was presented only on diameter class 10-20, 20-30 and 30-40. The middle diameter classes covered 61%, the first and last diameter classes shared 32% and 7% of the distribution respectively. *Sterculia setigeraI* species had the higher number of individuals in the older diameter classes (Figure 35, b).

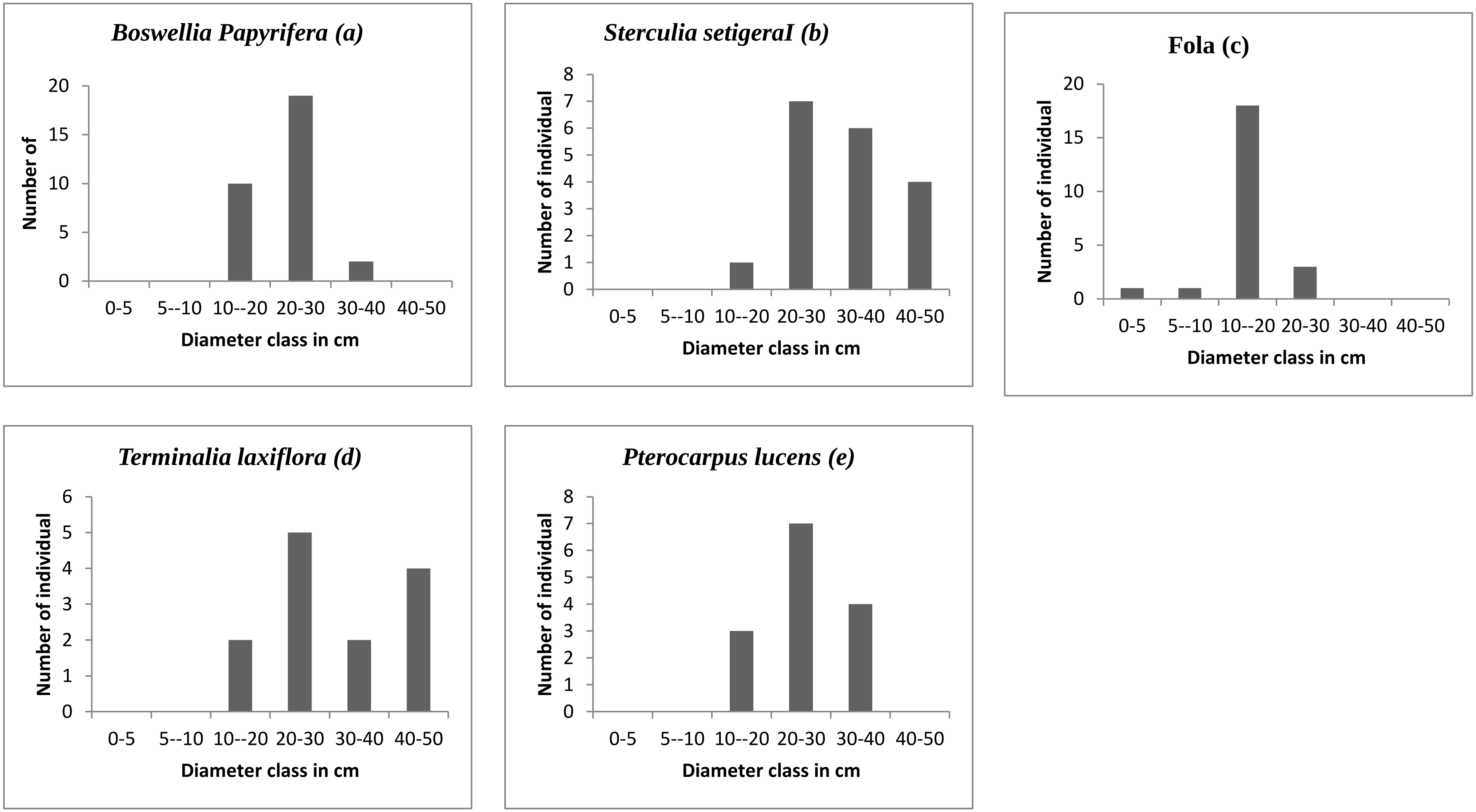

Figure 35: Diameter class frequency distribution of selected tree species on Metema

Tara Gedam

Important value index (IVI) was calculated for all 38 tree and shrub species with DBH >10 cm (Table 11). Among them *Juniperes procera* was found to have the highest IVI (51%) followed by *Acacia Abyssinica* (42.85%), *Buddleia polystachya* (41.45%), *Albizia gummifera* (29.59%), and *Croton macrostachia* (27.77%). The least IVI result was found from *Ilex mitis* (2.38%) species.

Table 12: Importance value indices of woody species for Tara Gedam (for the full list see the appendix 5)

Species	Relative basal area (%)	Relative Density	Relative Frequency (%)	IVI (%)	IVI rank
Juniperes procera	20.57439	20.91503	9.677419	51.16684	1
Acacia Abyssinica	14.61359	13.72549	14.51613	42.85521	2
Buddleia polystachya	6.715515	16.99346	17.74194	41.45091	3
Albizia gummifera	6.232694	10.45752	12.90323	29.59344	4
Croton macrostachyus	4.75624	8.496732	14.51613	27.7691	5
			. . .		
Ilex mitis	0.120955	0.653595	1.612903	2.387453 300	17

Most of dominant forest species in Tara Gedam had population distributions resembling a bell shaped distribution pattern. These species are *Juniperes procera*, *Albizia gummifera*, *Buddleia polystachya*, and *Croton macrostachia.* However, the second dominant species *Acacia Abyssinica* had an inverted J shaped diameter distribution (Figure 36).

Accordingly, the *Juniperes procera* population was found in four diameter classes, which ranged from 5cm to 40cm in diameter. Hence, 54% of individuals in the population represented the middle class. As we seen in the graph, *Juniperes procera* was not found in the seedling form.

As mentioned above, *Acacia Abyssinica* had an inverted J shaped distribution, but the first class was small, accounting for only 3% of the population. In addition, the last diameter class was disconnected from the other. *Buddleia polystachya* and *Albizia gummifera* were found in the first four and five diameter classes, respectively, and did not have any interruption. The highest number of the population concentrated in the middle two classes, which were accounted for 72% and 70% of the total population.

The fifth dominant species *Croton macrostachia*as mentioned above had a bell shaped distribution. Also, it runs into five diameter classes, but the last classes disconnected from others. The two middle class represented 73 % of the population.

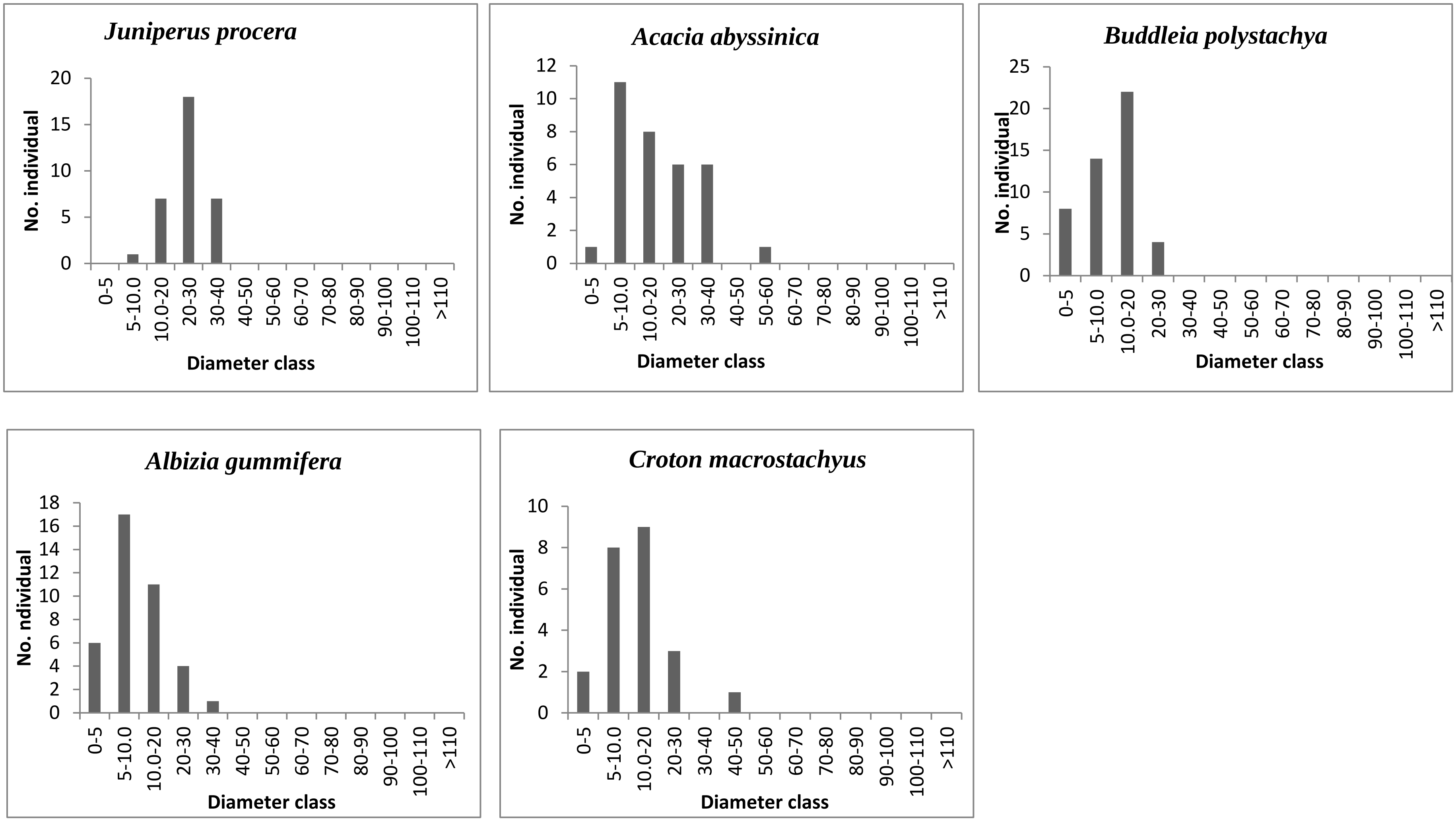

Figure 36: Diameter class frequency distribution of selected tree species on Tara Gedam.

