Variation in above ground biomass in Nyungwe Forrest, Rwanda

Johan Cohn

Uppsats för avläggande av naturvetenskaplig kandidatexamen i Miljövetenskap
15 hp
Institutionen för växt- och miljövetenskaper
Göteborgs universitet
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Summary

This study was carried out as a Minor Field Study (MFS) in Rwanda during spring and early summer, 2010. The main purpose was to evaluate carbon storage in Nyungwe tropical mountain forest in Rwanda, by measurements of aboveground biomass. The methods described by FAO (1997, 2004) were used for aboveground biomass determinations and calculations. Aboveground biomass was found to be 427.7 t C ha\(^{-1}\) in Nyungwe forest. This is an average value of the 40 quadrants (10×10 m) from 4 different trails. Diameter at breast height (DBH) was the most important factor for storage of aboveground biomass among the studied tree species. This means that old trees with large DBH were of crucial importance for the aboveground biomass storage in Nyungwe forest. The distribution of tree species was more dependent on the location of the trail in the forest than to the ground slope angle at each quadrant.

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1 Introduction

Global warming is an emerging issue of concern for everyone and everywhere. Carbon dioxide (CO$_2$) is by far the most important cause of anthropogenic climate change (Cunningham and Cunningham 2008). Forests, and in particular tropical forests, around the world act as important carbon sinks (Fellman et al. 2005). FAO (2004) underlined the importance of tropical forests in the context of climate change, since their biomass and carbon content are generally high, reflecting their influence on the global carbon cycle. Laforteza et al. (2009) estimated that the forests of the world store approximately 60 gigatons (Gt) of carbon from the atmosphere every year. Consequently, as FAO (2004) stated, successful land management planning can increase the uptake of CO$_2$ from forest in a short and medium term.

de Blij et al. (2004) have estimated most of the tropical rainforest in the world may disappear by the middle of this century. Goudie (2006) pointed out that rapid loss of rainforest could be extremely serious since the removal of the rainforests may contribute to crucial global environmental concerns like climate change and loss of biodiversity. The Copenhagen Climate Conference in 2009 did not become the starting point to reach an international agreement regarding limited greenhouse gases emissions. But, in an optimistic point of view, ocean and land were attended as CO$_2$ sinks in a way which has never happened before in the history of the environment. Allison et al. (2009) emphasized that the future of CO$_2$ sinks has not been revised since the Intergovernmental Panel on Climate Change Fourth Assessment Report in 2007 (IPCC AR4). As a result, forests became regarded as important carbon sinks during this top-level summit of climate. Hence, it is of crucial importance to find out more about forests and their role in the climate of the earth.

In Rwanda the Nyungwe forest covers an area of 970 km$^2$ of tropical mountain forest, located at (2º17'-2º50'S, 29º07'-29º26'E) and situated at 1600-2950 m altitude (Nsabimana and Wallin 2009). Nyungwe forest is together with the forest of Mukura and the forest of Gishwati ecosystems that is part of the Albert Rift afro-mountain forests (Ministry of Lands Resettlement and Environment 2003), see figure 1. Plumptre et al. (2002) stressed that the Nyungwe forest represents a key area for rainforest conservation and Masozera et al. (2004) concluded it is Rwanda’s largest remaining forest and one of the most biologically rich lower mountain rainforests in Africa. Nsabimana and Wallin (2009) emphasised that the Nyungwe forest is important for its biodiversity, its ecological processes and its ecosystem services. Masozera et al. (2004) have pointed out that fragmentation of family farms through generational transfers, growing population pressure and limited alternative employment opportunities have led to the expansion of cultivation onto marginal lands and natural forests in Rwanda. The total forested area in Rwanda was estimated to be 30% of total land area during the 1930s, and in 2005 it was reduced to 10% (Nsabimana and Wallin 2009). Obviously Nyungwe forest is depending on incentives besides conservation in order to become a protectable value. One way to achieve such an incentive could be to show that Nyungwe forest plays an important role in the climate of the earth, by developing an overall budget of climate. In this way, the forest can get a noteworthy value underlining its importance in the issue of global warming. This could hopefully make the forest more defensible in the future.
1.1 Importance of Land Use Change in the Consistency of Climate Change

Le Quéré et al. (2009) in Allison et al. (2009) stated that the combined global emissions of CO$_2$ from fossil fuel burning, cement production and land use change (mainly deforestation) in 2008 were 27% higher than in the year 1990. Allison et al. (2009) considered that CO$_2$ emissions from land use change were relatively constant in the past few decades. As evaluated by Allison et al. (2009) preliminary figures suggest that total CO$_2$ emissions have dropped in 2009, but this is just a temporary effect resulting from the global recession. In other worlds; there is no sign of the transformation required for stabilizing greenhouse gases in the atmosphere. Canadell et al. (2007) in Allison et al. (2009) estimated that the oceanic and terrestrial CO$_2$ reservoirs – the CO$_2$ sinks – have continued to absorb more than half of the total emissions of CO$_2$. Nonetheless, the fraction of emissions absorbed by the reservoirs has likely decreased by approximately 5% (from 60 to 55%) in the past 50 years. It is important to have in mind that the uncertainty in this estimate is large, because of the significant background variability and uncertainty in CO$_2$ emissions from land use change.

