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STRUCTURE, BIOMASS AND NET PRIMARY PRODUCTION IN  
A DRY TROPICAL AFROMONTANE FOREST IN ETHIOPIA

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**Final Project Report**

**April 2007**

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**ABSTRACT**

Species composition, structure, plant biomass and net primary productivity were studied on three sites of a dry afro-montane forest in Ethiopia. Number of plant species at the three sites range between 18 -22 ha<sup>-1</sup>, and dominant species were *Podocarpus falcatus* at lower and middle altitudes, and *Rapanea simensis* in upper altitude. Plant densities in the three sites range between 484 -1518 individuals ha<sup>-1</sup> and basal cover 14.3- 56.6 m<sup>-2</sup> ha<sup>-1</sup>. Above ground biomass in the study forest were 403.0 t ha<sup>-1</sup>, 754.3 t ha<sup>-1</sup> and 567.2 t ha<sup>-1</sup>, at Sites I, II and III, respectively. Herb layer biomass were 6.6, 6.4 and 5.5 t ha<sup>-1</sup> at Sites I, II and III, respectively. Net primary production in the forest range between 18 - 20 t ha<sup>-1</sup> year<sup>-1</sup> with 6.3- 11.6 ha<sup>-1</sup> year<sup>-1</sup> in the tree and shrub layer, 2.0-4.5 t ha<sup>-1</sup> year<sup>-1</sup> in the fine litter, and 3.9 -9.7 t ha<sup>-1</sup> year<sup>-1</sup> in the fine root. The above ground plant biomass and NPP in the present study forest was higher than most tropical dry forests and within the range of tropical rain forests, which imply the significance of dry afro-montane forests of Ethiopia in the global carbon pool/flux and thus climate change.

**Key words:-** above ground biomass, basal area/cover, fine root , herb biomass, litter fall, tree/shrub biomass and species number.

## 1. INTRODUCTION

The stocks of greenhouse gases in the atmosphere are rising because of human activity. The current level or stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO<sub>2</sub>, compared with only 280 ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades. Accordingly, a rise in global mean temperature of 2 or even 3.5 °C over the next 100 years is one of the most consistent predictions of climate change models (Houghton et al., 1996). It is widely anticipated that such a change will have profound impacts on natural ecosystems.

On the other hand, tropical rain forests contribute substantially to the global carbon cycle, accounting for 40 % of terrestrial net primary production, 60 % of forest biomass, and 27 % of carbon stored in forest soils. How tropical rain forests respond to changing climate and atmospheric CO<sub>2</sub> could strongly affect the rate of accumulation of atmospheric carbon dioxide. Recent modeling studies (Cox et al., 2000; Ito & Oikawa 2000; White et al., 2000; Cramer et al., 2001) have projected that a shift in the balance between respiration and photosynthesis in tropical forests in response to rising temperatures will accelerate the increase in atmospheric CO<sub>2</sub> during the next 100 years. Increased efforts has been placed on understanding and modeling of carbon flux and cycle in tropical forests, as global climate change, elevated greenhouse gas deposition, and land use changes threaten to alter the pattern of world's carbon and energy flow.

Tropical dry forests form the largest component, more than 40 percent, of all tropical forests (Murphy and Lugo, 1986a). In Africa, similarly dry forests account for 70- 80 percent of the forested area. At the same time, changing climate is causing on-going alterations in forest-level carbon exchange and Net Primary Production (NPP) in tropical forests. Because of the inevitable global climate change, researchers started to ponder questions such as what are the levels of biomass and productivity in tropical dry forests and where in the forest does this occur? What is the annual net carbon exchange rate of dry tropical forest? Furthermore, understanding how the storage and productivity of organic matter (carbon) in tropical dry forests relates to climate change is of critical need for global climate change management.

The Ethiopian highlands contribute to more than 50 percent of the land area with afro-montane vegetation (Yalden, 1983; Tamrat Bekele, 1994), of which dry forests form the largest part. However, there is no scientific work so far known to have focused on the potential role of dry afro-montane forests of Ethiopia in the global carbon cycle in general and, plant biomass and productivity in particular. Improvement in our understanding of the carbon pool and dynamics of such forests would be useful for developing better policy decisions related to forest utilization/conservation and more importantly in the management of global climate change. The objectives of the present study are to assess forest structure in terms of species composition and density-diameter distribution, biomass stock/distribution, and assess net primary production in a typical dry afro-montane forest in Ethiopia. In addition, standing biomass stock and net primary production of the study forest was compared with other tropical dry and rain forests to

evaluate the contribution of dry forests of Ethiopia in the global carbon pool/flux and in effect to the global climate change.

## 2. MATERIALS AND METHODS

### 2.1. Study Site

The Munessa-Shashemene forest is located on the eastern escarpment of the Main Ethiopian Rift Valley (7°13'N and 38°37'E) and covers an altitudinal range between 2100 and 2700, is a dry afro-montane natural forest (Friis, 1992). The total area of the forest is 96,000 hectares out of which the plantation is estimated to cover 7 percent of the total forest area. The mean annual rainfall of the area is about 1500 mm and the mean annual temperature is 15 °C, ranging daily from 8 to 24 °C. There is a bimodal rainfall pattern where the small rainy season is from March to May and a major rainy season from July to September. The long dry season is from October –February and small dry season May – June. Relative humidity of the air ranges from 35 to 79 % in the dry season to well above 90 % during rainy season.

The soils in the study are rich in clay, show a clear altitudinal zonation owing to homogenous, volcanic parent material, and classified as Mollic Andosol according to FAO (1998) and Typic Palehumults according to US Soil Taxonomy (Soil Survey Staff 2003). The soils developed from volcanic parent materials, principally volcanic lavas, ashes and pumices from quaternary volcanic activities in the Rift Valley.

The area originally supported deciduous natural forest, however, dominated by *Podocarpus falcatus* (Chaffey, 1979). The upper canopy tree species are *Podocarpus falcatus*, *Syzygium guineense*, *Celtis africana*, *Croton macrostachyus*, *Aningeria adolfi-friederici*, *Olea capense* and *Prunus africana*. The sub canopy species are *Polyscias fulva*, *Allophylus abyssinica*, *Fagaropsis angolensis*, *Apodytes dimidiata* and *Ilex mitis*. The Munessa-Shashemene forest has been subjected to commercial logging and continuous deforestation for more than 50 year and is still on going process.

### 2.2. Methodology

#### 2.2.1 Assessment of Forest Structure

Three contiguous sites were selected in a large tract of the dry afro-montane forest of the Munessa-Shashemene. The sites were chosen along a north-facing hillside. Site 1 at the hill base (2100 to 2300 masl), site 2 on the mid slope (2300 to 2500 masl) and Site 3 was at the summit of the hill (2500 to 2700 masl). In each of these sites, one –hectare forest area (100 m X 100 m plot), visually representative of the overall vegetation, were delineated for the detail study. The one-hectare plot at each site was further subdivided into four sub units of 50 X 50 m quadrates. Each quadrate further subdivided in to 2 x 2 m grid system to plot the position of each trees within the quadrates. The forest stand on each site was analyzed within the representative plot of the entire one-hectare plot. All individuals in each 50 x 50 m quadrate (four such quadrates per site) were identified, Girth at Breast Height (GBH) measured and recorded. Similarly, shrubs were identified

and measured at 10 cm above the ground. The vegetation data were analyzed for frequency, density and abundance following Muller-Dombois and Ellenberg (1974). An importance value calculated as the sum total of relative frequency, relative density and relative dominance. Species diversity parameters for tree layer, shrub layer and for was determined, using basal cover values, species richness and Shannon- Wiener diversity Index. Species richness and Shannon diversity index was calculated following Magurran (1988). In this study, plant identification followed Hedberg and Edwards (1989; 1995); Edwards *et al.* (1995; 1997) and Mesfin Tadesse (2004).