4.2 Growth rate

4.2.1 Cross dating

To conduct cross dating, 326 increment core samples were collected. The 118 core samples from Gelawdiwos forest, 178 core samples from Metema, and 30 core samples from the plantation forest were collected. From them, 203 core samples were successfully cross-dated for 58 species. 90% of the samples were from the plantation forest, 68% from Metema forest, and 53% from Gelawdiwos forest were successfully cross-dated.

Table 13: The number of sample collected and successfully cross-dated

Region and land use	Increment core collected	Successfully cross dated	Species successfully cross dated
Gelawdiwos natural forest	178	96	26
Metema	118	80	26
Gelawdiwos Plantation	30	27	6
	326	203	58

4.2.2 Periodic basal area increment

Gelawdiwos

In total 328 trees with a DBH > 10cm periodic (five years) basal area increments (BAI) were estimated by taking 96 increment core samples. The periodic increment analyses were made for two consecutive periods, from 2005 up to 2009 (period one) and from 2010 up to 2014 (period two). As a result, total Gelawdiwos forest mean basal area increment in period one was 2.97m^2ha^{-1} and in period two was 3.03 m^2ha^{-1} (Table 14). The current mean basal area of the whole forest was 20.55m^2ha^{-1}; this indicates that 29% of current basal area was coming up within 10 years. The period one and two BAI are 9.57m^2ha^{-1} and 9.00m^2ha^{-1} respectively.

Table 14: Periodic increment per ha at plot level at Gelawdiwos

Plot	ba.inc_2010-2014 (m^2/ha)	ba.inc_2005-2009 (m^2/ha)	2014(m^2/ha)
1	9.00	9.57	54.17
2	2.41	2.03	14.20
3	2.71	2.60	12.13
4	4.90	4.21	35.46
5	0.99	1.04	4.17
6	2.27	2.22	7.32
7	2.79	2.52	26.89
8	2.23	1.97	7.42
9	4.24	2.83	40.23
10	2.16	1.75	12.70
11	1.26	0.94	5.67
12	5.41	4.66	64.37
13	3.09	3.24	27.53
14	3.38	3.35	27.75
15	3.09	2.67	16.40
16	0.00	0.00	0.00
17	6.59	5.88	23.22
18	0.68	0.54	1.31
19	0.60	0.54	1.71
20	2.07	1.94	17.22
21	3.25	8.05	18.14
22	6.14	4.97	34.51
23	3.11	2.96	26.90
24	4.84	5.35	39.34
25	1.33	1.13	9.78
26	3.17	3.06	67.08
27	1.67	1.53	10.40
28	1.57	1.75	6.05
29	3.76	3.61	27.56
30	2.17	1.77	10.20
31	4.33	3.46	14.33
32	1.31	2.57	13.23
33	5.35	4.78	13.99
34	1.16	1.48	7.43
mean	**3.03**	**2.97**	**20.55**
SD	**1.95**	**2.07**	**17.10**

The average BAI contribution of the all tree species within one hectare were 0.099 m^2ha^{-1} and 0.101 m^2ha^{-1} period one and two respectively. However, the contributions of each species within a hectare were different. As result, *Chionanthus mildbraedii* was the highest contributor in both periods. It has covered 25% of the BAI of the whole species in the hectare, in period one the value was 0.746 m^2ha^{-1} and in period two, it was 0.744 m^2ha^{-1}. This result indicates that basal area and number of individuals per hectare influenced BAI. The lowest contributor species was *Allophylus abyssinicus* (0.001 m^2ha^{-1}) in both periods, which had provided only 0.03% of the increment (Table 15 and Figure 37).

Table 15: Contribution of species for increment per ha at Gelawdiwos

No.	Species	2014-2010(m^2/ha)	2009-2005(m^2/ha)	Ba_2014
1	*Buddleia polystachya*	0.062	0.047	0.199
2	*Bersama abyssinica*	0.022	0.013	0.048
3	*Croton macrostachyus*	0.243	0.232	0.818
4	*Apodytes dimidiata*	0.200	0.179	1.637
5	*Allophylus abyssinicus*	0.001	0.001	0.032
6	*Maytenus undata*	0.026	0.028	0.115
7	*Schefflera abyssinica*	0.084	0.089	1.487
8	*Vernonia amygdalina*	0.007	0.008	0.036
9	*Combretum molle*	0.054	0.035	0.120
10	*Koma*	0.046	0.048	0.420
11	*Dovyalis abyssinica*	0.128	0.138	0.485
12	*Kotkoto*	0.012	0.008	0.023
13	*Euphorbia abyssinica*	0.385	0.344	1.353
14	*Kumbel*	0.013	0.007	0.056
15	*Maesa lanceolata*	0.032	0.033	0.074
16	*Clausena anisata*	0.012	0.009	0.042
17	*Grewia ferruginea*	0.009	0.008	0.031
18	*Ekebergia capensis*	0.117	0.108	2.325
19	*Eucalyptus globulus*	0.053	0.104	0.536
20	*Rhus glutinosa*	0.006	0.005	0.021
21	*Teclea nobilis*	0.077	0.073	0.427
22	*Albizia gummifera*	0.369	0.294	0.981
23	*Myrica salicifolia*	0.032	0.028	0.112
24	*Galiniera saxifraga*	0.020	0.013	0.069
25	*Chionanthus mildbraedii*	0.744	0.746	7.924
26	*Dombeya torrida*	0.074	0.219	0.393
27	*Bridelia micrantha*	0.039	0.015	0.101
28	*Ficus ovata*	0.044	0.040	0.252
29	*Podocarpus falcatus*	0.071	0.054	0.309
30	*Calpurnia aurea*	0.050	0.042	0.123
	Mean	**0.101**	**0.099**	**0.685**
	SD	**0.156**	**0.152**	**1.483**
	Mean basal area per ha	**3.030**	**2.971**	**20.552**

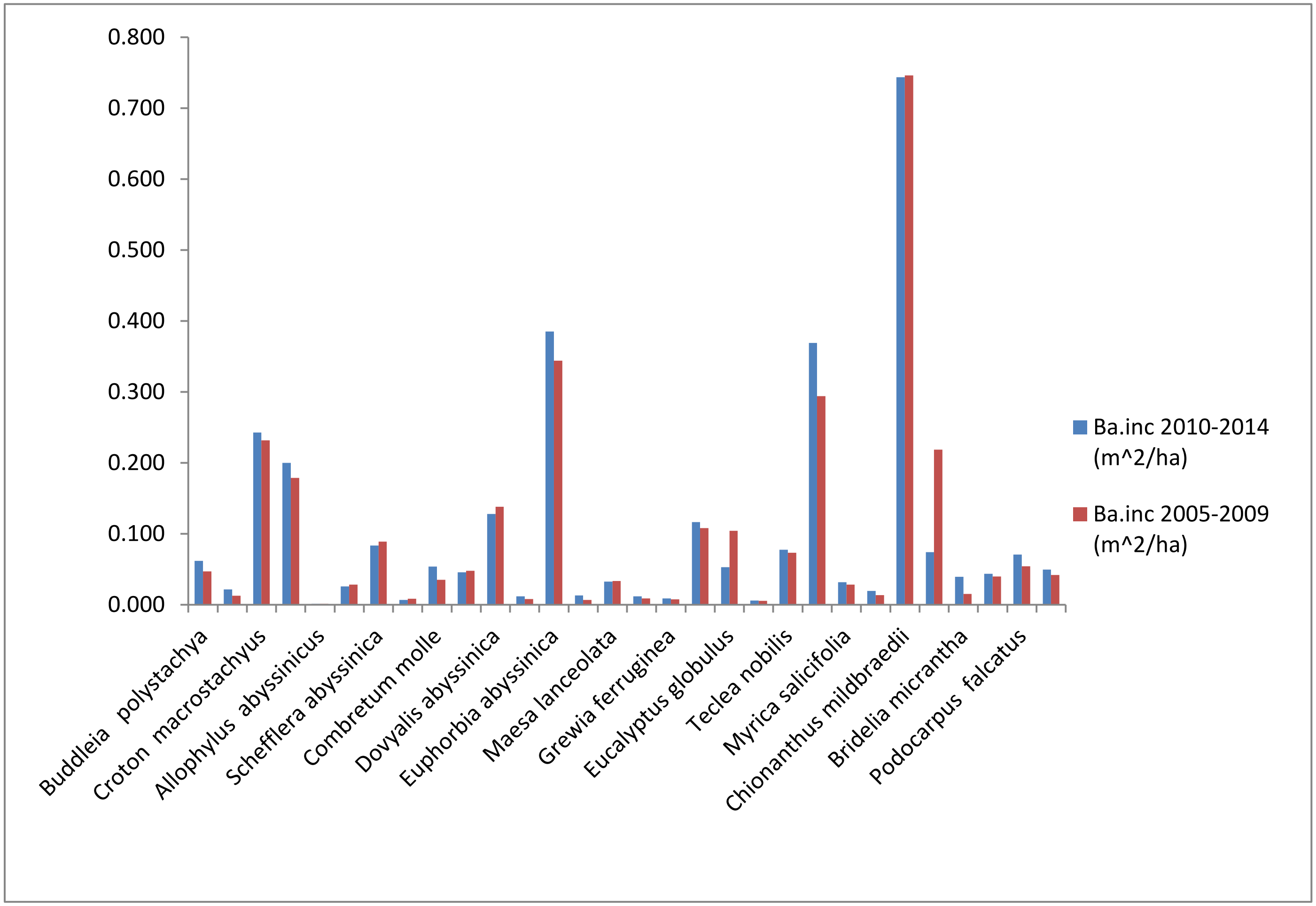

Figure 37: The contribution of each species per ha at Gelawdiwos

Metema

In total 257 trees with a DBH > 10cm periodic (five years) basal area increments (BAI) were estimated by taking 80 increment core samples. The periodic increment analyses were made for two consecutive periods that is from 2005 to 2009 (period one) and from 2010 to 2014 (period two). As a result, the mean basal area increment in period one was $1.23 m^2 ha^{-1}$ and in period two was $1.39 m^2 ha^{-1}$ (Table 16). The current mean basal area of the whole forest was $6.79 m^2 ha^{-1}$; this indicates that 39% of current basal area was coming up within 10 years. The maximum BAI in period one was $3.18 m^2 ha^{-1}$ and in period two was $3.15 m^2 ha^{-1}$.