1.2 State of Forest in Central Africa and Rwanda

Lafortezza et al. (2009) estimated that the total forest area in the world in 2005 was 3952 million ha or 30.3% of the total land area. Forest area in Africa was found equal to 635 million ha or 16.1% of global forest area, which corresponds to 21.4% of the African continent land area (Lafortezza et al. 2009).

Lafortezza et al. (2009) discussed the current rate of deforestation in Africa and observed that on a global basis are eighteen countries characterized by an estimated annual positive change of 1% or more due to natural expansion of forests and to reforestation. Among these nations are four countries located on the African continent. The countries are Rwanda (+6.9%), Lesotho (+2.7%), Egypt (+2.6%) and Tunisia (+1.9%). For central Africa, defined as a region...
composed of Burundi, Cameroon, the Central African Republic, Congo, Equatorial Guinea, Gabon and Rwanda, forest cover equals to 224 million ha in 2005. This is a reduction of 1.3% compared to 2000 and 4.8% compared to 1990. Expressed as a fraction of the 1990 forest cover of the land Rwanda had the largest increase (+50.9%) and Burundi the largest decrease (-47.9%) in Central Africa (Lafortezza et al. 2009). Due to Lafortezza et al. (2009) the increase in Rwanda was the result of a change in extent of forest plantations. This means that productive and protective forest plantations are combined. Lafortezza et al. (2009) estimated that their extent increased from 78% of the total forest area in 1990 (248×10^3 ha) to 87.2% (419×10^3 ha) in 2005. This trend observed in Rwanda not been found elsewhere in Central Africa (Lafortezza et al. 2009). On the other hand Nsabimana and Wallin (2009) estimated that the Rwandan deforestation rate was 3.9% between 1990 and 2000, which was in compliance with estimations from FAO (2001) and UNEP (2002).

The forests of Nyungwe, Mukura and Gishwati form the mountain forest in Rwanda, which are part of the Albert Rift afro-mountain forests. As described in Ministry of Lands Resettlement and Environment (2003) forests have a significant commercial value deriving from the use of different forest products. In fact, wood is the principal source of energy in Rwanda. 96.2% of households use wood as a source of energy and 31.4% use it as a source of lighting. More than 60% of the urban population use charcoal as a source of energy. Wood is also very much used for construction purposes.

Masozera et al. (2004) considered that fragmentation of family farms through generational transfers, growing population pressure and limited alternative employment opportunities have led to the expansion of cultivation onto marginal lands and natural forests. A significant connection, found by (Masozera et al. 2004), was that land size is expected to have a negative impact on forest dependency. Therefore, pressure on the forests will most likely increase in the future, since Rwanda both is a highly populated nation and a small country regarding total land area.

Concerning the question of deforestation, one new approach to handle the issue could be to develop an overall based carbon budget for Rwanda. Such a budget could give a lasting value for the forest of Nyungwe, if the forest could be integrated as a valuable resource regarding the mitigation of climate change.

1.3 Deforestation and degradation

One of the earliest and still continuing human impacts on the biosphere is the removal of the original vegetation cover and its replacement by either different vegetation or by man-made structures. According to Lafortezza et al. (2009) deforestation at the global scale is the most significant impact on ecosystems all around the world. Deforestation linked to timber harvest is the major anthropogenic disturbance regime that has a direct influence on forest dynamics. Brown and Pearce (1994) defined deforestation as a change of land use with the depletion of the tree crown cover to less than 10%. Changes within the forest class, from closed to open forest, which negatively affect the site of stand and in particular the decrease in the production capacity, are termed degradation.
1.4 Why measure aboveground biomass?

Nsabimana and Wallin (2009) stated;

“Field data on carbon stock, annual carbon increment in biomass and litter production in Rwanda forests are not available, but are needed for calculating the Rwanda carbon balance, predicting carbon emissions from the forest conversion to cleared land, predicting carbon-sequestration potentials, to support policy negotiations in relation to carbon offset and carbon sequestration market through reforestation projects, and to estimate sources and sinks of greenhouse gases to be reported the United Nations Framework Convention on Climate Change (UNFCCC)”,

and;

“Extensive studies including all structures of Rwanda forest will be needed in the future, and may lead to more precise estimates of carbon stocks for Rwanda forests.