### ***2.2.2 Measurements of tree biomass, shrub biomass and above ground biomass***

Tree biomass was measured using allometric equations relating tree diameter given by Brown (1997). The equation used in tree biomass analysis is follows:

$$Y = 42.69 - 12.800(\text{DBH}) + 1.242(\text{DBH}^2)$$

The method involves estimating the biomass per average tree of each diameter (diameter at breast height, dbh) class of the stand table, multiplying by the number of trees in the class, and summing across all classes. The mid-point of the class were used to represent the average diameter of the class following Brown (1997). For shrub plants (dbh size less than 10 cm), ten individuals of representatives of more frequent species were felled representing all available diameter classes. For sampling purposes, biomass was partitioned into four categories: bole, branches, leaves and coarse roots. Wet weight for bole, branch, leaves and coarse roots were determined in the field. The following samples were taken from each tree: four disks of the bole taken at different heights and six disks of branches. Complete samples of leaves and coarse roots were taken and oven dried all at 70 °C for 3-5 days until constant weight is obtained. Sample dry/wet weight proportions were then used to determine the dry weight of the plant. The harvest data were subjected to regression analysis to relate the dry weight of bole, branch, foliage and coarse root with diameter. Mean DBH value for each species for a diameter class was used in the regression equation to obtain an estimate of mean biomass for that diameter class.

The aboveground herbaceous biomass were harvested monthly (from April 2006-April 2007) from ten 50 X 50 cm quadrat per plot at three sites. Herbs were separated into live and dead shoots. The collections then brought to laboratory and dried at 70 °C in an oven dry for 24 h, and weighed. Monthly values were averaged to obtain a mean herbaceous biomass for each site. The sum of biomasses of trees, shrubs and herbs were used to estimate the above ground plant biomass of each site.

### ***2.2.3 Annual Stem Diameter Growth and Net Primary Production***

Permanent plots of 1.5 hectare land (0.5 hectare plot each in Sites I, II and III) were established in April 2005 for the study of annual stem diameter growth and net primary productivity of tree and shrub plants. The protocols for annual stem-diameter growth measurements and net primary productivity in the forest followed Clark *et al.* (2001). All

tree individuals  $\geq 4$  cm in diameter encountered in the three plot were identified, marked, and GBH were measured and recorded using meter tape to the nearest, millimeter, rounding down. The tape was passed under any vines or roots on the stem and then moved back and forth to clean the Point of Measurement (POM) of loose bark and debris. Boles were measured at 130 cm above the ground when this point is not affected by buttresses; otherwise the POM is moved above the irregularities. Each trees POM was marked with ink on the bole and recorded. Annual diameter growth would be calculated as the differences between successive annual diameter measurements at the same POM, divided by (days between measurements/365). Two-hundred thirty eight individuals (that belongs to twenty-five plant species) were marked, and GBH measured in April 2006. The marked individuals were re-measured in April 2007 (first year) and would also be re measured in April 2008 (second year). Using allometric equations, the biomass of the trees were calculated from the GBH measurements of 2006 ( $B_1$ ), 2007 ( $B_2$ ) and 2008 ( $B_3$ ). Only first year data  $B_1$  and  $B_2$  is available for trees annual girth increment in this report. The net biomass accumulations for the 2006-2007 ( $B_2-B_1$ ), and for 2007-2008 ( $B_3-B_2$ ) would be averaged for Annual Girth Increment. At the end, the average data of the two years would be used for estimation of Net Primary Production in the study forest. Fine litter fall consists of leaves, flowers and fruits. Data for leaf litter fall was measured from ten plots of 50 X 50 cm systematically placed quadrates at monthly intervals in each site. Materials collected were categorized as fresh leaf litter or partly decomposed litter and reproductive parts i.e. flower fruit and seed. The collections were taken to laboratory separately by category, oven dried and then oven dry weights determined. Below ground net primary production measurement was made from fine root biomass. Fine root biomass ( $< 5$  mm diameter) were determined from thirteen soil monoliths (15 X 15 X 15 cm) at the three sites. After collection, the roots were sieved separated into live and dead, and brought to laboratory for determination of oven dry weight.

#### **2.2.4. Data Analyses**

Important elements of forest structure, including GBH, DBH and Basal area/cover estimated based on standard protocols available. Statistical analysis was performed using One-Way ANOVA SPSS/PC Software. Tree Basal Area/Cover and Diameter at Breast Height (DBH) has been calculated as follows:

$$\text{Basal Area (BA)} = [0.5\text{DBH}]^2 \square$$

$$\text{Diameter at Breast Height (DBH)} = 2 [\sqrt{\text{BA}/\square\square}]$$

### 3. RESULTS

#### 3.1. Number of Species and Shannon Diversity (H')

Results of number of species (only woody plants) and diversity at Sites I, II and III are given in Table 1. At Site I about 21 species that belong to 18 plant families were recorded. In this site, the family Rubiaceae was represented by three genera and species, and the families Celastraceae and Fabaceae were represented each by two genera and species. Upper story trees constituted 54 % of the species. At Site II about 18 species that belong to 16 plant families were recorded and the family Rubiaceae was represented by three genera and species. Upper story trees and shrub layer constituted each 50 % of the species. Site II (the middle altitude) had the lowest number of species compared to the other two sites. At Site III about 22 species that belong to 16 plant families were recorded and the family Rubiaceae was represented by four genera and species; and the family Rosaceae by two genera and species. Upper story trees constituted 40 % of the species. Over all, the total number woody species recorded from the three sites were 36 species of which trees constituted slightly higher proportions (53 %) than shrubs. On the other hand, Site III had relatively higher number of shrub species.

Shannon index has shown that Site III (upper altitude) had relatively higher diversity, followed by Site II. The lowest Shannon diversity was found at Site I (lower altitude) (Table 1). Results of Jaccard similarity index (in terms of species) between the sites had shown that highest similarity was found between Sites I and II (0.53), followed by Sites I and III (0.3); and lowest similarity found between Sites II and III (0.29).

Table 1: Species richness (woody plants) and Shannon diversity at Sites I, II and III in Munessa-Shashemene forest

| Site     | No. of tree species | No. of shrub species | Total no. of species | Shannon index (H') |
|----------|---------------------|----------------------|----------------------|--------------------|
| Site I   | 12                  | 10                   | 22                   | 1.49               |
| Site II  | 9                   | 9                    | 18                   | 2.66               |
| Site III | 9                   | 13                   | 22                   | 2.77               |

#### 3.2. Forest Structure

Results of number of plants recorded (density), frequency, dominance, basal area/cover and importance value index of species at Sites I, II and III in the study forest are given in Table 2. Plant densities recorded (plants  $\geq 2$  cm dbh) in the three Sites varied considerably. Highest plant density was recorded in Site III (1518 individuals ha<sup>-1</sup>), followed by Site I (1159 individuals ha<sup>-1</sup>); lowest density found in Site II (484 individual ha<sup>-1</sup>). Similarly, tree densities (plants  $> 10$  cm dbh) recorded in the three sites were 178, 238 and 276 individuals ha<sup>-1</sup> at Sites I, II and III, respectively. Similarly, the densities of plants with dbh  $< 10$  cm recorded in the three sites were 306, 921, 1242 individuals ha<sup>-1</sup>.

The top story of the vegetation at Site I was dominated by species of *Podocarpus falcatus* and *Croton macrostachyus*. The shrub layer was dominated by *Rytigynia neglecta* and *Bersama abyssinica* species. At Site II the top story of the vegetation was dominated by *Podocarpus falcatus* and *Prunus africana*; the shrub layer dominated by *Teclea nobilis* and *Galiniera saxifraga*. At site III the top story of the vegetation was dominated by *Maytenus addat* and *Nuxia congesta*; the shrub layer dominated by *Rapanea simensis*.

Summary of results of trees and shrubs basal area/cover recorded at the three sites are given in Table 3. Accordingly, trees basal area/cover in the three sites of the study forest varied between 10.4 m<sup>2</sup> and 55.2 m<sup>2</sup> ha<sup>-1</sup>; and shrubs basal area/cover varied between 3.8 m<sup>2</sup> and 1.3 m<sup>2</sup>. The highest trees basal area was recorded at Site II and lowest at Site III. Similarly, the total (trees and shrubs) basal area/cover recorded in the three sites range between 56.6 m<sup>2</sup> and 14.3 m<sup>2</sup> ha<sup>-1</sup>. The highest total basal area was found at Site II and the lowest at Site III. The percentage contributions of shrub plants to the total basal area/cover was 7.7, 2.4 and 26.5 in Sites I, II and III, respectively. Shrub plants basal area/cover contribution was more important in Site III as compared to the other two sites. Tree basal area/cover at Site II (the middle altitude) was two fold higher than at Site I (the lower altitude) and five fold higher than at Site III (the upper altitude). The total basal area/cover at Site II was two fold higher than at Site I and four fold higher than at Site III. On the other hand, shrubs basal area/cover at Site III was three fold higher than Sites I and III. Over all, the average trees, shrubs and total basal area/cover per hectare in the study forest were 30.8 m<sup>2</sup>, 2.1 m<sup>2</sup>, and 33.0 m<sup>2</sup>.