Table 16: Periodic increment per ha at plot level at Metema

Plot	ba.inc_2010-2014 (m^2/ha)	ba.inc_2005-2009(m^2/ha)	2014(m^2/ha)
1	0.36	0.35	1.46
2	1.17	1.51	8.03
3	1.70	1.35	8.71
4	1.55	1.28	7.58
5	2.35	1.91	10.66
6	1.63	1.43	7.94
7	0.80	0.73	3.69
8	3.15	3.18	14.78
9	1.97	1.34	8.85
10	1.06	1.13	8.49
11	1.23	0.88	6.14
12	1.88	1.81	6.74
13	1.56	1.48	6.94
14	1.59	1.30	4.04
15	1.13	0.97	7.83
16	0.76	0.58	3.02
17	2.14	1.99	12.70
18	1.67	1.33	7.51
19	0.00	0.00	0.00
20	0.00	0.00	0.00
21	1.45	1.30	7.48
mean	**1.39**	**1.23**	**6.79**
SD	**0.76**	**0.71**	**3.76**

As mentioned above, each species had a different contribution for periodic increment of the forest. Accordingly, the mean contributions of the whole tree species within a hectare were 0.042 $m^2 ha^{-1}$ and 0.048 $m^2 ha^{-1}$ for period one and two, respectively. However, the contributions of each species within a hectare were different. In Metema, the frequency of the species highly influenced results of BAI. As a result, in both periods, the highest contributor species was *Sterculia setigera*, which covered 12% and 13% of the BAI of the hectare and yield the values of0.151 m^2ha^{-1} and two 0.181 m^2ha^{-1} for period one and two respectively. The lowest contributor species was Zobi (0.001 m^2ha^{-1}) in both periods, which had only provided 0.07% of increment per hectare (Table 17 and Figure 38).

Table 17: Contribution of species for increment per ha at Metema

No.	Species	2014-2010(m^2/ha)	2009-2005(m^2/ha)	Ba_2014
1	Abalo	0.034	0.039	0.158
2	Abetere	0.015	0.018	0.054
3	Alasha	0.004	0.007	0.026
4	Ameja	0.077	0.068	0.263
5	Ameshe gwariya	0.022	0.015	0.102
6	chamida	0.052	0.039	0.131
7	charya	0.065	0.057	0.564
8	chelekilika	0.054	0.039	0.304
9	Dabda	0.004	0.003	0.017
10	Darlie	0.181	0.151	1.009
11	dawuda	0.082	0.059	0.350
12	dergeja	0.025	0.018	0.110
13	Enkoy	0.005	0.003	0.018
14	Enkudikuda	0.005	0.004	0.023
15	Etse Menahi	0.007	0.006	0.030
16	fola	0.096	0.081	0.331
17	forha	0.071	0.056	0.277
18	Gambilo	0.011	0.019	0.068
19	Guwarya	0.054	0.061	0.116
20	kirikira	0.047	0.083	0.483
21	kongera	0.055	0.055	0.173
22	Kukuba	0.009	0.008	0.054
23	lenquata	0.011	0.012	0.037
24	qurqura	0.074	0.041	0.184
25	Wacho	0.026	0.032	0.099
26	waliya meker	0.180	0.140	0.841
27	Wenbela	0.116	0.113	0.949
28	werkina	0.004	0.003	0.012
29	zobi	0.001	0.001	0.006
	mean	0.048	0.042	0.234
	SD	0.049	0.041	0.282
	Mean BA per ha	1.388	1.230	6.790

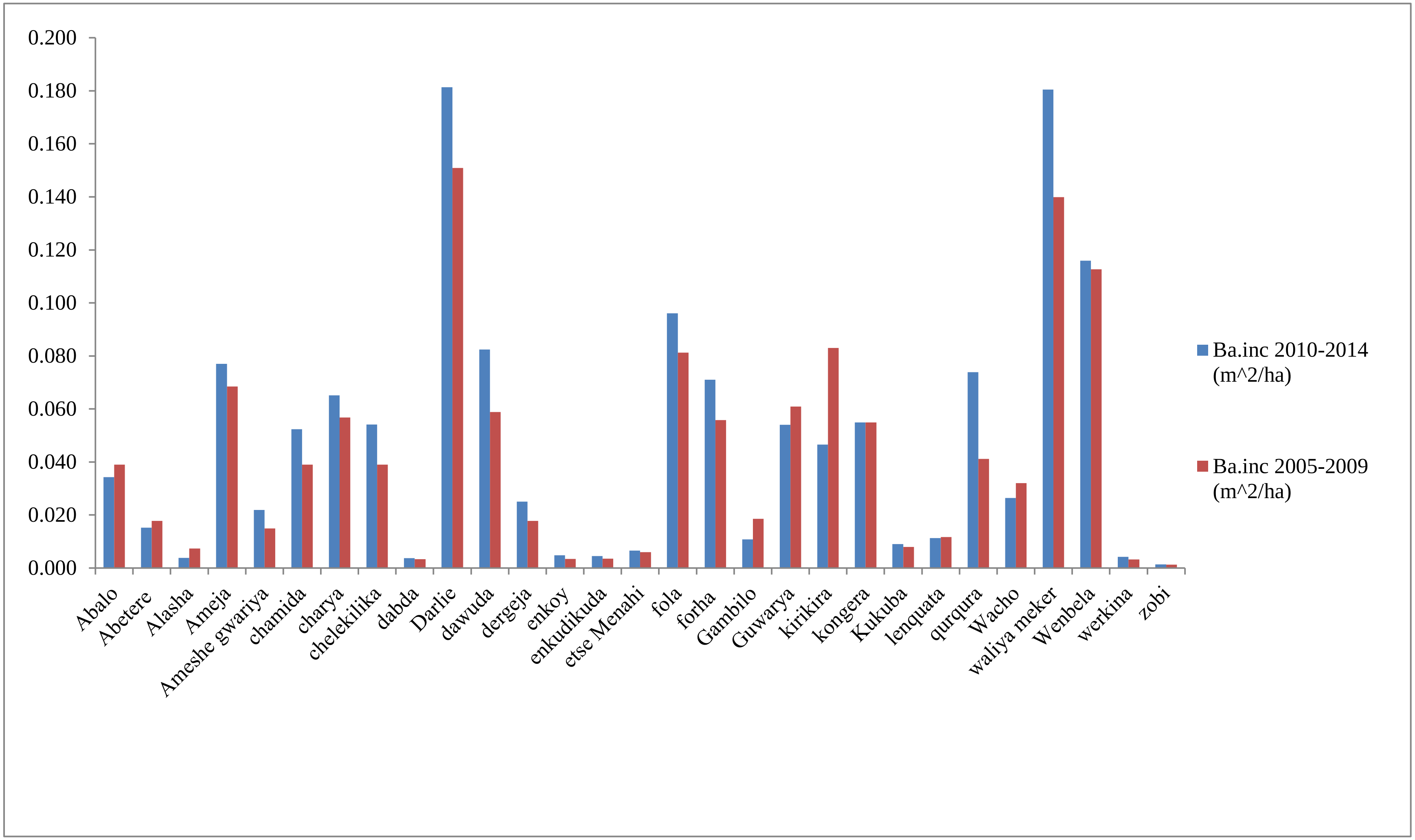

Figure 38: The contribution of each species per ha at Metema

Gelawdiwos plantation forest

The current total basal area of the forest is 16.01 m^2ha^{-1}. *Cupressus lusitanica* is also dominant in the stand in terms of basal area. The two successive periods gave an average BAI of 4.02 and 4.3 (Table 18). As the result, the 53% of the BAI is coming up within 10 years. The maximum BAI in period one was 9.57m^2ha^{-1} and in period two, was 6.57m^2ha^{-1}. This has been found in the dense part of the stand.

Table 18, Periodic BAI per hectare

Plot	ba.inc_2010-2014 (m^2/ha)	ba.inc_2005-2009(m^2/ha)	2014(m^2/ha)
1	1.20	2.40	10.14
2	3.49	2.21	16.09
3	0.00	0.00	0.00
4	5.31	6.66	30.63
5	2.07	2.57	8.64
6	3.60	4.11	17.64
7	8.43	6.57	20.52
8	8.43	6.25	16.12
9	4.00	4.98	22.65
10	7.78	7.11	19.61
11	8.32	4.82	21.95
12	7.64	5.86	27.52
13	0.92	0.89	2.45
14	4.32	3.23	15.63
15	7.73	7.68	40.32
16	2.60	3.32	15.21
17	0.00	0.00	0.00
18	6.17	5.91	16.06
19	2.32	3.04	13.44
20	1.91	2.73	5.67
mean	**4.31**	**4.02**	**16.01**
SD	**2.96**	**2.34**	**10.14**

The density of the trees influenced the contribution of each species to BAI. For instance, the contribution of *Cupressus lusitanica* (2.17 m^2h^{-1} and 2.68 m^2h^{-1}) is nearly four times greater than the average of all of the trees (0.67m^2h^{-1} at first period and 0.71m^2h^{-1} in the second period). The second contributor is *Eucalyptus globules,* which contributed 35 % of the whole increment per hectare. The lowest contributor is *Croton macrostachyus,* which contributed only 0.4% for overall BAI per hectare (Table 19 and Figure 39).