1.5 Previous studies on aboveground biomass

Since the Copenhagen Climate Conference in 2009 is forest throughout the world in current time associated as important CO$_2$ sinks (Allison et al. 2009). Besides, it will be interesting to see which extended standing CO$_2$ sinks will get in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5). The report will very most likely be published in June 2013 (Williams 2007).

Measurement of aboveground biomass is a new way to estimate the value of forests as carbon sinks. Accordingly the examples in the literature are telling few (FAO 2004). Nevertheless the studies from FAO (2004) “Assessing carbon stocks and modeling win-win scenarios of carbon sequestration through land use changes”, Keith et al. (2009) “Re-evaluation of forest biomass carbon stocks and lessons from the world’s most carbon-dense forests” and Nsabimana and Wallin (2009) “Carbon stock and fluxes in Nyungwe forest and Ruhande arboretum in Rwanda” are good models for this report.

Keith et al. (2009) determined forest biomass carbon stocks in the highlands of Victoria, which is located in the southeastern part of Australia. They found that _E. regnans_ forest in the O’Shannassy Catchment of the Central Highlands (53 sites within a 13000 ha catchment) contains an average of 1053 t C ha$^{-1}$ in living aboveground biomass and 1867 t C ha$^{-1}$ in living plus dead total biomass in stands with cohorts of trees > 100 years old sampled at 13 sites. They examined this catchment in detail because it had been subject to minimal human disturbance, either by Indigenous people or from post-European settlement land use. No other records of forests have values as high as those found for _E. regnans_. Apparently, this is the world’s most carbon-dense forest. Temperate forests have higher biomass than tropical and boreal ones. They suggested that temperate forests has particularly high biomass carbon density included those dominated by _Tsuga heterophylla, Picea sitchensis, Pseudotsuga menziesii_ and _Abies amabilis_ in the Pacific Northwest of the North America (range in living above biomass of 224-587 t C ha$^{-1}$ and total biomass of 568-794 t C ha$^{-1}$). The reason for high
biomass carbon densities in *E. regnans* is due to a prolonged absence of direct human land-use activity.

It has been argued that primary forests, especially very old forests, are unimportant as carbon sinks, due to mainly to reasons. *First*; their carbon exchange is considered to be just around zero. *Second*; young trees grow faster and consume more carbon than older ones. This declaration has formed the basis of modifying forestlands, from old tree clumps to new younger ones with rapid growth. Recent research finding have countered the first argument for all three major forest biomes (tropical, temperate and boreal) and confirmed that old-growth forests are likely to be functioning as carbon sinks. They have developed a framework for identifying forests with high biomass carbon stocks. This structure is based on Australian Eucalyptus Regnans Forest (*E. regnans*). They found four overall factors controlling the biomass carbon stocks: *First*; environmental conditions. *Second*; life history and morphological characteristics of each tree species. *Third*; natural disturbance, such as for example fire. *Fourth*; land-use activity. The fourth aspect could be explained as a freestanding factor which include anthropogenic disturbance. Large carbon stocks can be developed in a forest as a result of a combination and interaction between these four factors.

Nsabimana (2009) has written his Ph.D. thesis by a cooperation agreement between the Department of Plant and Environmental Science, University of Gothenburg and the Department of Biology, National University of Rwanda. In this thesis Nsabimana and Wallin examined carbon stocks in Ruhande Arboretum and Nyungwe forest in Rwanda.

Total carbon storage was found to be between 356-1252 Mg C ha\(^{-1}\) in the Ruhande Arboretum and between 382-798 Mg C ha\(^{-1}\) in the Nyungwe forest. The largest carbon fraction was stored in aboveground biomass which was 70% in the Ruhande Arboretum and 57.3% in the Nyungwe forest. These values of carbon storage are larger in comparison to figures reported in other tropical forests. The explanation for large carbon storage in Ruhande Arboretum and Nyungwe forest was a relatively high number of large trees per area on the investigated plots.

Forest carbon stocks are here measured in six different pools, which are aboveground biomass, belowground biomass, coarse, litter, herbaceous vegetation and soil. Aboveground biomass was investigated in Nyungwe forest in July 2008. All trees within the plots having a stem diameter at breast height (DBH) of more than 10 cm were measured using a Vertex III and a Transponder T3 (Haglöf, Sweden AB). The wood density was determined using wood samples collected from the field and oven-dried at 70 °C for 48 hrs, following the method described by Standards Australia (2000). The volume of the biomass was calculated using the measured DBH and height after the allometric equation in FAO (2004). The total aboveground biomass was calculated by multiplying the volume, wood density and biomass expansion factor. Aboveground biomass was found to be 161 Mg ha\(^{-1}\) at BTP: blue trail plot, 490 Mg ha\(^{-1}\) at GTB: green trail plot and 512 Mg ha\(^{-1}\) at YTP: yellow trail plot.