Table 3: Summary results of trees and shrubs basal area/cover at Site I, II and III in the Munessa-Shashemene forest

| Site     | Tree basal cover m <sup>2</sup> ha <sup>-1</sup> | Shrub basal cover m <sup>2</sup> ha <sup>-1</sup> | Total basal cover m <sup>2</sup> ha <sup>-1</sup> |
|----------|--|---|---|
| Site I   | 27   | 1.3   | 28.3  |
| Site II  | 55.2   | 1.4   | 56.6  |
| Site III | 10.4   | 3.8   | 14.3  |
| Average  | 30.8   | 2.1   | 33.0  |

Table 2: Results of species relative density, dominance, frequency, basal area and Importance Value Index (IVI) at three sites (Sites I, II and III) in Munessa-Shashemene forest.

**Site I**

| Habit | Scientific name                    | Family         | No. of indiv. | Relative density | Basal area m <sup>2</sup> | Relative dominance | Relative frequency | IVI % |
|-------|------------------------------------|----------------|---------------|------------------|---------------------------|--------------------|--------------------|-------|
| Tree  | <i>Allophylus abyssinicus</i>      | Sapindaceae    | 7             | 0.0060           | 0.490                     | 0.01700            | 0.06               | 2.7   |
| Tree  | <i>Aningeria adolfi-friederici</i> | Sapotaceae     | 2             | 0.0017           | 0.0748                    | 0.00260            | 0.02               | 0.8   |
| Tree  | <i>Apodytes dimidiata</i>          | Icacinaceae    | 1             | 0.0008           | 0.0161                    | 0.00050            | 0.02               | 0.7   |
| Tree  | <i>Cassipourea malosana</i>        | Rhizophoraceae | 23            | 0.0198           | 0.5404                    | 0.01900            | 0.08               | 3.9   |
| Tree  | <i>Celtis africana</i>             | Ulmaceae       | 19            | 0.0163           | 1.0955                    | 0.03800            | 0.06               | 3.7   |
| Tree  | <i>Croton macrostachyus</i>        | Euphorbiaceae  | 137           | 0.1182           | 5.7157                    | 0.20100            | 0.08               | 13.2  |
| Tree  | <i>Fagaropsis angolensis</i>       | Rutaceae       | 3             | 0.0025           | 0.6603                    | 0.02300            | 0.04               | 2.1   |
| Tree  | <i>Ficus sur</i>                   | Moraceae       | 6             | 0.0051           | 0.2658                    | 0.00930            | 0.02               | 1.1   |
| Tree  | <i>Lepidotrichilia volkensii</i>   | Meliaceae      | 1             | 0.0008           | 0.0013                    | 0.00005            | 0.02               | 0.6   |
| Tree  | <i>Maytenus addat</i>              | Celateraceae   | 46            | 0.0396           | 0.4724                    | 0.01660            | 0.08               | 4.5   |
| Tree  | <i>Millettia ferruginea</i>        | Fabaceae       | 13            | 0.0112           | 0.7780                    | 0.02740            | 0.06               | 3.2   |
| Tree  | <i>Podocarpus falcatus</i>         | Podocarpaceae  | 15            | 0.0129           | 17.3425                   | 0.61200            | 0.08               | 23.3  |
| Shrub | <i>Bersama abyssinica</i>          | Melanthaceae   | 95            | 0.0819           | 0.2396                    | 0.00845            | 0.08               | 5.6   |
| Shrub | <i>Calpurnia aurea</i>             | Fabaceae       | 51            | 0.0440           | 0.0665                    | 0.00234            | 0.04               | 2.8   |
| Shrub | <i>Canthium oligocarpum</i>        | Rubiaceae      | 30            | 0.0258           | 0.0169                    | 0.00059            | 0.02               | 1.5   |
| Shrub | <i>Dovyalis abyssinica</i>         | Flacourtiaceae | 3             | 0.0025           | 0.0437                    | 0.00154            | 0.04               | 1.4   |
| Shrub | <i>Lobelia gibroa</i>              | Lobeliaceae    | 7             | 0.0060           | 0.0037                    | 0.00013            | 0.04               | 1.5   |
| Shrub | <i>Maytenus senegalensis</i>       | Celasteraceae  | 1             | 0.0008           | 0.1559                    | 0.00550            | 0.02               | 0.8   |
| Shrub | <i>Rytigynia neglecta</i>          | Rubiaceae      | 681           | 0.5875           | 0.8443                    | 0.02980            | 0.04               | 21.8  |
| Shrub | <i>Solanum sp.</i>                 | Solanaceae     | 11            | 0.0094           | 0.0021                    | 0.00007            | 0.04               | 1.6   |
| Shrub | <i>Teclea nobilis</i>              | Rutaceae       | 4             | 0.0034           | 0.0022                    | 0.00007            | 0.04               | 1.4   |
| Shrub | <i>Vernonia urticifolia</i>        | Asteraceae     | 3             | 0.0025           | 0.0012                    | 0.00004            | 0.02               | 0.7   |

## Site II

| Habit | Scientific name                    | Family         | No. of indiv. | Relative density | Basal area m <sup>2</sup> | Relative dominance | Relative frequency | IVI % |
|-------|------------------------------------|----------------|---------------|------------------|---------------------------|--------------------|--------------------|-------|
| Tree  | <i>Allophylus abyssinicus</i>      | Sapindaceae    | 25            | 0.0516           | 1.5631                    | 0.02757            | 0.08               | 5.4   |
| Tree  | <i>Aningeria adolfi-friederici</i> | Sapotaceae     | 1             | 0.0026           | 0.0031                    | 0.00005            | 0.02               | 0.7   |
| Tree  | <i>Cassipourea malosana</i>        | Rhizophoraceae | 22            | 0.0448           | 0.3037                    | 0.00535            | 0.08               | 4.4   |
| Tree  | <i>Celtis africana</i>             | Ulmaceae       | 8             | 0.0163           | 0.1519                    | 0.00268            | 0.04               | 2     |
| Tree  | <i>Croton macrostachyus</i>        | Euphorbiaceae  | 21            | 0.0428           | 2.1054                    | 0.03713            | 0.08               | 5.4   |
| Tree  | <i>Maytenus addat</i>              | Celateraceae   | 52            | 0.1061           | 0.9609                    | 0.01694            | 0.08               | 6.8   |
| Tree  | <i>Nuxia congesta</i>              | Loganiaceae    | 1             | 0.0026           | 0.2577                    | 0.00454            | 0.02               | 0.9   |
| Tree  | <i>Podocarpus falcatus</i>         | Podocarpaceae  | 92            | 0.1877           | 42.3078                   | 0.74630            | 0.08               | 34.4  |
| Tree  | <i>Prunus africana</i>             | Rosaceae       | 130           | 0.2685           | 7.5550                    | 0.13325            | 0.04               | 15.0  |
| Shrub | <i>Bersama abyssinica</i>          | Melanthaceae   | 40            | 0.0816           | 0.0877                    | 0.00154            | 0.08               | 5.5   |
| Shrub | <i>Calpurnia aurea</i>             | Fabaceae       | 5             | 0.0103           | 0.0409                    | 0.00072            | 0.02               | 1.0   |
| Shrub | <i>Canthium oligocarpum</i>        | Rubiaceae      | 9             | 0.0183           | 0.0240                    | 0.00042            | 0.06               | 2.6   |
| Shrub | <i>Dovyalis abyssinica</i>         | Flacourtiaceae | 3             | 0.0061           | 0.0012                    | 0.00002            | 0.04               | 1.5   |
| Shrub | <i>Ekebergia capensis</i>          | Meliaceae      | 4             | 0.0081           | 0.2549                    | 0.00449            | 0.04               | 1.7   |
| Shrub | <i>Galiniera saxifrage</i>         | Rubiaceae      | 15            | 0.0306           | 0.4268                    | 0.00752            | 0.06               | 3.3   |
| Shrub | <i>Rytigynia neglecta</i>          | Rubiaceae      | 21            | 0.0428           | 0.0369                    | 0.00065            | 0.02               | 2.1   |
| Shrub | <i>Solanum sp.</i>                 | Solanaceae     | 14            | 0.0285           | 0.0003                    | -                  | 0.04               | 2.3   |
| Shrub | <i>Teclea nobilis</i>              | Rutaceae       | 21            | 0.0551           | 0.6150                    | 0.01084            | 0.06               | 4.2   |