Table 19, Contribution of species for BAI

No.	Species	2014-2010(m^2/ha)	2009-2005(m^2/ha)	Ba_2014(m^2/ha)
1	*Acacia decurrens*	0.095	0.137	0.283
2	*Croton acrostachyus*	0.019	0.018	0.160
3	*Eucalyptus globulus*	1.292	1.569	7.358
4	*Albizia gummifera*	0.051	0.014	0.093
5	*Eucalyptus camaldulensis*	0.174	0.109	0.753
6	*Cupressus lusitanica*	2.680	2.170	7.367
	mean	**0.719**	**0.670**	**2.669**
	SD	**1.077**	**0.950**	**3.643**
	Mean Ba per ha	**4.312**	**4.017**	**16.014**

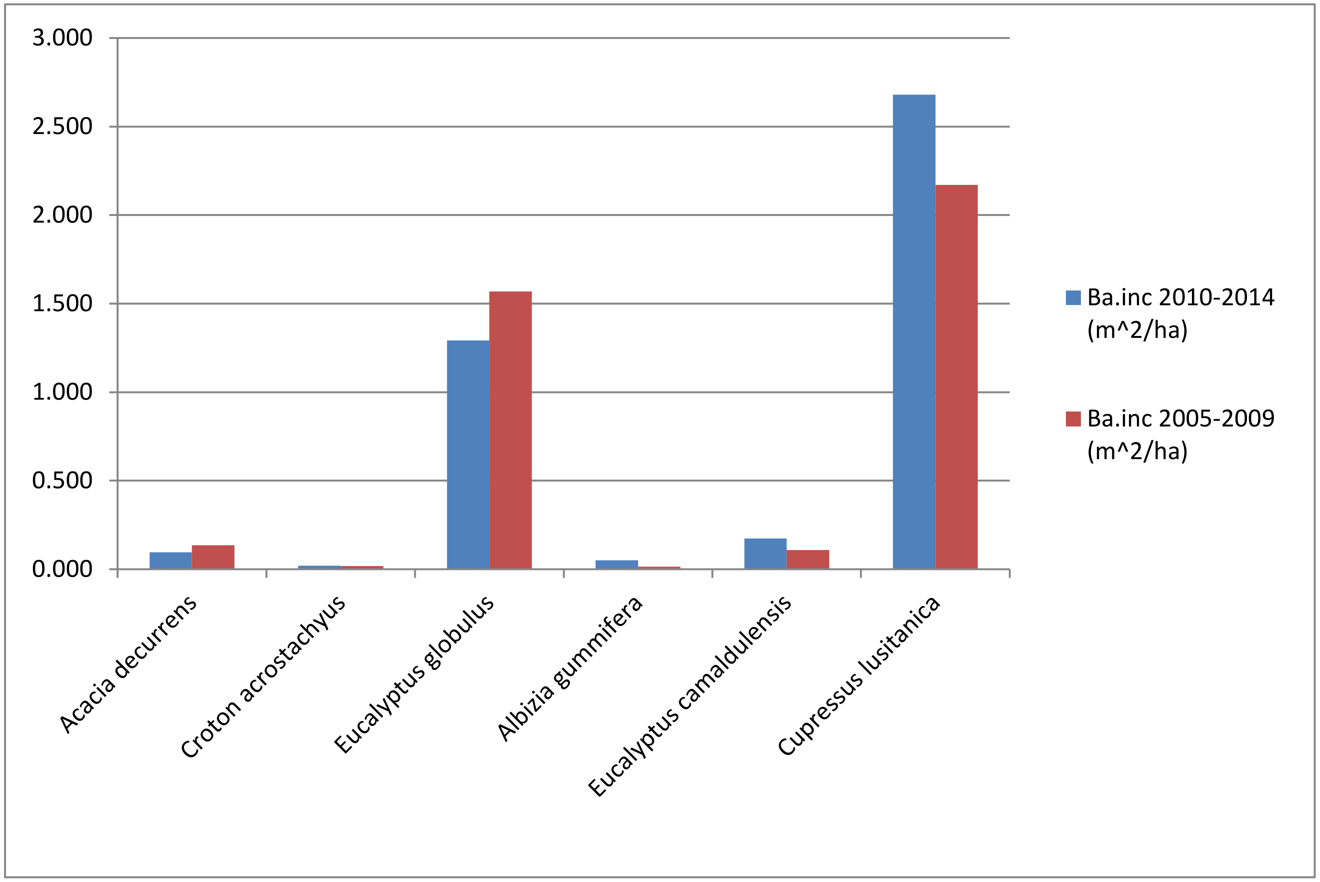

Figure 39: Periodic basal area increment per hectare among the species at Gelawdiwos plantation forest

4.2.3 Basal area Increment along the region and land use

A two way between subjects ANOVA was conducted to compare the two successive BAI measurements in Gelawdiwos and Metema natural forest and Gelawdiwos plantation forest. Additionally, the analysis was also used to compare increments of two successive growing periods within each forest.

It was found that there was no significant difference between the increment of Gelawdiwos natural and plantation forest in both growth periods. However, Metema forest had significantly different increments in both growing periods.

There was no significant difference between the two periodic BAI increments within each forest. This result revealed that there was constant BAI within the previous 10 years (Table 20).

Table 20, Analysis of variance (ANOVA) among land use and region

No.	Region	Gelawdiwos	Metema	Plantation
1	**Ba.inc_2010-2014 (m^2/ha)**	3.01 ± 2.04^a	1.38 ± 0.75^b	4.31 ± 2.96^a
2	**Ba.inc_2005-2009 (m^2/ha)**	2.84 ± 1.88^a	1.23 ± 0.71^b	4.01 ± 2.33^a

As we have seen in Figure 37, Metema has a comparatively narrow box plot which indicates that they have less variability in the value of BAI in both periods. 50 % of BAI values were found between the ranges of 1.5 to 2 m^2h^{-1}. However, it had two extreme small and large values in period two, whereas, in period one only one extreme value was found.

Gelawdiwos has relatively similar values of BAI distribution in both periods. 50 % of BAI fell between the range of 2 m^2h^{-1} - 4 m^2h^{-1}. This indicates that there was a relatively similar growth pattern throughout the forest area. However, there are two outliers in growth period one and one outlier in period two, these might be due to an area where trees with large DBH were concentrated.

The plantation BAI had relatively different distributions between the periods. In period one and two 50% of BAI were found between the interval 2 m^2h^{-1} – 6 $m^2h^{-1}$and 2 m^2h^{-1} - 8 m^2h^{-1} respectively. Within the growing period larger variability was found among the area of the forest, which might have happened due to uneven distribution of the trees. For instance, in some parts of the forest there was areas of extremely high density reaching 1800 trees per hectare.

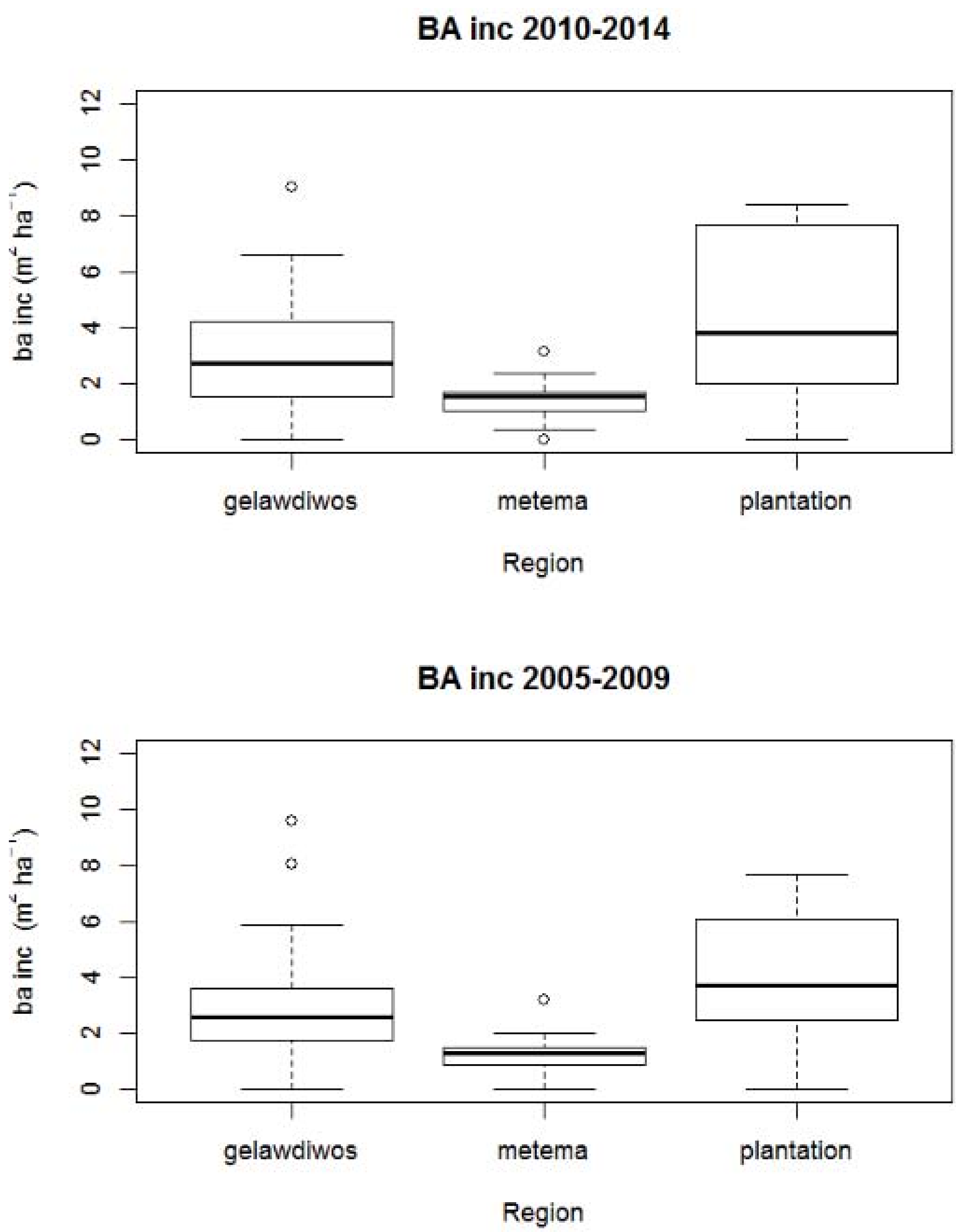

Figure 40: Period 1 and 2 basal area increment across the region

5. DISCUSSION

5.1 Diversity

5.1.1 Tree and shrub species composition

Tree and shrub species composition of vegetation might be showed as species abundance, richness and life form (Lamprecht, 1989). In this study, a total of 123 trees and shrub species, excluding herbs and climbers, were identified within four study regions. These species represent 46 families. Among them, the highest numbers of species were found at Tara Gedam and Injibara.