FAO (2004) is a comprehensive survey of recommendations and standards for aboveground biomass. In addition, three different case study results are discussed, where aboveground biomass are investigated. The first case is the Texcoco River in Mexico, the second case is the tropical forest lowlands of Bacalar, Quintana Roo in Mexico and the third case is the Rio
Cauto Watershed in Cuba. Each case is discussed considering effecting factors for carbon in aboveground biomass and adjusted methods for aboveground biomass estimations at different locations.

The human activities cultivation and forestry play a crucial role in the storage of carbon in forests.

In Texcoco River were the regression equation proposed by FAO (1999) used. The regression equation method, based on biomass as a function of measurements of volume, proved to be the most adequate method for estimating the biomass of the type of tropical forests in Bacalar in the Yucatan Peninsula. The aboveground biomass of forested areas in the Rio Cauto study area were estimated using regression equation FAO-1 for dry tropical areas receiving more than 900 mm of annual precipitation. This equation gave the best fit to data in the least-squares sense.

1.6 Aim and research questions

The aim of this report was to estimate the carbon storage in the Nyungwe forest measurements of aboveground biomass. More specifically, the overall purpose was to evaluate whether the previously measurements of aboveground biomass are in correlation with expected standards or not.

The aim gives rise to the following research questions:

1) How large is the aboveground biomass per hectare (t C ha\(^{-1}\))?

2) How is aboveground biomass divided depending on tree species hectare (t C/species ha\(^{-1}\))? 

3) How is the aboveground biomass divided regarding to the slope of the ground (t C/slope intervals ha\(^{-1}\))? 

4) How is the different tree species distributed according to the slope of the ground (tree species/slope intervals)? 

2 Method

This study was carried out as a Minor Field Study (MFS) to Rwanda during spring and early summer, 2010. The main purpose was to evaluate the importance of Nyungwe forest as carbon storage, by measurements of aboveground biomass. The field study was supported by the Swedish International Development Cooperation Agency (Sida). In addition to the various studies that Sida supports, Sida also have the ambition to give their MFS-participators an extended view in global issues and international relief work.

It is desirable if the report could contribute with a little step in the direction to increase the understanding of Nyungwe forests as a sink for CO\(_2\), playing a more crucial role in the future climate of the earth.
2.1 Important definitions for the method

There are important definitions in relation to measurement of aboveground biomass which has to be understood and followed, providing right demarcations during field work and supplementary work with the field data. Definitions regarding: tree, forest, biomass and biomass for a region or a country, tree diameter, forest carbon stocks, aboveground biomass and deforestation and degradation are all considered as central for this report and require accordingly more precise definitions.

2.1.1 Tree, Forest, Biomass and Biomass for a Region or a Country

In FAO (1997) a tree is defined generally as: “A woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definite crown and a height greater than breast height (1.3 m)”.

According to FAO (1997) forests are classified as:

“Forests are defined as land under natural or planted stands of trees with tree crown cover of more than 10 percent and area of more than 0.5 ha, whose primary use is forestry. The trees should be able to reach a minimum height of 5 m at maturity in situ (FAO unpublished report of expert consultation "Kotka III"). A tree is defined generally as a woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definite crown and a height greater than breast height (1.3 m)”

In compliance with FAO (2004) biomass is characterized as follows:

“Biomass is defined here as the total amount of live organic matter and inert organic matter (IOM) aboveground and belowground expressed in tones of dry matter per unit area (individual plant, hectare, region or country). Typically, the terms of measurement are density of biomass expressed as mass per unit area, e.g. tones per hectare”.

Biomass can be delineated for a certain area or country as described in FAO (2004): “The total biomass for a region or a country is obtained by up-scaling or aggregation of the density of the biomass at the minimum area measured”.

2.1.2 Tree Diameter and Forest Carbon Stocks

In conformity with FAO (1997) trees with a diameter that is greater than or equal to 10 cm are usually used as a general limit for included in biomass calculations. However FAO (1997) elucidated special circumstances can change this separation, depending on which forest biome that is under investigation. For forests or trees of smaller structure, such as those in the arid or in montane zones, degraded forests, or secondary forests FAO (1997) recommend that lower minimum diameters should be chosen.

Forest carbon stocks consist of measurements including aboveground biomass, belowground biomass, coarse deadwood, litter, herbaceous vegetation and soil (Nsabimana and Wallin 2009).
2.2 Aboveground Biomass Measurements

Detailed estimations of biomass of all land cover types are necessary for carbon accounting. According to FAO (2004) aboveground biomass can be estimated in mainly three different ways: First; classification of vegetation cover and generation of a vegetation type map. This partitions the spatial variability of vegetation into relatively uniform zones or vegetation classes. These can be useful in the identification of groups of species and in the spatial interpolation and extrapolation of biomass estimates. Second; indirect estimation of biomass by using some form of quantitative relationship between band ratio indices. Examples of this standard procedure are Normalized Differential Vegetation Index (NDVI) and Green Vegetation Index (GVI). Direct radiance values per pixel or digital numbers per pixel can be combined with direct measurements of biomass or with parameters related directly to biomass, as for example Leaf Area Index (LAI). Third; the application of ground observations together with diameter and height calculations of the trees, by using FAO (1997, 2004) standards for aboveground measurements.