## Site III

| Habit | Species                       | Family         | No. of indiv. | Relative density | Basal area m <sup>2</sup> | Relative dominance | Relative frequency | IVI % |
|-------|-------------------------------|----------------|---------------|------------------|---------------------------|--------------------|--------------------|-------|
| Tree  | <i>Dombeya torrida</i>        | Sterculiaceae  | 6             | 0.0039           | 0.1031                    | 0.00721            | 0.02               | 1.0   |
| Tree  | <i>Hagenia abyssinica</i>     | Rosaceae       | 28            | 0.0184           | 1.5918                    | 0.11139            | 0.05               | 6.2   |
| Tree  | <i>Ilex mitis</i>             | Aquifoliaceae  | 30            | 0.0197           | 0.1647                    | 0.01152            | 0.05               | 2.8   |
| Tree  | <i>Maesa lanceolata</i>       | Myrsinaceae    | 128           | 0.0843           | 0.8354                    | 0.05846            | 0.05               | 6.6   |
| Tree  | <i>Maytenus addat</i>         | Celateraceae   | 138           | 0.0909           | 3.3355                    | 0.23341            | 0.05               | 12.9  |
| Tree  | <i>Nuxia congesta</i>         | Loganiaceae    | 116           | 0.0764           | 2.3574                    | 0.16496            | 0.05               | 10.0  |
| Tree  | <i>Olinia rochetiana</i>      | Oliniaceae     | 6             | 0.0039           | 0.5680                    | 0.03974            | 0.02               | 2.2   |
| Tree  | <i>Podocarpus falcatus</i>    | Podocarpaceae  | 178           | 0.1172           | 1.0518                    | 0.07360            | 0.05               | 8.3   |
| Tree  | <i>Prunus africana</i>        | Rosaceae       | 12            | 0.0079           | 0.4335                    | 0.03033            | 0.04               | 2.6   |
| Shrub | <i>Bersama abyssinica</i>     | Meliantaceae   | 56            | 0.0368           | 0.3565                    | 0.02494            | 0.05               | 3.8   |
| Shrub | <i>Brucea antidysenterica</i> | Simaroubaceae  | 10            | 0.0065           | 0.0013                    | 0.00009            | 0.05               | 1.9   |
| Shrub | <i>Canthium oligocarpum</i>   | Rubiaceae      | 4             | 0.0026           | 0.0011                    | 0.00007            | 0.05               | 1.8   |
| Shrub | <i>Dovyalis abyssinica</i>    | Flacourtiaceae | 8             | 0.0039           | 0.0026                    | 0.00018            | 0.05               | 1.8   |
| Shrub | <i>Ekebergia capensis</i>     | Meliaceae      | 6             | 0.0039           | 0.0988                    | 0.00691            | 0.04               | 1.7   |
| Shrub | <i>Galiniera saxifrage</i>    | Rubiaceae      | 26            | 0.0171           | 0.4742                    | 0.03318            | 0.05               | 3.4   |
| Shrub | <i>Hypericum revolutum</i>    | Clusiaceae     | 6             | 0.0039           | 0.0693                    | 0.00484            | 0.05               | 2.0   |
| Shrub | <i>Lobelia gibroa</i>         | Lobeliaceae    | 2             | 0.0014           | 0.0097                    | 0.00067            | 0.02               | 0.7   |
| Shrub | <i>Pavetta abyssinica</i>     | Rubiaceae      | 4             | 0.0026           | 0.0031                    | 0.00021            | 0.02               | 0.7   |
| Shrub | <i>Rapanea simensis</i>       | Myrsinaceae    | 720           | 0.4743           | 2.7992                    | 0.19588            | 0.05               | 24.9  |
| Shrub | <i>Rytigynia neglecta</i>     | Rubiaceae      | 30            | 0.0197           | 0.0327                    | 0.00228            | 0.05               | 2.4   |
| Shrub | <i>Vernonia urticifolia</i>   | Asteraceae     | 4             | 0.0026           | 0.0069                    | 0.00048            | 0.04               | 1.4   |

### 3.3. Plant Density and Diameter Class Distribution

Results of the density-diameter class structure recorded in the three sites are given in Figure 1. At Site I of the 1159 individuals recorded, 83.5 % of the individuals were less than 10 cm dbh size; 8 % in dbh class of 10- 20 cm; 4 % in dbh class of 20- 30 cm; 2 % in dbh class of 30-40 cm; 1 % in dbh class of 40 -50 cm and; 1.5 % in dbh classes of 50-220 cm. Eight individuals (mainly species of *Podocarpus falcatus*, and *Croton macrostachyus*) had dbh greater than 100 cm size. The largest dbh measured was 216 cm size and was from *Podocarpus falcatus* species.

At Site II of the 484 individuals recorded, 57 % of the individuals were less than 10 cm dbh size; 26 % in dbh class of 10-20 cm; 3 % in dbh class of 20-30 cm; 2 % in dbh class of 30 -40 cm; 3 % in dbh class of 40 -50 cm; 2 % in dbh class of 50- 60 cm; 1.5 % in dbh class of 60 –70 cm; 1 % in dbh class of 70-80 cm; 1 % in dbh class of 80-90 cm and; 0.5 % in dbh classes of 90-100 cm. About 3 % of the individual had dbh over 100 cm and the largest dbh measured is 194 cm. Trees greater than 100 cm dbh were from species of *Podocarpus falcatus*.

At Site III of the 1518 individuals recorded, 82 % of the individuals had dbh size less than 10 cm; 10 % in dbh class of 10-20 cm; 5 % in dbh class of 20- 30 % cm; 2 % in dbh class of 30-40 cm; 0.5 % in dbh class of 40-50 cm and; nearly 1 % in dbh classes of 50 -100 cm. The highest dbh measured was 95 cm size and was from *Podocarpus falcatus* species. Average plant density (dbh  $\geq$  2 cm) in the study forest is estimated as 1053 individuals ha<sup>-1</sup>.

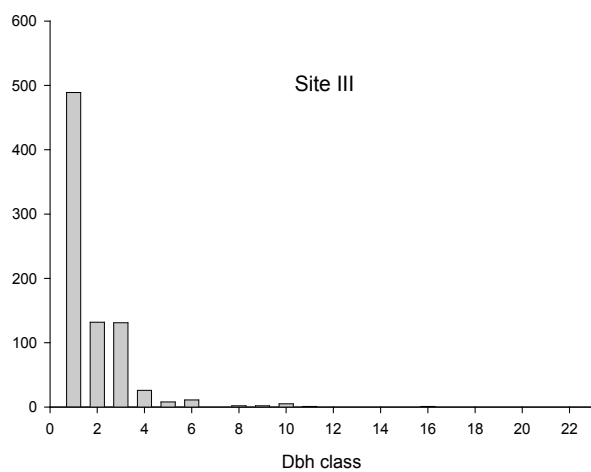
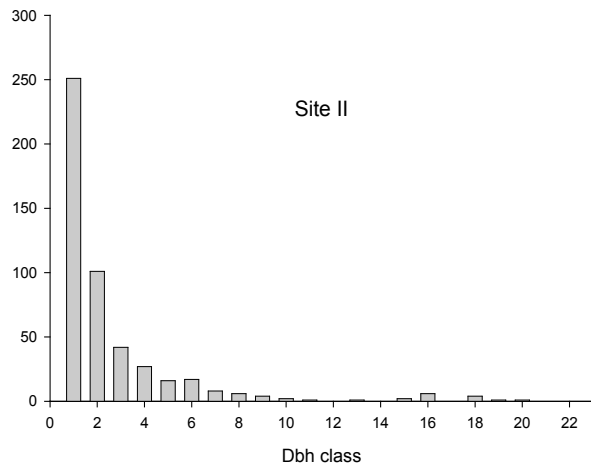
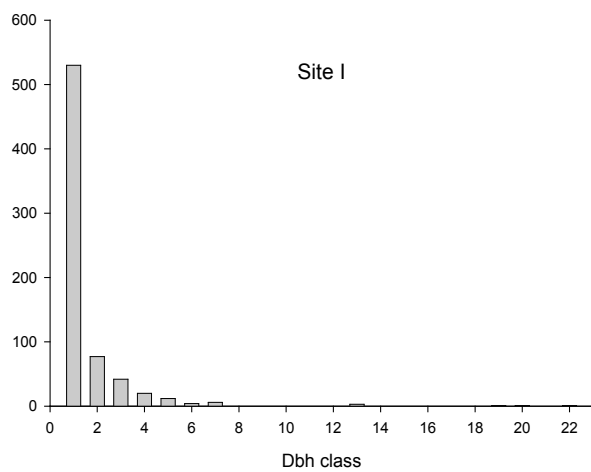