In Tara Gedam, 64 % of species were at sapling and seedling stage. This indicates that the Tara Gedam forest was at an early stage (Martin and Gower, 1996). While, in Gelawdiwos and Injibara 70% of species were found at tree stage. In addition, the density of the trees per hectare result, shows that these forests were at the climax stage of succession (Martin and Gower, 1996).

In Metema forest, 34 species were identified, and from them, 50% the species were only found as a form of a tree, which means half of the species have not regenerated. Moreover, only 6% of species were found in all the stages of life. These results revealed that the forests have a regeneration problem. This happened due to adverse environmental conditions and intensive free cattle grazing which did not allow for seedlings to grow (Wale et al., 2012).

The number of 42 species identified in Gelawdiwos was equal to the number species that was reported the in a similar study 10 years before (Wassie et al., 2005). This indicates that the forest has not lost species within 10 years.

5.1.2 Species diversity

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 Shannon evenness index.

This study was conducted in the levels of Alpha and Gamma diversity. Gamma diversity is overall diversity in a collection of sample units (Jost, 2005). Accordingly, in overall species diversity, Tara Gedam forest had the highest species diversity in both indices and also in the evenness index. Metema forest exhibited the next highest relative abundance. In terms of species diversity, after Tara Gedam, the highest species diversity was recorded in Metema and Gelawdiwos.

The highest number of species was recorded in Injibara. However, compared to others, this forest has less species diversity (H'=2. 91 and D=11. 78) and abundance (J=0. 74). This indicates that the Injibara forests have been dominated by a few species. For instance, IVI revealed that the first five dominant species dominancy index value is much higher than the rest of the species, found in Injibara.

In species evenness index, the highest value was observed in Metema, due to a lower dominancy effect among the species. According to the value of IVI, the dominance of one species is relatively less (*Boswellia Papyrifera*= 33%). Although in Injibara, from one species, only 87% (*Albizia gummifera*) IVI value was recorded. Therefore, the lowest relative abundance was observed in Injibara forest.

Overall species diversity (gamma diversity) masked the attribute of the forest diversity. Therefore, analysis of alpha diversity helps to know how the forest looks like in detail. Alpha diversity shows the diversity of species in individual sample units (Jost, 2005). Accordingly, on the main plot in both diversity indices (Shannon and Simpson), the highest tree and shrub diversity was observed in Metema forest. However, in sapling and seedling level, significantly lower species diversity was observed (table 4). This indicated that most of the species were found at tree level. Moreover, as described at the part of tree and shrub species composition, most of the species found in the main plot have no seedlings and saplings to replace them. This happened due to erratic rainfall and long dry spells that are frequently observed in the region (Wale et al., 2012). The species evenness value was also less among the region, even though, the relative distribution within a tree, sapling, and seedling were significantly different (Table 6).

The Tara Gedam forest has shown the lowest tree species diversity. However, in sapling level, it showed highest species diversity and species richness. This indicates that the most species present were shrub species. Moreover, as explained in the tree and shrub composition of the region, from the completely recorded species, more than 50% species were found only in this level. Seedling diversity was also less observed in both diversity indices. This indicates that, in earlier times, the forest was highly disturbed by encroaching mature tree individuals. For instance, the highest numbers of stump per hectare were observed in Tara Gedam, which is 13 tree stumps per hectare. For that matter, 12% of the forest trees have ≥ 10cm diameter was cut off by encroachment.

Gelawdiwos forest followed in second place in both diversity indices in diversity of tree, sapling and seedling. As we have seen in Figure 16, 50% species were present in all stages (tree, sapling and seedling). This shows that the forest is in good condition and most of the species have regeneration. The relative distribution of the tree was also found to be higher than the other, but the seedlings were rarely evenly distributed through the forest. This indicates tree species were relatively distributed throughout the forest (Jost, 2010).

As we have seen in gamma diversity, Injibara had lowest diversity. However, in alpha diversity, it showed highest tree diversity and highest sapling and seedling diversity. There was not much difference in the diversity value of Injibara forest, when compared to the region, which had the highest diversity. This indicates that the forest is found, relatively, in good state and with less human interference.

5.1.3 Similarity

Similarity index is used to compare the species diversity of one forest with another forest, and it can give a general impression of the ecosystem overall species richness, diversity and phytogeographical similarity (Mohammed and Abraha, 2013). According to Wallace, phytogeography shows the geographical distribution of the species and their influence on the ecosystem (Wallace, 1895). With this consideration, each forest is compared to see the distribution pattern of tree and shrub species among those study forests, and to determine the relative similarity in tree and shrub species composition. To evaluate the similarity of the forest, Sorensen's similarity index was applied (Krebs, 2014).

The result of similarity ratio support null hypothesis. Therefore, Gelawdiwos and Tara Gedam had the highest similarity ratio (Table 7), they shared 30% of the species. This may be due to geographical proximity and similarity in elevation and climatic zone of the forests area

(Gurmessa et al., 2013). Gelawdiwos and Injibara shared 21%, and Injibara and Tara Gedam shared 20% of their species. In general, these three forests have shared a significant number of species.

Metema forests had very high dissimilarity with the other three forests because the altitude (835 masl), mean temperature, and mean precipitation of the Metema site are obviously very different from other study sites. However, Metema shares two species with Gelawdiwos (*Combretum molle* and *Grewia ferruginea*) and Tara Gedam (*Grewia ferruginea* and *Acacia seyal*), and three species with Injibara (*Grewia ferruginea*, *Combretum molle* and *Ximenia Americana*). These species are known to be widespread in Ethiopia, particularly *Ximenia Americana* can grow in 500-2450 m altitudinal range (Edwards, 1995).

5.1. 4 Density and basal area

The density of trees ranges between 307stem ha^{-1} at Gelawdiwos and 129 stem ha^{-1}at Tara Gedam. The density of sapling/shrub < 10m was 3,273 individuals ha^{-1}at Tara Gedam and 667 individuals ha^{-1}at Metema. The density of regeneration range between 19,814 individual ha^{-1}at Injibara and 655 individual ha^{-1}at Metema. The highest basal area was observed in Gelawdiwos (20 m^2/ha) and followed by 12.25 m^2/ha at Injibara. The lowest basal area was recorded 6.81 and 6.61 m^2/ha at Tara Gedam and Metema respectively.

Alemayehu, reported 1109 ha^{-1} number tree and 52m^{2}h^{-1} basal area per hectare at Gelawdiwos, but in this study 307 steam ha^{-1} and 20 m^2/ha basal area were found (Wassie et al., 2005). In addition, in Tara Gedam forests, several studies were conducted. However, the results of most of the study highly deviated from each other. For instance, in this study at Tara Gedam, the density of species was found to be 5247h^{-1}, whereas, Zegeye and Gedefaw reported values of 3001h^{-1} and 7155h^{-1} (Gedefaw and Soromessa, 2014; Zegeye et al., 2011). The lack of consistency among the result of the studies may be due to the sampling method used. These influence the decision-making processes and may be led to mismanagement system. Therefore, formulation of permanent inventory design throughout the country helps to avoid this confusion.

According to Murphy review report, the dry tropical forests across the world reported basal area between 17 and 40 m^2/ha (Murphy and Lugo, 1986). This means that only Gelawdiwos forest falls in the range of dry tropical forest basal area, therefore, other our studied forest have been highly disturbed compared to tropical dry forest.

5.1. 5 Regeneration and Diameter distribution

The pattern of DBH class distribution indicated the general trends of population dynamics and recruitment processes of the species (Zegeye et al., 2011). The overall seedling and sapling diameter distribution analysis was conducted by separating the DBH into 0-9 cm (regeneration stages), and above the 10 cm DBH, it was put into tree and shrubs. It is categorized in two parts because it helps to quantify the proportion of the seedling, sapling and tree/shrub stage in detail. Accordingly, the regeneration parts were again classified into seedling stage (0-5 cm) and sapling stage (5-10 cm).

The proportion of seedling and sapling number determined regeneration status of the forest. Generally, it is a good regeneration if the seedling number is more than the sapling number and a poor regeneration if the seedling number is less than sapling (K et al., 2010).

As a result, in Gelawdiwos and Injibara, the number of seedlings was significantly higher than the number of saplings (Table 6), which suggests that they have good regeneration potential. However, at Metema and Tara Gedam, the number of seedlings was found to be significantly lower than the sapling count (Table 6), which indicates that the forests are in poor regeneration status. The major reason for poor regeneration of Metema and Tara Gedam forest are unfavorable environmental conditions, such as elongated dry season, erratic rainfall, rocky land, and poorly developed soil (Wale et al., 2012). The human disturbance, particularly intensive livestock grazing and selective cutting of mother trees might be the reason. As Alemayehu reported church and monasteries forest are believed as the property of GOD, consequently, considered sacred, therefore, trees in the compound are not to be cut unless for the purpose of church itself (Alemayehu et al., 2005). However, during inventory the evidence of livestock grazing and tree encroachment tree were observed at Tara Gedam, whereas in Metema the outside human intervention is low but during data collection the property of monastery cattle intense grazing were observed.