This report is implemented by using the third alternative. Thus, it is needed to further describe the characteristics of this way of proceeding.

FAO (1997) refer to two different approaches for aboveground biomass density. The first approach is based on the use of existing measured volume estimates (VOB per ha) converted to biomass density (t ha⁻¹) using a variety of tools (Brown et al. 1989; Brown and Iverson 1992; Brown and Lugo 1992; Gillespie et al. 1992 in FAO 1997). VOB means inventoried volume over bark of free bole, for example from stumps or buttress to crown point or first main branch. This method is classified as biomass density based on existing volume data (FAO 1997). The second approach directly estimates biomass density using biomass regression equations. These regression equations are mathematical functions that relate oven-dry biomass per tree as a function of a single or a combination of tree dimensions. They are applied to stand tables or measurements of individual trees in stands or in lines (for example windbreaks, live fence posts and home gardens). This method is classified as biomass density based on stand tables (FAO 1997).

Of crucial importance, highlighted in FAO (1997), is the following statement: “To use either of these methods, the inventory must include all tree species. There is no way to extrapolate from inventories that do not measure all species”.

The first approach is characterized in FAO (1997):

“[…] and is best used for secondary to mature closed forests only, growing in moist to dry climates. It should be used for closed forest only because the original data base used for developing this approach was based on closed forests. The primary data needed for this approach is VOB ha⁻¹ that is inventoried volume over bark of free bole, i.e. from stump or buttress to Crown Point or first main branch. Inventoried volume must include all trees, whether presently commercial or not, with a minimum diameter of 10 cm at breast height or above buttress if this is higher”.
By using the first approach to evaluate aboveground biomass density the measurements has to follow the terms of instructions in form of the general equation stated in FAO (1997), according to Brown & Lugo (1992):

Aboveground biomass calculates in density tones (t) / hectare (ha) = VOB×WD×BEF,

where:

VOB = Inventoried volume over bark of free bole, for example from stumps or buttress to crown point or first main branch,

WD = Wood density as oven-dry mass per unit of volume. The WD factor should be calculated either in tons (t) / cubic metres (m$^3$) or grams (g)/ cubic centimetres (cm$^3$)

and,

BEF = Biomass expansion factor, which stands for ratio of aboveground oven-dry biomass of trees to oven-dry total biomass of inventoried volume.

It is of vital importance to be aware of the WD factor effect on the determinations of aboveground biomass (Göran Wallin; personal communication). The WD factor is marred by a high level of uncertainty, since it varies with different tree species. The BEF factor is a way to include the branches, roots etc of the estimate of the trees biomass (Göran Wallin; personal communication). In FAO (1997) BEF is fixed to 1.3.

2.3 Situation and Division

Uwinka Centre for researchers and tourists constituted as a camp location and meeting-place for the project in Nyungwe forest, see figure 2. Four areas were selected as references areas. They were assumed to be representative of the tree species occurring in that region of Nyungwe forest. The reference areas were divided up separately into four 10×100 meters areas. Their names and GPS-positions at start were: Green Trail 1 quadrant 1 (S 02°.28'.27.6", E 029°.11'.48.4"), Green Trail 2 quadrant 1 (S 02°.28'.33.6", E 029°.11'.47.4"), Blue Trail quadrant 1 (S 02°.29'.10.2", E 029°.11'.59.4") and Yellow Trail quadrant 1 (S 02°.29'.13.1", E 029°.11'.47.2").
Each 10×100 m site was divided into 10 quadrants (10×10 m), according to the standards in FAO (2004) for aboveground biomass measurements, see figure 3. Cords were fast up to discern the quadrants from the rest of the forest (see figure 4). The measurements started at quadrant 1 and ended at quadrant 10 at each of the four different locations; Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail. The measurements always followed a straight course from quadrant 1 to 10 – totally irrespective of the ground conditions – which here represents of ground slope angle and vegetation.

2.4 Species Names and Tree Measurements

All trees, within the 10×100 m areas and 10×10 m quadrants, with a diameter ≥ 5 centimetres, were selected for height and DBH measurements. If a tree was located just at the border line for the 10×10 m quadrants, the following rule was used: If more than half of the tree trunk was inside the quadrants it was include and if more than half of the tree trunk was outside the quadrants it was excluded from the measurements, see figure 5.
The trees were given a number and name. Both Kinyarwanda and scientific names were used. Jérémy Nzarora who was a local field assistant, was responsible for the name identification of the tree species, see chapter Collaborators during field work.