Figure 1: DBH class distributions of all plant individuals recorded at Sites I, II and III in the Minessa-Shashemene forest (DBH class: 1= 0-10; 2= 10-20; 3= 20-30; 4= 30-40; 5= 40-50; 6= 50-60; ..... , 22= 210-220 cm)

### 3.4. Plant Biomass

#### 3.4.1. Shrub Oven -Dry Weight and Regression Equation

Shrub biomass regression equation in the study forest was developed through direct harvest and measurement of oven dry weights of 10 sample individuals with dbh size range between 2- 10 cm. The biomass regression equation and oven dry weights of the shrub plants are given in Figure 2 and Appendix 1, respectively. The ten individuals (belong to 5 different species) were sampled for their bole, branch, foliage and coarse roots oven dry weights. The dry weight results of the sampled individuals has shown three different categories:- the first group have four individuals each plant dry weight less than 2.5 kg; the second group have three individuals each plant dry weight range between 2.7 - 3.7 kg; and the third group have two individuals each plant dry weight range between 8-12 kg. Shrubs biomass regression equation in the study forest is given as:

$$Y = a + bX$$

Where Y is the plant dry weight/biomass (kg); a = 0.22; X is the dbh; b= 0.82; and the adjusted  $R^2 = 0.99$ .

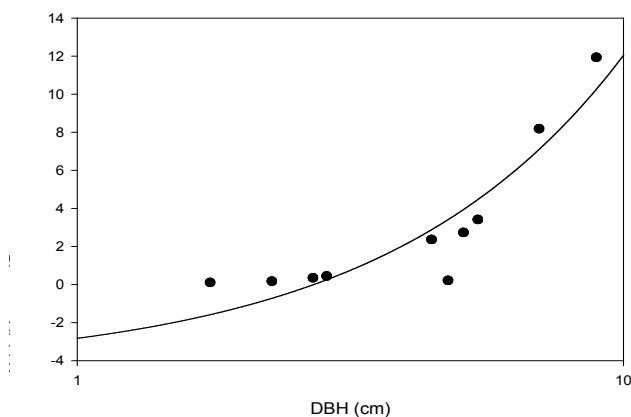


Figure 2: Relationship between dbh and oven dry weight (biomass) of shrub plants (dbh size 2-10 cm) in Munessa- Shashemene forest

#### 3.4.2. Tree and Shrub Biomass

Results of tree and shrub layers biomass recorded in Sites I, II and III in the study forest are given in Table 4. Trees (dbh size  $\geq 10$  cm) biomass in the three Sites range between 392.7 and 746.9 t ha<sup>-1</sup>. The highest tree biomass was recorded at Site II (the middle altitude), followed by Site III (upper altitude). The shrubs biomass was estimated using the regression equation shown in the above section. Shrub biomass at the three Sites range between 1.02 and 3.8 t ha<sup>-1</sup>. On the other hand, the highest shrub biomass was recorded at Site III (upper altitude), followed by Site I. The contributions of bole, branch, foliage and coarse roots to shrubs biomass were 46.5, 22.5, 7.5 and 23.5 %, respectively.

The average trees and shrubs biomass in the study forest were estimated as 559.7 t ha<sup>-1</sup> and 2.89 t ha<sup>-1</sup>, respectively.

Table 4: Trees, shrubs and herb layers biomass at Sites I, II and II in Munessa-Shashemene forest

| Site     | Shrub biomass t ha <sup>-1</sup> | Tree biomass t ha <sup>-1</sup> | Herb layer biomass t ha <sup>-1</sup> | Above ground biomass t ha <sup>-1</sup> |
|----------|----------------------------------|---------------------------------|---------------------------------------|---|
| Site I   | 3.78                             | 392.7                           | 6.6                                   | 403.08                                  |
| Site II  | 1.02                             | 746.9                           | 6.4                                   | 754.32                                  |
| Site III | 3.89                             | 557.9                           | 5.5                                   | 567.29                                  |
| Average  | 2.89                             | 559.79                          | 6.1                                   | 574.89                                  |

### 3.4.3. Herb Layer Biomass

Results of herb layer biomass in the three Sites are given in Table 4. Herb layer biomass in the three Sites ranged between 5.5 and 6.6 t ha<sup>-1</sup>. Relatively higher herb layer biomass was recorded at Site I, followed by Site II; and low herb layer biomass was found in Site III. Average herb layers biomass in the study forest was estimated as 6.1 t ha<sup>-1</sup>.

### 3.4.4. Above Ground Biomass

Results of above ground plant biomass that constituted biomass of trees, shrubs and the herb layers in the study forest are summarized in Table 4. The above ground plant biomass at the three Sites of the study forest range between 403.08 t ha<sup>-1</sup> and 754.3 t ha<sup>-1</sup>. The highest above ground plant biomass was recorded at Site II (middle altitude), followed by Site III (upper altitude); and the lowest above ground plant biomass was recorded at Site I (lower altitude). The average above ground plant biomass in the study forest was estimated as 574.89 t ha<sup>-1</sup>.

## 3.5. Annual Biomass Productivity

### 3.5.1. Fine Litter Fall

Results of fine litter fall in the three Sites of the study forest are given in Table 5. Fine liter fall in the Sites ranged between 2.0 and 4.5 t ha<sup>-1</sup>. Relatively higher fine litter fall was recorded in Site I (lower altitude), followed by Site II (middle altitude); and low fine

litter biomass was recorded in Site III (upper altitude). Average fine litter fall in the study forest was estimated as 3.5 t ha<sup>-1</sup>. Analysis of variance indicated significant differences

### **3.5.2. Fine Root Biomass**

Results of fine roots biomass in the three Sites of the study forest are given in Table 5. Fine roots biomass in the three Sites ranged between 3.9 and 9.7 t ha<sup>-1</sup>. The highest fine roots biomass was recorded in Site III (upper altitude), followed by Site II (middle altitude), and the lowest was found in Site I (lower altitude). Average fine roots biomass in the study forest was estimated as 7.24 t ha<sup>-1</sup>.

### **3.5.3. Annual Stem Diameter Growth**

Results of stem diameter increment in the three Sites are presented in Table 5. However, the detailed analyses of the annual stem diameter increment of the two-hundred thirty eight individuals (in 1.5 ha plots) marked and measured in April 2006 and re-measured in April 2007 is not yet ready for the reporting calendar, due to timing overlap. However, a preliminary analysis was conducted on major plant species and the result revealed that stem diameter increment in the three Sites range between 6.3 t ha<sup>-1</sup> and 11.6 t ha<sup>-1</sup>. The highest stem diameter increment was recorded at Site I, followed by Site II; and the lowest recorded at Site III.

### **3.5.4. Net Primary Production (NPP)**

Results of net primary production in the three Sites are given in Table 5. The annual biomass productivity or NPP in the three Sites ranged between 18 t ha<sup>-1</sup> year<sup>-1</sup> and 20 t ha<sup>-1</sup> year<sup>-1</sup>. Relatively, higher Net Primary Production was recorded in Site I and followed by Site II; and the lowest was recorded in Site III. The contribution of fine litter to NPP was 22.5, 20.1 and 11.1 % at Sites I, II and III, respectively. Similarly, the contribution of fine roots to NPP was 19.5, 40.7 and 53.8 % at Sites I, II and III, respectively.

In a related study, Lieth (1973) developed formula based on the relationship of net primary productivity (NPP) to mean annual temperature, [ $Y = 3000/(1 + e^{1.315-0.119X})$ ; where Y is net primary productivity (g m<sup>-2</sup> year<sup>-1</sup>) and X is the mean annual temperature (°C)], and to mean annual precipitation [ $Y = 3000/(1 - e^{-0.000664X})$ ; where Y is net primary productivity (g m<sup>-2</sup> year<sup>-1</sup>) and X is the mean annual precipitation (mm year<sup>-1</sup>)]. Accordingly, by using the mean annual temperature and precipitation-based models, the NPP for the study forest is predicted between 18.4 t ha<sup>-1</sup> year<sup>-1</sup> and 47.5 t ha<sup>-1</sup> year<sup>-1</sup>. The NPP value reported in the present study (although it is not the final one) is on the lower range as compared to the temperature and precipitation based model projection.