The general pattern of diameter distribution of Gelawdiwos and Injibara forests looks like inverted J shaped distribution, where, the majority of the tree individuals are distributed in the first DBH class. This showed that the inverse relation between diameter class and number of individuals. Therefore, the DBH class size increases, the number of individual gradually decreases (Figure 26). These general tree and shrub distribution patterns indicate a healthy status of Gelawdiwos and Injibara forests forest.

5.1.6 Important Value Index and Population structure of Dominant species

The important value index is imperative to compare the ecological significance of species. It indicates the extent of dominance of a species in the structure of a forest. It is stated that species with the greatest importance value are the leading dominant species of the forest (Gebrehiwot and Hundera, 2014). Accordingly, the five leading dominant species in Gelawdiwos in descending order: *Chionanthus mildbraedii, Euphorbia abyssinica, Albizia gummifera, Croton macrostachyus,* and *Dovyalis abyssinica*. *Chionanthus mildbraedii* (62%) is an enormously dominant species in the whole forest; due to its high basal area, and being an upper story tree. For example, second dominant species *Euphorbia abyssinica* had a dominancy index value of only 32%. Similarly the five leading dominant species of Injibara are: *Albizia gummifera* (87%), *Croton macrostachyus* (29%),*Prunus Africana* (29%), Kenebela (22%) and Gimibilitini (18%). *Albizia gummifera* is a highly dominant species due to its occurrence in very high frequency. The five leading dominant species in Metema are: *Boswellia Papyrifera, Sterculia setigeraI, Terminalia laxiflora,* Fola and *Pterocarpus lucens.* In Tara Gedam, the dominant species are: *Juniperes procera, Acacia Abyssinica, Buddleia polystachya, Albizia gummifera,* and *Croton macrostachia.* In Metema and Tara Gedam the IVI value of the dominant species are very similar which indicates that, the distribution pattern of most species was relatively similar throughout the forest.

In general, those revealed dominant species are the most ecologically important species in their region. However, IVI also helps to identify the endangered species and those species need first priority in conservation effort. Accordingly, the species with low IVI values need conservation.

Population structures of trees have significant implication on their management, sustainable use, and conservation. The diameter distribution of dominant species exhibited different trends from species to species within a region, and different regions for the same species, showing different diameter distribution patterns, for example, *Albizia gummifera* (Fig. 27b, Fig. 28a and Fig. 30d). However, the same species were also dominant in more than one region, showing more or less similar patterns in all regions, for example *Croton macrostachia* (Fig. 27d, Fig. 28b and Fig. 30e). In General, the diameter distribution pattern was categorized in the following pattern:

a. Species having bell shaped, which showed that the number of individual in the middle diameter classes is high, and low, in the lower and higher diameter class.
   Species having bell shaped pattern, from Gelawdiwos: *Chionanthus mildbraedii, Albizia gummifera, Croton macrostachyus,* and *Euphorbia abyssinica.*
   From Injibara: *Croton macrostachia* and Gimibilitini.
   From Metema: Fola
   From Tara Gedam: *Juniperes procera, Albizia gummifera, Buddleia polystachya,* and *Croton macrostachia.*
b. Species having irregular shaped, in which they are distributed differently in almost all class, and had absence of individuals between diameter classes. Those species are: From Gelawdiwos: *Dovyalis abyssinica* and *Ekebergiacapensis*
   From Injibara: Kenebela
   From Metema: *Terminalia laxiflora* and *Pterocarpus lucens.*
c. Species having inverted J-shaped, showed that the species frequency was highest in the lower diameter class, and decreased gradually towards the higher class. Those species are:
   From Injibara: *Albizia gummifera* and *Prunus Africana*
   From Tara Gedam: *Acacia Abyssinica*
d. Species having J shaped distribution, which showed that the number of individuals was low in the lower diameter classes, and increased towards the higher diameter classes.
   These species are: *Boswellia Papyrifera* and *Sterculia setigeraI* at Metema.

Species grouped in ‘a’ (bell shaped) indicate a poor reproduction and recruitment potential. The species grouped in ‘b’ (irregular shaped), indicate selective cutting. The species grouped in ‘c’ (inverted J pattern), indicate good biological functions and recruitment capacity for the species. The species grouped in ‘d’ indicate less competent to reproduce, and hence reveal poor reproduction and weaker position in regeneration. In general, other than group ‘c’, all other groups exemplified unstable population structure of different sort, which may have resulted under the influence of different natural or anthropogenic disturbances, including exploitation of individuals of woody plants within desirable diameter classes by stakeholders or poachers.

5.2 Growth rate

5.2.1 Cross dating

"Cross dating or tree-ring dating, has mostly been limited to temperate and boreal regions, because of their marked climate seasonality that induces the periodic formation of growth rings with clear wood anatomical boundaries in trees" (T. H G Wils et al., 2011). "Dendrochronology has not been widely applied in tropical forest due to the common assumption, yet erroneous, that tropical trees are lacking annual rings" (Lieberman et al., 1985; Milton et al., 1994). Several reasons may be given for the limited success. Among the reasons, many tropical trees have indistinct growth rings and the cycle of growth rings may be annual, bi-annual or irregular (Berlyn, 1982).

However, growth rings may still be observed periodically in arid and semi-arid areas in the tropics, where moisture is the main limiting factor and there is variation of precipitation between the rainy season and dry season (T. H G Wils et al., 2011; Worbes et al., 2003). In addition, drought and dormancy may result in the formation of growth rings, because of moderately dry season, coarse and well-drained soil. Hence, many tropical forest trees rings have proven the existences of annual rings (D.W et al., 1999; Eshete and Ståhl, 1999; Halle et al., 1978; Tommy H G Wils et al., 2011; Worbes et al., 2003).

Ethiopia has few and fragmented experiences with cross dating tree rings. The successful studies were reported in Acacia species (Eshete and Ståhl, 1999; Gebrekirstos et al., 2008) and Juniper *procera* (Bräuning et al., 2010) trees from the southern lowland of Ethiopia. Similar successful studies have been reported in tree species of *Juniper procera, Ekebergia capensis* and *Prunes africana* from northern highland of Ethiopia (T. H G Wils et al., 2011; Tommy H G Wils et al., 2011).

This study estimates the growth rate of the forest of natural and plantation forest in two regions. To do this, 326 increment core samples were collected. 118 core samples from Gelawdiwos forest, 178 core samples from Metema, and 30 core samples from a plantation forest were collected. From them, 203 core samples were successfully cross-dated for 58 species. 90% of the samples from plantation forest, 68% from Metema forest, and 53% from Gelawdiwos forest were successfully cross-dated. The success of cross dating of the plantation was higher because the number of species found was less compared to others.

The reasons for the higher success rate of the samples in cross dating is attributed to the study area having an unimodal precipitation pattern (Figure 1).The trees found in the areas experiencing unimodal precipitation patterns have a distinct rings and reliable annual rings due to the prevailing long, dry season (Tommy H G Wils et al., 2011). However, during this process, unsuccessful cross dating occurred due to the samples being broken and showing false, indistinct, or missing rings.

5.2.2 Periodic basal area increment

The extensive logging of natural forest broadened the discussion about and installation of sustainable management systems throughout the world. The success of these systems is bound to an exact knowledge of growth rates of trees and productivity of natural forest (Worbes et al., 2003). The knowledge of growth rate and productivity of natural forest has been rather poor (Yitebitu et al., 2010). Some plantation forest enterprises have conducted growth rate estimations for a few species by repeating the measurement of DBH.

Mostly, the study of growth rate in Ethiopia, with an emphasis on tree ring measurements, has been conducted by estimating growth rates for individual trees. There have been limitations affecting the ability to estimate growth rate of the whole forest (Eshete and Ståhl, 1999; Gebrekirstos et al., 2008; Tommy H G Wils et al., 2011). Our results, however, estimated the growth of the whole forest. These results help to plan the yield of a tree, a species, and an entire forest stand.

According to the null hypothesis, the periodic basal area increment (PBAI) of plantation forest is significantly higher than the natural forest because in plantation forests well proper management is carried out and the trees encounter less computation for utilization of resources(Jordan and Farnworth, 1982). However, the result of this study does not support the null hypothesis as it was found that there is no significant difference between plantation and natural forests of Gelawdiwos region in both growing periods (Tabale 20). This is likely a result of the density of the plantation forest being highly influenced by BAI. The mean density of the plantation forest is much higher than in the Gelawdiwos natural forest, at 570 tree per hectare (Table 4). In addition, plantation forests are composed of the same species which competes for the same resources, therefore influences the rate of growth of the forests.

Theoretically, the growth rates of the trees decrease, when the age of the tree increases. However, the result of the study shows that there is no significant difference between the two consecutive growth periods of Gelawdiwos forest, Metema forest, and the plantation forest. This result might be due to the age of individual trees being different in the natural forest which yields a constant growth rate.

There is no published data to compare our result with other studies carried out in the country. The mean annual basal area increment of 0.6 m^2h^{-1} in Gelawdiwos forest exceeds the result of 0.46m^2h^{-1} from Nicaragua, and the result of 0.25 m^2h^{-1} from West African forests. Our result is less than the result of 1m^2h^{-1} from the Amazon forest (Marín et al., 2005; Nebel et al., 2001). Annual increment result of 0.26$m^2h^{-1}yr^{-1}$ in Metema is equivalent to the result of 0.2 $m^2h^{-1}yr^{-1}$of another similar region of tropical lowland forests (Louppe et al., 2008).

Periodic basal area increment (PBAI) contributions of the upper story trees are much greater than the understory trees. For instance, in Gelawdiwos, the highest growth rate is contributed by *Chionanthus mildbaedii* (0.744m^2ha^{-1} and0.746m^2ha^{-1}), which is in the upper story and is the dominant species in the forest. However, in Metema, the upper story tree does not influence the growth rate, this is due to the trees being sparsely distributed and having a low number of trees per hectare (94 ha^{-1}).Therefore, the contribution of species for PBAI per hectare is influenced by the dominance of the particular species.