Trees consisting of a diameter ≥ 5 cm were measured using a calliper with a diameter capacity of ≥ 80 cm. For trees with lager diameters, the perimeter was measured instead by using a traditionally measuring tape. The diameter was consistent measured at DBH, which corresponds to exactly 130 cm from the ground. The perimeters were translated to diameters, by using the fundamental formula;

\[ p = \pi \times d \]

and,

\[ d = \frac{p}{\pi} \]

where;

\[ p = \text{perimeter (m)}, \quad \pi = \text{pi} \text{ and } d = \text{diameter (m)}. \]

The height of the trees, with a diameter ≥ 5 cm, was calculated by using a Vertex III and a Transponder T3 (Haglöf, Sweden AB). The distance between the Vertex III and the transponder was always measured to 10 m and the transponder was fasted up at DBH at the tree trunks. In a few cases, when the tree trunk was bended and the tree was short, a measuring tape was used instead to calculate the height of the tree.

### 2.4 GPS-position, Elevation and Ground Slope Angel Measurements

At each quadrant were the GPS-position and elevation red, using a Garmin GPSmap 60CS, in the centre of each sector. In some instance, when the vegetation was to impenetrable, GPS-position and elevation was recorded as closed to the sector centre as even possible (see figure 6).
The ground slope angle for each quadrant was measured using the Vertex III and the Transponder T3 (Haglöf, Sweden AB).

### 2.5 Equipment and tools used for Aboveground Biomass Measurement

The equipment and tools used for aboveground biomass measurements are shown in figure 8.
2.6 Calculation of Aboveground Biomass

Since the ground conditions in Nyungwe forest are quite steep, the areas of the quadrants had to be recalculated. They did not correspond to 10×10 m, after the recommendations in FAO (2004), because of the steep gradient of the ground. The leveled ground distance was measured by using the formula;

\[ \text{SGD} = \cos \theta \times x \]

where;

\( \cos \theta \) = is the ground slope angle in degrees (°) and \( x \) = is the distance of the two smaller sides of a right-angled triangle in meter (m).

The total quadrant area was calculated by multiplying the number of quadrants with the area of each quadrant.

To be able calculate the total volume of biomass for the inventoried quadrants the base area of the stem \( A_b \) (m\(^2\)) at DBH for each tree has to be measured by following the formula in (FAO 2004:19);

\[ A_b = \pi \times r^2 \]

where;

\( \pi = \pi \) and \( r = \) radius (m).

The site dependent constant for cubing \( K_c \) is needed to determine the volume for each tree according to the equation for volume in FAO (2004). The value of 0.5 for \( K_c \) was found to be reasonable for the volume calculations. It is based on the assumption that the volume of the tree trunk is consider to be half the volume of a cylinder, which give \( K_c = 0.5 \).

To find the volume of each tree the formula in (FAO 2004) was used;

\[ V = A_b \times H \times K_c \]

where;

\( A_b = \) base area of the stem at DBH in square metres (m\(^2\)), \( H = \) height of the tree in metres (m) and \( K_c = \) site dependent constant for cubing (0.5).

Wood Density (WD) was appointed for each tree species by using indexes from cdm.unfccc.int/index.html, datadryad.org, fao.org, and worldagroforestry.org. Biomass Expansion Factor (BEF) was fixed by the standards in FAO (1997).

Aboveground Biomass was calculated by using the formula in FAO (1997), after Brown & Lugo (1992);

\[ \text{Aboveground biomass in density tones (t) / hectare (ha)} = \text{VOB}\times\text{WD}\times\text{BEF}, \]
For definition of VOB, WD and BEF, see above.

3 Results

Please consider the chapter Acknowledgements before you read this section.

The result of the report is presented according to the aim and research questions.

3.1 How large is the aboveground biomass per hectare ($t\ C\ ha^{-1}$)?

The total aboveground biomass was found to be 157.57 t C within the investigated area. The total investigated area of the quadrants was found to be 3684.3 m$^2$ or 0.3684 ha. Hence, the aboveground biomass was found to be $157.57\ t\ C / 0.3684\ ha = 427.7\ t\ C\ ha^{-1}$ in Nyungwe forest. This value was expressed as an average value of the 40 quadrants from Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail.

3.2 How is aboveground biomass divided depending on tree species ($t\ C/tree\ species\ ha^{-1}$)?

The total aboveground biomass from the 40 investigated quadrants was divided on different tree species as according to table 1.