Table 5: Fine litter fall, fine roots biomass, stem diameter increment and NPP in three Sites in Munessa-Shashemene forest

| Site     | Fine litter biomass<br>t ha <sup>-1</sup> year <sup>-1</sup> | Fine root biomass<br>t ha <sup>-1</sup> year <sup>-1</sup> | Stem diameter Increment<br>t ha <sup>-1</sup> year <sup>-1</sup> | Above ground NPP<br>t ha <sup>-1</sup> year <sup>-1</sup> | Total NPP<br>t ha <sup>-1</sup> year <sup>-1</sup> |
|----------|--|--|--|---|--|
| Site I   | 4.5  | 3.9  | 11.6   | 16.1  | 20   |
| Site II  | 4.0  | 8.1  | 7.8  | 12.1  | 19.9   |
| Site III | 2.0  | 9.7  | 6.3  | 11.7  | 18   |

#### 4. DISCUSSION

Numbers of woody plant species per hectare in wet and rain forests in Puerto Rico range 15- 50 species (Weaver and Murphy, 1990). The number of woody plant species per hectare in the present study (18- 22 species) is within the range of forests in Puerto Rico, but much lower than an Amazonian Bolivia rain forest (94 species) (Boom, 1986).

On the other hand, the total woody plant species reported in the study forest (36 woody species) is lower than the range of other dry afro-montane forests in eastern and central Ethiopia (48- 81 species) (Sebsebe Demissew, 1988; Tamrat Bekele, 1994; Simon Shibiru and Girma Balcha, 2004). The reasons for low species number might be due to the dominance of few tree species (*Podocarpus*, *Croton* and *Prunus*) over the others i.e. species lack equal chances for competition and human impacts in the form of intensive logging. However, the reported woody plant species richness in the present study is comparable to wet forests in southwestern Ethiopia (28 - 68 species) (Mateos Ersado and Yoseph Assefa, 2002).

Woody plant densities in dry afro-montane forests of Ethiopia range between 1750 - 2494 individuals ha<sup>-1</sup> (Tamrat Bekele, 1994; Simon Shibiru and Girma Balcha, 2004). The reported woody plant density in the present study (484 - 1518 individuals ha<sup>-1</sup>) is lower than the dry afro-montane forests in Ethiopia. However, the woody plant density is within the range reported for Wof-Washa dry forest in central Ethiopia (1018 individual ha<sup>-1</sup>) (Tamrat Bekele, 1994). In a related study Lugo et al. (1978) reported stem density per ha (plant dbh size > 5 cm) in forests of Puerto Rico range 540 – 2260 individuals ha<sup>-1</sup>. According to Weaver and Murphy (1990), tree densities per hectare in Puerto Rico forests range 1750-1850 individuals.

On the other hand, Lugo et al., (1978) reported that stem density (plant dbh size > 10 cm) in forests in Puerto Rico range 100- 280 individuals ha<sup>-1</sup>. Stem densities (plants with dbh size > 10 cm) reported in the present study range 178- 276 individuals ha<sup>-1</sup> and therefore comparable to forests in Puerto Rico. However, the reported stem densities (plants with dbh size > 10 cm) is lower than the range reported for other dry forests in Ethiopia (322- 638 individuals ha<sup>-1</sup>) (Tamrat Bekele, 1994; Simon Shibiru and Girma Balcha, 2004); wet forests in southwestern Ethiopia (387- 584 individuals ha<sup>-1</sup>) (Mateos Ersado and Yoseph Assefa, 2002). Similarly, stem densities (plants with dbh size > 10 cm) in an Amazonian Bolivia rain forest was 649 individuals ha<sup>-1</sup> (Boom, 1986) and in Papua New Guinea forest was 693 individuals ha<sup>-1</sup> (Wright et al., 1997). The reasons for low stem density per hectare in the present study forest were grazing, trampling, selective cutting and logging.

Plant basal area of tropical rainforests was within the range 23- 37 m<sup>2</sup> ha<sup>-1</sup> (Dawkins 1959, cited in Lamprecht, 1989). Plant basal area in wet and rain forests in Puerto Rico range 40- 65 m<sup>2</sup> ha<sup>-1</sup> (Weaver and Murphy, 1990). Similarly, plant basal areas in an Amazonian Bolivia rain forest was 21.4 -38.6 m<sup>2</sup> ha<sup>-1</sup> (Boom, 1986; Alves et al., 1997); and in Papua New Guinea forest was 37.1 m<sup>2</sup> ha<sup>-1</sup> (Wright et al., 1997). Plant basal area reported in the present study range 14 - 56 m<sup>2</sup> ha<sup>-1</sup> is within the range of other dry forests in eastern and central Ethiopia (32.4 - 49 m<sup>2</sup> ha<sup>-1</sup>) (Tamrat Bekele, 1994; Simon Shibiru and Girma Balcha, 2004); and wet forests in southwestern Ethiopia (29 -50.8 m<sup>2</sup> ha<sup>-1</sup>) (Mateos Ersado and Yoseph Assefa, 2002). However, it is lower than plant basal area in Wof –Washa forest (100 m<sup>2</sup> ha<sup>-1</sup>) in central Ethiopia (Tamrat Bekele, 1994).

According to Wright et al.,(1997) in a forest from Papua New Guinea the density of individuals (dbh size of > 10 cm) in the successive diameter size class decreased with each 10 cm rise, for example, 60.7 %, 20 %, 9.6 %, 4.4 %, 2.1 %, 1.2 %, 0.7 %, 0.4 %, 0.3 %, 0 %, 0% and 0.1%, and the highest dbh measured was 136 cm. Similarly, density diameter distribution of plants in tropical rainforest of Amazonian Bolivia (70 % in 10-19 cm size class, 22 % in 20-29 cm size class, 4.8 % in 30-39 cm size class, 1.5 % in 40-49 cm size class, 0.9 % in 50-59 cm size class, 0.6 in 60-69 cm size class, 0 % in 70-79 cm size class 0.3% in the 80-89 cm size class and 0.2% in 90-99 cm size class) (Boom, 1986), is similar to the density diameter distribution of plants in the present study forest. In related studies, the dry forests in eastern and central Ethiopia had shown same patterns of density diameter distribution with that of the present study forest (Tamrat Bekele, 1994; Simon Shibiru and Girma Balcha, 2004). Accordingly, continuous density diameter distributions of plants in the eastern and central Ethiopian dry forests make them closely resemble Site II (middle altitude) within the present study forest in particular. According to Mateos Ersado and Yoseph Assefa (2002), the density diameter distribution of plants in forests of south-western Ethiopia is continuous with progressive decline in proportion of individuals in the successive diameter classes (for example, 52-71 %; 20-40 %; 3.9-8.4 %; 0.3-2.8 %; 0.1-0.8 % in dbh classes of 10-20, 20-50, 50-80, 80-110, 110-140 and > 140 cm, respectively). However, the missing of some individuals in the intermediate diameter classes in Chilmo forest in central Ethiopia makes it resembles Sites I and III (lower and upper altitudes) within the present study forest.

Tropical forest structures were known to vary with climate, topography and human impacts (Clark and Clark, 2000). The patterns of density diameter distributions of plants in the three Sites within the study forest are the results of human factors and topography. Human impact on the density diameter distributions can be seen at Site I where total density per hectare is relatively low, plants with dbh < 10 cm size constituted 80 % of the population and several individuals in the intermediate diameter classes were missed. In Site II where human interference is presumably least, plant density is relatively much higher and plant density diameter class distribution is continuous. The inverse- J shape structure in Site II revealed the healthy natural regeneration of the forest in the middle altitude in particular. At Site III where human impact relatively low compared to Site I, the density diameter class distributions is not continuous and characterized by missing of some individuals in the intermediate diameter classes.

According to Brown (1997), the understory vegetation constitutes less than three percent of the above ground biomass in tropical forests while trees constituted up to ninety-seven percent. In the present study, tree biomass constituted over ninety-seven percent of the above ground plant biomass. In a related study in a dry tropical forest of India tree biomass constituted eighty-two percent of the above ground biomass (Singh and Singh, 1991).