6. CONCLUSION

The result of the study indicates that 123 species were documented from the four natural forests. In Injibara and Tara Gedam equally high numbers of species were recorded. In overall diversity, Tara Gedam forest showed higher species diversity than the other study areas while Injibara forest has showed the least species diversity is shown on both diversity indices. The evenness index shows that the Tara Gedam forest is more evenly distributed which is due to less dominancy effect among the species. However, due to the dominant effect of *Albizia gummifera* tree throughout the forest, Injibara forest shows a lower evenness index.

The similarity index displays the result that, Gelawdiwos, Injibara and Tara Gedam have shown close similarity due to the graphical proximity and climatic zone similarity. However, Metema forest has shown less similarity with other forests and only shared three of the same species. These three similar species are widespread across Ethiopia.

The result of the density and basal area measurements show that Gelawdiwos forest has a higher stem number and basal area per hectare than other forests. However, Tara Gedam forests has less trees than the other forests which indicates that the forest is highly disturbed by encroaching mature individual trees. In addition, this activity reduced the species regeneration potential in Tara Gedam forest due to the loss of mother trees and disturbance.

The result of the periodic increment (five year increment) shows that there is no significant difference between the growth rate of natural and plantation forest of Gelawdiwos. However, there is the significant difference the growth rate of Gelawdiwos and Metema natural forest, as well as between Gelawdiwos plantation forest and Metema natural forest.. The result of the two consecutive five year growth (2014-2010 and 2009-2005) shows that there is no significant difference between the growth rates of two consecutive periods. This is may be due to equality of the recruitment rate of new trees between the periods.

In general, according to the cross dating result, it is possible to estimate the growth rate of trees in Ethiopia, particularly the area having unimodal precipitation. However, this study conducted in specific area, therefore, further studies important in different part of Ethiopia to get better understanding on tree growth rate.

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10. LIST OF ABRIVATION

ARARI	Amhara region agricultural research institute
BA	Basal area
BAI	Basal area increment
cm	Centimeter
DBH	Diameter at breast height
EOTC	Ethiopian Orthodox Tewahido church
F	Frequency
ha	Hectare
IBC	Institute of biodiversity conservation
inc	Increment
IVI	Important value index
JICA	Japan International Cooperation Agency
km	Kilometer
m	Meter
mm	Millimeter
masl	Meter above sea level
N	Number of representing tree
PBAI	Periodic basal area increment
^{0}C	Degree centigrade
SARC	Sirinka agricultural research centre

11. REFERENCE

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12. APPENDICES

Appendix 1: List of tree and shrub species found in the study sites, with their scientific name and locale name

No.	Local name (Amharic name)	Local name (Awi name)	Scientific name	Family name	Gelawdiwos	Injibara	Metema	Tara Gedam
1	Abalo	Abalo	*Combretum molle*	Combretaceae	✓	✓	✓	
2	Abetere		*Ziziphus mucronata*	Rhamnaceae			✓	
3	Agam		*Carissa edulis*	Apocynaceae				✓
4	Alasha		*Dombeya quinquesta*	Stericuliaceae			✓	
5	Almit		*Discopodium penninervum*	Solanaceae	✓			
6	Ameja		*Hypericum gnidiifolium*	Guttiferae			✓	
7	Ameshe gwariya						✓	
8	Anfar		*Buddleja polystachya*	Loganiaceae				✓
9	Ashkori	Ashkori				✓		
10	Atat	Atat	*Maytenus undata*	Celastraceae	✓	✓		✓
11	Atquar		*Buddleia polystachya*		✓			✓
12	Azamer	Azamiri	*Bersama abyssinica*	Melianthaceae	✓	✓		✓
13	Bazira girara	Tsatsi	*Acacia abyssinica*	Fabaceae		✓		✓
14	Bimpini	Bimpini				✓		
15	Birbira	Waggaru	*Millettia ferruginea*	Fabaceae		✓		
16	Bisana	Bisana	*Croton macrostachyus*	Euphorbiaceae	✓	✓		✓
17	Chamida						✓	
18	Charyia		*Pterocarpus lucens*	Fabaceae			✓	
19	Cheba	Cheba	*Acacia nilotica*	Fabaceae	✓	✓		
20	Checho		*Ocimum gratissimum*	Lamiaceae				✓
21	Chelekilika		*Apodytes dimidiata*	Icacinaceae			✓	
22	Dabda						✓	
23	Darlie		*Sterculea setigera*	Sterculiaceae			✓	
24	Dawuda						✓	
25	Dedeho		*Euclea divinorum*	Ebenaceae				✓
26	Demakesie		*Ocimum lamiifolium*	Lamiaceae				✓
27	Dengorita	Dengorita	*Solanum giganteum*	Solanaceae		✓		
28	Dergeja		*Lannea fruticosa*	Anacardiaceae			✓	
29	Dokma	Bagootsi	*Strychnos spinosa*	Loganiaceae		✓		

30	Donga	Zindi	*Apodytes dimidiata*	Icacinaceae	✓	✓		
31	Donga seber				✓			
32	Embus	Keneberi	*Allophylus abyssinicus*	Sapindaceae	✓	✓		✓
33	Enkudikuda						✓	
34	Enqoqo		*Embelia schimperi*		✓			✓
35	Esina duri	Esina duri	*Myrsinaceae*			✓		
36	Etse Menahi						✓	
37	Feyele feji		*Flueggea virosa*	Euphorbiaceae	✓			✓
38	Fola						✓	
39	Forha						✓	
40	Gambilo		*Gardenia ternifolia*	Rubiaceae			✓	
41	Geram Atat	Geram Atat	*Maytenus undata*	Celastraceae	✓	✓		✓
42	Getem		*Schefflera abyssinica*	Araliaceae	✓			✓
43	Gimbltini	Gimbltini				✓		
44	Gorgoro						✓	
45	Grawa	Khokhitsi	*Vernonia amygdalina*	Asteraceae	✓	✓		✓
46	Gumero		*Capparis tomentosa*	Capparidaceae				✓
47	Guwarya		*Acacia polycantha*	Fabaceae			✓	
48	Indod	Sebeti	*Phytolacca dodecandra*	Phytolaccaceae		✓		
49	Inkoy	Tutuqa	*Ximenia americana*	Olacaceae		✓	✓	
50	Itsepatos	Itsepatos	*Dracaena steudneri*	Dracaenaceae		✓		
51	Kanabala	Kanabala				✓		
52	Kansin							
53	Kega		*Rosa abyssincia*	Rosaceae				✓
54	Kelewa	Abaliyh	*Maesa lanceolata*	Myrsinaceae		✓		
55	Kentefa		*Endata abyssinica*	Mimosoideae				✓
56	Keret		*Osyris quadripartita,*	Lamiaceae	✓			✓
57	Kese		*Lippia adoensis*	Verbenaceae	✓			
58	Ketiketa		***Dodonaea*** *angustifolia*	Sapindaceae				✓
59	Kewoot	Equa	*Celtis africana*	Ulmaceae		✓		
60	Key bahirzaf		*Eucalyptus camaldulesis*	Myrtaceae				✓
61	Kilabo	Kilabo				✓		✓
62	Kirikira		*Anogeissus leiocarrpa*	Combretaceae			✓	
63	Kola abalo		*Combretum molle*	Combretaceae	✓			
64	Koma				✓			
65	Kongera		*Combretum spp*	Combretaceae			✓	
66	Korepete	Korepete				✓		

67	Korha						✓	
68	Koshim		*Dovyalis abyssinica*	Flacourtiaceae	✓			
69	Kotkoto				✓			
70	Kubkuba						✓	
71	Kulqual	Kulkual	*Euphorbia abyssinica*	Euphorbiaceae	✓	✓		✓
72	Kumbel		Myrica salicifolia	Myricaceae	✓			
73	Kuraba		*Maesa lanceolata*	Myricaceae	✓			
74	Lega Seber	Lega seber				✓		
75	Lembech	Lunsi	*Lembech*	*Clausena anisata*	✓	✓		✓
76	Lenquata	Alenqoza	*Grewia ferruginea*	Tiliaceae	✓	✓	✓	✓
77	Lol	Churi	*Ekebergia capensis*	Meliaceae	✓	✓		✓
78	Markida	Merkida	*Strychnos innocua*	Loganiaceae		✓		
79	Miserch		*Ilex mitis*	Aquifoliaceae				✓
80	Mukerba	Mukerba	*Boraginaceae*	Ehretia cymosa		✓		
81	Nacha		*Acalypha ornata*	Euphorbiaceae	✓			
82	Nech bahirzaf	Nech bahirzaf	*Eucalyptus globulus*	Myrtaceae	✓	✓		
83	Qamo		*Rhus glutinosa*	Anacardiaceae	✓			✓
84	Qoba	Qoba	*Maytenus obscura*	Celastraceae		✓		
85	Quando berberie		*Schinus molle*	Anacardiaceae				✓
86	Qurqura						✓	
87	Sankoy	Sankoy				✓		
88	Sehel		*Teclea nobilis*	Rutaceae	✓			✓
89	Senef woyra							✓
90	Serkabeba							✓
91	Sesa	Sesa	*Albizia gummifera*	Fabaceae	✓	✓		✓
92	Shamli		*Erythrococca trichogyne*	Euphorbiaceae		✓		
93	Shansha						✓	
94	Shegimbi	Shegimbi				✓		
95	Shenet		*Myrica salicifolia*	Myricaceae	✓			
96	Shiwshiwa		*Casuarina equisetifolia*	Casuarinaceae				✓
97	Shmel	Shemel	*Oxytenanthera abyssinica*	Poaceae			✓	
98	Shola	Shola	*Ficus sur*	Moraceae		✓		
99	Tekur enchet	Tekur enchet	*Prunus africanus*	Rosaceae	✓	✓		✓
100	Tembelel		*Jasminum abyssinicum*	Oleaceae				✓
101	Tintasi	Tintasi	*Pzemana schimperi*			✓		
102	Tota Kolet		*Galiniera saxifraga*	Rubiaceae	✓			✓
103	Tsedo		*Rhamnus staddo*	Rhamnaceae				✓