*Table 1. Aboveground biomass in $t\ C/species\ ha^{-1}$ expressed as an average value of the 40 quadrants from Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail. *The unidentified species were 2 trees from Green Trail 2 Quadrant 6 and 2 trees from Green Trail 2 Quadrant 9.*

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>t C/species ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alchornea hirtella</td>
<td>0.04</td>
</tr>
<tr>
<td>Allophylus abyssinicus</td>
<td>0.11</td>
</tr>
<tr>
<td>Allophylus chaunostachys</td>
<td>1.52</td>
</tr>
<tr>
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<td>28.18</td>
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<tr>
<td>Carapa grandiflora</td>
<td>26.00</td>
</tr>
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<td>1.56</td>
</tr>
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</tr>
<tr>
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</tr>
<tr>
<td>Diospyros gabonensis</td>
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<tr>
<td>Faurea saligna</td>
<td>16.52</td>
</tr>
<tr>
<td>Ficalhoa laurifolia</td>
<td>0.93</td>
</tr>
<tr>
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<td>14.28</td>
</tr>
<tr>
<td>Newtonia buchananii</td>
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</tr>
<tr>
<td>Olea hochstetteri</td>
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</tr>
<tr>
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</tr>
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<td>Podocarpus latifolius</td>
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<tr>
<td>Psychotria mahoni</td>
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Rapanea melanophloeos 0.41
Rhamnus prinoides 0.11
Symphonia globulifera 4.59
Syzygium guineense ssp. Parvifolium 201.71
Teclea nobolis 0.10
Undentified species* 54.30

<table>
<thead>
<tr>
<th>C/species ha⁻¹</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 ≤ 0.99</td>
<td>t C</td>
</tr>
<tr>
<td>1.00 ≤ 4.99</td>
<td>t C</td>
</tr>
<tr>
<td>5.00 ≤ 14.99</td>
<td>t C</td>
</tr>
<tr>
<td>15.00 ≤ 54.99</td>
<td>t C</td>
</tr>
<tr>
<td>55.00 ≤ 202.00</td>
<td>t C</td>
</tr>
</tbody>
</table>

### 3.3 How is the aboveground biomass divided regarding to the slope of the ground?

Figure 8, table 2 and figure 9 summarized the profile, total drop, average ground slope angle, aboveground biomass and aboveground biomass in ground slope angle intervals of the trails.
Figure 8. Profiles of GT1, GT2, BT and YT expressed as altitude (m) at each quadrant of the trails.

Table 2. Total drop (distance from highest to lowest quadrant in (m)), average ground slope angle in (°) and aboveground biomass t C/trail ha⁻¹.

<table>
<thead>
<tr>
<th>Trail name</th>
<th>Distance from highest to lowest quadrant (m)</th>
<th>Average ground slope angle (°)</th>
<th>Aboveground biomass t C/trail ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT1</td>
<td>47</td>
<td>24.1</td>
<td>92.24</td>
</tr>
<tr>
<td>GT2</td>
<td>23</td>
<td>15.7</td>
<td>239.18</td>
</tr>
<tr>
<td>BT</td>
<td>20</td>
<td>18.9</td>
<td>51.75</td>
</tr>
<tr>
<td>YT</td>
<td>33</td>
<td>24.5</td>
<td>44.55</td>
</tr>
</tbody>
</table>

Figure 9. Aboveground biomass in t C/ground slope angle intervals ha⁻¹.
### 3.4 How is the different tree species distributed according to the slope of the ground?

The distribution of tree species regarding the slope of the ground is reproduced in table 3.

*Table 3. Table 3 represents the distribution of species in consideration of ground slope angle (°) in number of species and per cent (%).*

<table>
<thead>
<tr>
<th></th>
<th>a)</th>
<th>b)</th>
<th>c)</th>
<th>d)</th>
<th>e)</th>
<th>f)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GT1</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Allophylus abyssinicus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>4</td>
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<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Casearia runssorica</td>
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<td></td>
<td></td>
<td></td>
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<td>1</td>
</tr>
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<td>1</td>
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<tr>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
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<td></td>
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<tr>
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<td>3</td>
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<tr>
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<td>Slope 14.00°-20.99°</td>
<td>Slope 21.00°-27.99°</td>
<td>Slope 28.00°-35.00°</td>
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%  
52.0  0.0  0.0  8.0  40.0

**Total**

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<td><strong>6</strong></td>
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</tbody>
</table>

%  
0.0  9.4  76.6  9.4  4.7

**YT**  

3.5 Statistics

Table 4 and figure 10 indicated that the location of the trails in Nyungwe forest is highly important for the contribution of the total aboveground biomass.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Formula</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average value</td>
<td>$\bar{x} = \frac{\sum x}{n}$</td>
<td>10.69</td>
</tr>
<tr>
<td>Variance</td>
<td>$s^2 = \frac{\sum (x-\bar{x})^2}{n-1} = \frac{\sum x^2 - \bar{x} \sum x}{n-1}$</td>
<td>474.51</td>
</tr>
<tr>
<td>Standard deviation (s.d.)</td>
<td>$s = \sqrt{\frac{\sum (x-\bar{x})^2}{n-1} = \sqrt{\frac{\sum x^2 - \bar{x} \sum x}{n-1}}}$</td>
<td>21.78</td>
</tr>
<tr>
<td>Index of dispersion ($I$)</td>
<td>$I = \frac{s^2}{\bar{x}}$</td>
<td>44.38</td>
</tr>
</tbody>
</table>