Global pattern above ground biomass in tropical dry and wet forests ranged between 30-273 t ha<sup>-1</sup> and 213- 1173 t ha<sup>-1</sup>, respectively (Murphy and Lugo, 1986b). Above ground biomass in Amazonian Brazil forests ranged between 290- 495 t ha<sup>-1</sup> (Alves et al., 1997). Similarly, the above ground biomass reported in the present study (403.08 - 754.32 t ha<sup>-1</sup>) is within the range reported for various tropical moist and premontane moist forests, mixed and old growth dipterocarp forests and evergreen moist tropical forests (Bandhu et al., 1973, Huttel and Bernhard-Reversat, 1975, Huttel 1975, Kira 1978, all cited in Brown and Lugo 1982; Brown, 1997). Moreover, the average above ground biomass reported in the present study forest (576 t ha<sup>-1</sup>) is five fold higher than the previous estimates (about 101 t ha<sup>-1</sup>) of plant biomass for forests of Ethiopia (Brown, 1997). On the other hand, above ground biomass in tropical and subtropical forests in Puerto Rico ranged between 80 - 190 t ha<sup>-1</sup> (Weaver and Murphy, 1990). The above ground plant biomass reported in the present study forest is generally higher than several tropical dry and wet forests in Africa, Asia and Latin America countries. Although the central and eastern afro-montane forest in Ethiopia generally characterized by distinct climate seasonality, plant biomass production in the forest is closely similar to that of (moist/ wet) rainforests in tropical Asian and Latin American countries.

According to Brown and Lugo (1982) litter fall in dry tropical forests range between 5.6-8.2 t ha<sup>-1</sup> year<sup>-1</sup>. Lugo et al., (1978) reported that annual litter fall in a tropical dry forest in Puerto Rico was 2.0 t ha<sup>-1</sup> year<sup>-1</sup>. Fine litter biomass in the present study forest range 2-5 t ha<sup>-1</sup> year<sup>-1</sup> which is in the lower range to the values reported for dry tropical forests (Brown and Lugo, 1982). One of the reasons for low litter fall production in the present study forest attributed to the dominance of the narrow-leaved, evergreen conifer plant (Podocarpus). On the other hand, fine litter biomass in tropical forests range 2 -16 t ha<sup>-1</sup> year<sup>-1</sup> and its contribution to above ground biomass is less than 5 percent (Brown, 1997). Similarly, litter fall in tropical and subtropical forests in Puerto Rico ranged between 3.1-8.61 t ha<sup>-1</sup> year<sup>-1</sup> and the contribution to NPP was estimated to 89.5 percent (Weaver and Murphy, 1990). In the present study, the contributions of fine litter fall to above ground net primary production and total net primary production were 26.3 and 18.1 percent, respectively. In a related study, fine litter fall ranged between 4.88- 6.71 t ha<sup>-1</sup> year<sup>-1</sup> in a dry forest in India (Singh and Singh, 1991) and between 3-10 t ha<sup>-1</sup> year<sup>-1</sup> for a variety of dry tropical forests (Murphy and Lugo 1986b).

Assessment of fine root dynamics received high priority because of the potentially large fraction of NPP that can be involved (for example, 32- 49 % in Alaskan taiga forests) (Clark et al., 2001). Fine root biomass contributed 2.5- 4.6 t ha<sup>-1</sup> year<sup>-1</sup> in a dry tropical forest (Singh and Singh, 1991). Accordingly, fine roots contribution to NPP ranged 22.1 - 31.0 percent. The reported fine root biomass in the study forest (3.9 - 9.7 t ha<sup>-1</sup> year<sup>-1</sup>) is

slightly higher than the values reported for variety of dry tropical forests and comparable to fine root biomass in wet forests in Puerto Rico (2.25.- 15.6 t ha<sup>-1</sup>) (Cairns et al., 1997). The average contribution of fine root biomass to NPP in the study forest is 37.3 percent.

Net primary production ranged 8- 21 t ha<sup>-1</sup> year<sup>-1</sup> for a variety of dry tropical forests, and 13- 28 t ha<sup>-1</sup> year<sup>-1</sup> for wet tropical forests (Murphy and Lugo, 1986b). Similarly, in a dry forest of India net primary production ranged 11- 19 t ha<sup>-1</sup> year<sup>-1</sup> (Singh and Singh, 1991). The net primary production reported in the present study (18- 20 t ha<sup>-1</sup> year<sup>-1</sup>) is comparable to net primary productions of other tropical forests (Brown and Lugo, 1982; and references cited in there). According to Brown and Lugo (1982) net primary production in forests in Puerto Rico ranged between 12.6- 20.8 t ha<sup>-1</sup> year<sup>-1</sup> for tropical premontane moist forest; 11.1- 19.3 t ha<sup>-1</sup> year<sup>-1</sup> for tropical moist forest; and 15.3 t ha<sup>-1</sup> year<sup>-1</sup> for subtropical moist forest and 11.0 t ha<sup>-1</sup> year<sup>-1</sup> for subtropical dry forest. Similarly, the temperature and precipitation based model (Lieth, 1973) projection of net primary production in the study forest (18- 47 t ha<sup>-1</sup> year<sup>-1</sup>) provided closer estimate (on the lower range) to the measured NPP. Aboveground tree and shrub net primary production in dry forests of India ranged 2.8- 7.7 t ha<sup>-1</sup> year<sup>-1</sup> and 2.7- 3.7 t ha<sup>-1</sup> year<sup>-1</sup>, respectively (Singh and Singh, 1991). Accordingly, the contributions of trees and shrubs to NPP were 12- 18 % and 33- 43.7 %, respectively. In the present study, tree and shrub contribution to the above ground NPP and total NPP were 63.9 % and 44.0 %, respectively. In a related study, above ground NPP in Puerto Rico forest was 7.6 t ha<sup>-1</sup> year<sup>-1</sup> and tree and shrub biomass contribution to the total NPP was 7.8 % (Weaver and Murphy, 1990). According to Brown and Lugo (1982) above ground NPP in tropical forests ranged 11.1- 18.2 t ha<sup>-1</sup> year<sup>-1</sup> for tropical premontane moist forests; 9.6 - 16.7 t ha<sup>-1</sup> year<sup>-1</sup> for tropical moist forest; 13.9 t ha<sup>-1</sup> year<sup>-1</sup> for subtropical wet and moist forests. In the present study above ground NPP range between 11.7- 16.1 t ha<sup>-1</sup> year<sup>-1</sup> and the contribution to the total NPP is 68.9 percent. The contribution of above ground NPP to the total NPP in the study forest, therefore, is in the lower range to other tropical premontane moist and tropical moist forests.

In 1989 forest cover in Ethiopia was estimated to 2.7 % of the country and deforestation rate estimated between 150,000- 200,000 hectares per annum (average 163,600 ha) (EFAP, 1994). The annual above ground biomass loss due to deforestation in Ethiopia is therefore, estimated between  $6.59 \times 10^7$  t-  $1.23 \times 10^8$  t year<sup>-1</sup> and, the annual carbon loss is estimated  $3.28 \times 10^7$ -  $6.17 \times 10^7$  t C year<sup>-1</sup>. In conclusion, the study dry forest in Ethiopia has shown similar (comparable) results in forest structure, basal area, above ground biomass and net primary production to several tropical rain forests in Africa and elsewhere in the world. The above ground biomass and NPP of the study forest in particular are much higher than for most dry tropical forests and within the range of tropical rain forests. Such comparable results in above ground plant biomass and NPP to tropical rain forests imply the significance of dry forests in Ethiopia in the global carbon pool/flux and hence climate change.

## 5. FUTURE DIRECTIONS

1. I plan to continue on inventory of structure, biomass and NPP of wet forests in southwestern Ethiopia for comparison with dry forest and provide accurate information on the national biomass stock and carbon pool/flux (of both dry and wet afro-montane forests) and their potential role in the global climate change
2. Mapping deforestation and carbon fluxes of the Ethiopian montane forests using Multi-Date SPOT-VGT Imagery and the Normalized Difference Vegetation Index (NDVI) image differencing method and predict the dynamics of carbon pool and CO<sub>2</sub> flux over time.
3. Establish long-term CO<sub>2</sub> flux measurements using the eddy covariance method for estimation of Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) in selected forest in Ethiopia and monitoring seasonal CO<sub>2</sub> fluxes and response of whole canopy photosynthesis to environment variables and climate change
4. Evaluate impact of climate change on reproductive phenology and spatial distribution of dominant trees in the montane forests in Ethiopia and the eastern Africa in general.