104	Wacho		*Acacia seyal*	Fabaceae			✓	✓
105	Waginese							✓
106	Waliya meker		*Boswellia papyrifera*	Burseraceae			✓	
107	Wanza	Bugtitsi	*Cordia africana*	Boraginacea		✓		
108	Warka		*Ficus vasta*	Moraceae				✓
109	Weira	Weira	*Olea europaea*	Oleaceae	✓	✓		✓
110	Wenbela		*Terminalia laxiflora*	Combretaceae			✓	
111	Werkina						✓	
112	Wogeda		*Chionanthus mildbraedii*	Oleaceae	✓			
113	Wulkefa	Wulkefa	*Dombeya torrida*	Sterculiaceae	✓	✓		✓
114	Yabesha Tsed		*Juniperus procera*	Cupressaceae				✓
115	Yahya zekakbe							✓
116	Yeferenj tid	Yeferenj tid	*Cupressus lusitanica*	Cupressaceae		✓		
117	Yeferenji grar	Yeferenji grar	*Acacia decurrens*	Fabaceae		✓		
118	Yeneber tefer		*Bridelia micrantha*	Euphorbiaceae	✓			
119	Yewef shola		*Ficus ovata*	Moraceae	✓			
120	Zagristi	Zagrist				✓		
121	Zana		*Stereospermum kunthianum*	Bignoniaceae			✓	
122	Zegba		*Podocarpus falcatus*	Podocarpaceae	✓			
123	Zegeta /Degeta		*Calpurnia aurea*	Fabaceae	✓			✓
124	Zobi		*Dalbergia melanoxylon*	Fabaceae			✓	

Appendix 2. Importance value indices of woody species for Gelawdiwos

Species	Relative basal area (%)	Relative Density (%)	Relative Frequency (%)	IVI (%)	IVI rank
Buddleia polystachya	0.97	3.68	2.82	7.47	12
Bersama abyssinica	0.25	1.53	2.11	3.89	20
Croton macrostachyus	3.58	9.20	9.15	21.94	4
Apodytes dimidiata	8.36	1.53	2.82	12.71	7
Allophylus abyssinicus	0.17	0.31	0.70	1.18	30
Maytenus undata	0.36	0.61	0.70	1.68	26
Schefflera abyssinica	7.59	0.61	1.41	9.62	11
Vernonia amygdalina	0.18	0.31	0.70	1.19	29
Combretum molle	0.85	3.99	4.93	9.76	10
Koma	1.72	1.23	2.11	5.06	17
Dovyalis abyssinica	2.03	8.59	10.56	21.18	5
Kotkoto	0.12	0.61	1.41	2.14	25
Euphorbia abyssinica	9.41	15.34	7.04	31.79	2
Myrica salicifolia	0.29	0.61	1.41	2.31	23
Maesa lanceolata	0.42	2.76	2.11	5.29	16
Clausena anisata	0.21	0.92	2.11	3.25	22
Grewia ferruginea	0.16	0.61	1.41	2.18	24
Ekebergia capensis	6.47	2.45	4.93	13.86	6
Eucalyptus globulus	3.57	2.45	1.41	7.43	13
Rhus glutinosa	0.09	0.61	0.70	1.41	28
Teclea nobilis	2.92	3.37	4.23	10.52	9
Albizia gummifera	4.93	14.42	4.93	24.28	3
Myrica salicifolia	0.57	0.31	0.70	1.58	27
Galiniera saxifraga	0.92	1.23	2.11	4.26	18
Chionanthus mildbraedii	38.59	11.96	11.97	62.52	1
Dombeya torrida	1.08	0.92	1.41	3.41	21
Bridelia micrantha	0.49	2.15	3.52	6.16	15
Ficus ovata	1.25	0.61	2.11	3.98	19
Podocarpus falcatus	1.61	3.07	2.11	6.79	14
Calpurnia aurea	0.85	3.99	6.34	11.17	8
	100	100	100	300	

Appendix 3: Importance value indices of woody species for Injibara

Species	Relative basal area (%)	Relative Density (%)	Relative Frequency (%)	IVI (%)	IVI rank
Acacia abyssinica	1.64	2.61	2.36	6.61	11
Albizia gummifera	36.45	30.45	20.08	86.98	1
Allophylus abyssinicus	3.68	2.37	4.33	10.38	8
Apodytes dimidiate	6.47	1.66	3.15	11.28	7
Bersama abyssinica	0.78	1.90	4.72	7.40	10
Bimpini	0.25	0.36	0.39	1.00	27
Cordia africana	2.12	3.79	2.76	8.67	9
Ekebergia capensis	3.03	0.24	0.79	4.05	16
Ciltes africana	0.05	0.12	0.39	0.56	31
Croton macrostachyus	8.26	13.39	14.17	35.82	2
Cupressus lusitanica	0.03	0.12	0.39	0.54	33
Dombeya torrida	0.07	0.36	1.18	1.61	20
Strychnos spinosa	0.97	0.12	0.39	1.48	21
Dracaena steudneri	0.80	0.95	2.76	4.50	14
Ehretia cymosa	2.98	0.47	0.79	4.24	15
Combretum molle	0.27	0.71	1.18	2.17	17
Eucalyptus globulus	5.23	4.27	2.36	11.86	6
Euphorbia abyssinica	0.07	0.36	0.39	0.82	29
Ficus sur	2.07	2.84	1.18	6.10	12
Gimibilitini	2.89	7.82	7.87	18.58	5
Kenebela	2.68	11.61	7.48	21.77	4
Lega Seber	0.02	0.12	0.39	0.54	34
Millettia ferruginea	0.26	0.47	0.39	1.13	24
Maesa lanceolata	0.27	0.95	0.79	2.01	19
strychnos innocua	0.14	0.24	0.79	1.17	22
Maytenus obscura	0.73	0.59	0.79	2.11	18
Olea europaea	0.01	0.12	0.39	0.53	36
Prunus Africana	15.64	4.98	8.27	28.89	3
Sankoy	0.04	0.12	0.39	0.55	32
Erythrococca trichogyne	0.03	0.24	0.79	1.06	26
Shegimbi	0.04	0.24	0.79	1.07	25
Pzemana schimperi	0.02	0.12	0.39	0.53	35
Vernonia amygdalina	0.60	2.37	1.97	4.93	13
Maytenus gracilipes	0.16	0.36	0.39	0.90	28
ximenia Americana	0.11	0.24	0.79	1.13	23
Zagristi	0.04	0.24	0.39	0.67	30

Appendix 3: Importance value indices of woody species for Metema

Species	Relative basal area (%)	Relative Density (%)	Relative Frequency (%)	IVI (%)	IVI rank
Hypericum gnidiifolium	3.67	7.78	6.96	18.41	6
Combretum molle	2.84	3.50	4.35	10.69	12
Ziziphus mucronata	0.87	2.72	3.48	7.07	16
Dombeya quinquesta	0.40	0.39	0.87	1.66	27
Ameshe gwariya	1.52	1.56	1.74	4.81	19
chamida	1.84	2.33	4.35	8.53	14
Pterocarpus lucens	7.69	5.45	6.09	19.23	5
Apodytes dimidiata	3.64	3.50	3.48	10.62	13
Dabda	0.27	0.39	0.87	1.53	29
Sterculea setigera	15.78	7.00	6.96	29.74	2
Dawuda	5.18	4.28	3.48	12.94	8
Lannea fruticosa	1.73	1.17	2.61	5.51	17
Ximenia americana	0.26	0.78	0.87	1.91	26
Enkudikuda	0.37	0.39	0.87	1.63	28
Etse Menahi	0.48	1.17	1.74	3.38	22
Fola	4.87	8.17	7.83	20.87	4
Forha	4.02	7.00	6.09	17.11	7
Gardenia ternifolia	0.86	1.56	2.61	5.02	18
Acacia polycantha	2.08	3.50	1.74	7.32	15
Anogeissus leiocarrpa	5.85	3.11	3.48	12.44	9
Combretum spp	2.06	4.67	5.22	11.95	10
Korha	0.41	0.78	0.87	2.06	25
Kukuba	0.81	1.17	1.74	3.72	21
Grewia ferruginea	0.62	1.56	1.74	3.91	20
Ziziphus mauritiana	3.35	6.23	1.74	11.32	11
Acacia seyal	0.43	0.78	0.87	2.08	24
Boswellia papyrifera	13.34	12.06	7.83	33.23	1
Terminalia laxiflora	13.45	5.45	6.09	24.99	3
Werkina	0.18	0.78	1.74	2.70	23
Dalbergia elanoxylon	0.10	0.39	0.87	1.36	30
Hypericum gnidiifolium	3.67	7.78	6.96	18.41	6

Appendix 5. Importance value indices of woody species for Tara Gedam

Species	Relative basal area (%)	Relative Density (%)	Relative Frequency (%)	IVI (%)	IVI rank
Acacia Abyssinica	14.61	13.73	14.52	42.86	2
Albizia gummifera	6.23	10.46	12.90	29.59	4
Buddleia polystachya	6.72	16.99	17.74	41.45	3
Bersama abyssinica	1.87	3.92	3.23	9.02	10
Croton macrostachyus	4.76	8.50	14.52	27.77	5
Allophylus abyssinicus	1.04	2.61	3.23	6.88	11
Eucalyptus camaldulesis	1.37	1.96	1.61	4.94	14
Ficus vasta	4.00	3.92	1.61	9.53	9
Schefflera abyssinica	12.99	0.65	1.61	15.26	8
Juniperus procera	20.57	20.92	9.68	51.17	1
Ekebergia capensis	0.99	2.61	1.61	5.22	12
Ilex mitis	0.12	0.65	1.61	2.39	17
Olea europaea	19.06	3.27	4.84	27.17	6
Senef wiera	0.58	1.31	3.23	5.12	13
Teclea nobilis	4.54	7.19	4.84	16.57	7
Galiniera saxifraga	0.26	0.65	1.61	2.52	16
Dombeya torrida	0.29	0.65	1.61	2.56	15