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## REFERENCES

- Alves, D., Soares, V.J., Amaral, S. Mello, E., Almeida, S., Silva, O. and Silveira, A. 1997. Biomass of primary and secondary vegetation in Rondonia, Western Brazilian Amazon. *Global Change Biology*, 3: 451-461.
- Boom, B. 1986. A forest inventory of in Amazonian Bolivia. *Biotropica* 18: 287-294.
- Brown, S. and Lugo, A. 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* 14: 161-187.
- Brown, S., Gillespie, A. and Lugo, A. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* 35:881-902.
- Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: a Primer. FAO Forestry Paper – 134, Rome.
- Cairns, M., Brown, S., Helmer, E. and Baumgardner, G. 1997. Root biomass allocation in the world's upland forests. 111: 1-11-
- Chaffey, D. 1979. South-west Ethiopia forest inventory project: a reconnaissance inventory of forest in south-west Ethiopia. Land Resources Development Center, England.
- Clark, D.B. and Clark, D.A. 2000. Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecology and Management* 137: 185-198.
- Clark, D.A., Brown, S., Kicklighter, D., Chambers, J., Thomlinson, J., and Ni, J. 2001. Measuring net primary production in forests: concepts and field methods. *Ecological Applications* 11: 356-370
- Cox, M., Betts, R., Jones, C., Spall, S. and I.J. Totterdell. 2000. Acceleration of global warming due to carbon cycle feedbacks in a couple climatic model. *Nature* 408: 184- 187.
- Cramer, W., Bondeau, A., Woodward, I., Prentice, I., Betts, R., Brovkin, V., Cox, P., Fisher, V., Foley J., Friend A., Kucharik, C., Lomas, M., Ramankutty, N., Sitch, S., Smith, B., A. White A. and Young-Molling, C. 2001. Global response of terrestrial ecosystem structure and function to CO<sub>2</sub> and climate change. *Global Change Biology* 7: 357-373
- Edwards, S., Mesfin Tadesse and Hedberg, I. 1995. Flora of Ethiopia and Eritrea. Vol 2 Part 2, Addis Ababa, Ethiopia and Uppsala, Sweden.
- Edwards, S., Sebsebe Demissew and Hedberg, I. 1997. Flora of Ethiopia and Eritrea. Vol.6. Addis Ababa, Ethiopia and Uppsala, Sweden.
- EFAP, 1994. Ethiopian Forestry Action Programme. EFAP, Environmental Protection Authority, Addis Ababa, Ethiopia.
- FAO, 1998. World reference base for soil resources. Food and Agriculture Organization of the United Nations. Rome, Italy, 165 p.
- Friis, I. 1992. Forests and forest trees of North East tropical Africa. *Kew Bull. Add. Ser.* 15, 1-396.
- Hedberg, I. and Edwards, S. 1995. *Flora of Ethiopia and Eritrea*. Vol. 7. Addis Ababa, Ethiopia, and Uppsala, Sweden.
- Hedberg, I., and Edwards, S. 1989. Flora of Ethiopia. Vol. 3. Addis Ababa, Ethiopia, and Uppsala, Sweden.
- Houghton, J.T., Meira-Filho, L. G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K. 1996. Climate change 1995: the science of climate change. New York, USA, Cambridge University Press.
- Ito, T. and Oikawa, T. 2000. A model analysis of the relationship between climate perturbations and carbon budget anomalies in global terrestrial ecosystems: 1970 to 1997. *Climate Research* 15: 161-183.

- Lamprchet, H. 1989. *Silviculture in the tropics- tropical forest ecosystems and their tree species*. Verlagsgesells, Germany
- Lieth, H. 1973. Primary production: terrestrial ecosystems. *Human Ecology* 1: 303-322.
- Lugo, A., Gonzalez-Liboy, J., Cintron, B. and Dugger, K. 1978. Structure, Productivity, and Transpiration of a subtropical dry forest in Puerto Rico. *Biotropica* 10: 278-291.
- Magurran, E.A. 1988. *Ecological diversity and its measurement*. Princeton University, New Jersey.
- Mateos Ersado and Yoseph Assefa, 2002. Structural characteristics of the moist montane forests in southwest Ethiopia. In G. Balcha, T. Bekele and K. Yeshitela (eds.). *Proceedings of Forest Resources of Ethiopia: Status, Challenges and Opportunities*. Institute of Biodiversity Conservation Ethiopia. Pp 77-87, Addis Ababa, Ethiopia.
- Mesfin Tadesse 2004. *Flora of Ethiopia and Eritrea*. Vol. 4 Part 2. Addis Ababa, Ethiopia and Uppsala, Sweden.
- Muller-Dombois, D. and Ellenberg, H. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley and Sons inc. USA.
- Murphy, P. G. and Lugo, A. E. 1986a. Ecology of tropical dry forest. *Ann. Rev. Ecol. Syst.* 17: 67-88.
- Murphy, P.G. and Lugo, A.E. 1986b. Structure and biomass production of a dry tropical forest in Puerto Rico. *Biotropica*, 18: 89-96.
- Sebsebe Demissew, 1988. The floristic composition of Menagesha State Forest and the need to conserve such forests in Ethiopia. *Mt. Res. Dev.* 8: 243- 247.
- Simon Shibru and Girma Balcha, 2004. Composition, structure and regeneration status of woody species in Dindin natural forest, Southeast Ethiopia: an implication for conservation. *Ethiopian Journal of Biological Sciences*, 3: 15-35.
- Singh, L. and Singh, J.S. 1991. Species structure, Dry matter Dynamics and Carbon Flux of a dry tropical forest in India. *Annals of Botany* 68: 263- 273.
- Soil Survey Staff, 2003. *Keys to soil taxonomy*. United States Department of Agriculture, Natural Resources Service. Washington, USA, 332 p.
- Tamrat Bekele, 1994. *Studies on remnant afro-montane forests on the central plateau of Shewa, Ethiopia*. Ph.D. dissertation, Acta Universitatis Upsalensis, Uppsala, Sweden.
- Weaver, P. and Murphy, P. 1990. Forest structure and productivity in Puerto Rico's Luquillo Mountains. *Biotropica* 22: 69-82.
- White, A., M.G.R. Cannel, and A.D. Friend. 2000. CO<sub>2</sub> stabilization, climate change and the terrestrial carbon sink. *Global Change Biology*, 4: 817-833.
- Wright, D., Jessen, J., Burke, P. and Silva Garza, H. 1997. Tree and liana enumeration and diversity on a one hectare plot in Papua New Guinea. *Biotropica* 29: 250-260.
- Yalden, D. W. 1983. The extent of high ground in Ethiopia compared to the rest of Africa. *SINET, Ethiop. J. Sci.* 6: 35-39.

## APPENDIX

Appendix 1: Plant bole, branch, foliage and coarse root oven dry weights of ten sampled individuals (dbh size 1.5-9 cm) from Munessa-Shashemene forest

| Species                     | DBH<br>(cm) | Bole<br>(g) | Branch<br>(g) | Foliage<br>(g) | Coarse<br>root (g) | Total<br>(g) |
|-----------------------------|-------------|-------------|---------------|----------------|--------------------|--------------|
| <i>Bersama abyssinica</i>   | 1.5         | 55.5        | 5.0           | 11.0           | 400                | 111.5        |
| <i>Rytigynia neglecta</i>   | 2.0         | 99.0        | 22.0          | 16.0           | 41.0               | 178.0        |
| <i>Bersama abyssinica</i>   | 2.5         | 226.2       | 6.0           | 36.0           | 185.5              | 453.7        |
| <i>Canthium oligocarpum</i> | 3.0         | 151.8       | 75.6          | 63.0           | 66.0               | 3546.4       |
| <i>Canthium oligocarpum</i> | 4.5         | 888.2       | 520.0         | 410.0          | 923.0              | 2741.2       |
| <i>Vernonia urticifolia</i> | 5.0         | 1016        | 425.5         | 210.0          | 585.0              | 2236.5       |
| <i>Bersama abyssinica</i>   | 5.5         | 2505.3      | 147.0         | 81.0           | 690.0              | 3423.3       |
| <i>Maytenus addat</i>       | 6.5         | 1147.5      | 640.0         | 297.0          | 286.0              | 2370.5       |
| <i>Bersama abyssinica</i>   | 8.0         | 3025.0      | 2380.0        | 444.0          | 2345.0             | 8194.0       |
| <i>Maytenus addat</i>       | 9.0         | 6565.0      | 2806.0        | 450.0          | 2120.0             | 11941.0      |