Table 4. Table 4 summarized the statistics in terms of: Average value, Variance, Standard Deviation (s.d.) and Index of Desperation ($I$).
Figure 10. GT 2 showed more than 50% contribution of the total aboveground biomass and had therefore a large impact on the average value of the 40 quadrants.

4 Discussion

The aboveground biomass was found to be 427.7 t C ha\(^{-1}\) in Nyungwe forest. This is an average value of the 40 quadrants from Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail. The ground conditions at each trail were quite steeply. That is why the ground slope angel was measured at each quadrant of the trails; it is needed for recalculation of the area of every quadrant. This was made to reach the total investigated area in ha.

Syzygium guineense ssp. Parvifolium had the largest amount of aboveground biomass; it was found to be 201.71 t C ha\(^{-1}\). DBH is considered to be the most important factor for storage of aboveground biomass among the different tree species. It points towards the conclusion that old trees with large DBH are of crucial importance for the aboveground biomass storage in Nyungwe forest. Macaranga kilimandscharica had the largest number of trees, especially at Blue Trail, but these trees had overall small DBH values, which gave this species a moderate contribution to the total aboveground biomass.

Green Trail 2 showed the largest amount of aboveground biomass compared to Green Trail 1, Blue Trail and Yellow Trail. Green Trail 2 stored approximately to times as much aboveground biomass compared to Green Trail 1 and three times as much compared to Blue Trail and Yellow Trail. Green Trail 2 has the smallest average ground slope angel.

It is a difficult task to find a connection between the ground slope angel at the quadrants and the distribution of tree species. The numbers of species of each trail were more dependent on the location of the trail than to the ground slope angel.

5 Conclusions

Expressed as an average value of the 40 quadrants from Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail is the aboveground biomass in Nyungwe forest found to be 427.7 t C ha\(^{-1}\).
Syzygium guineense ssp. Parvifolium stores the largest amount of aboveground biomass in the investigated area; it was estimated to be 201.71 t C.

DBH is the most significant factor for large aboveground biomass storage in Nyungwe forest. Consequently; old trees with large DBH were more important for the storage of aboveground biomass than high number tree species.

The number of species at Green Trail 1, Green Trail 2, Blue Trail and Yellow Trail is dependent on the location of the trail in the forest. Ground slope angle had a moderate contribution to the division of tree species within the investigated area.

Acknowledgements

Thanks to;

Johan Fredin Uddling, Junior research scientist, Department of Plant and Environmental Science, University of Gothenburg, for introducing the Minor Field Study (MFS) project in Rwanda.

Göran Wallin, University Lecturer, Head of the Department, Department of Plant and Environmental Science, University of Gothenburg, for field work instructions, supplementary work with the field data and the synthesis of the report.

Donat Nsabimana, Ph. D, Head of the Department, Department of Biology, National University of Rwanda, for field work instructions.

Göran Dave, University Lecture, Department of Plant and Environmental Science, University of Gothenburg, for the synthesis of the report.

The Swedish International Development Cooperation Agency (Sida) for receiving the Sida scholarship and the arrangement of the Minor Field Study (MFS) preparation course during the 18-19 of March 2010 in Gothenburg, Sweden.

Fiedel and Jérémie, living at the Nyungwe forest, Rwanda for their assistance during field work, see chapter Collaborators during Field Work.

Eric Dusenge Mirindi and Felix Niyonzima, students at National University of Rwanda, Department of Biology, for help finding literature concerning Nyungwe forest.

Minor Field Study (MFS) participators Josefin Arlesten and Sofia Lejon for rewarding conversations regarding international relief work during the time in Rwanda.

Pervious Minor Field Study (MFS) participator Johanna Gårdesten for useful pre-land information.
Collaborators during Field Work

In FAO (2004) the following statement is made;

“One of the most difficult tasks in practical fieldwork is the identification of the species on the ground. Owing to practical constraints, it is not possible to collect plants with all the morphological components needed for identification in a herbarium. Therefore, the knowledge of local people who have been working and living in or near the forest should play an important role in data collection. Local people can identify species accurately using local or even botanical names. This provides a useful alternative to the inclusion of a full-time botanist in the multidisciplinary team conducting the study. However, wherever possible, validation procedures should be set up in order to calibrate the validity of the method for identifying species, by collecting samples for botanical identification in the herbarium”.

The writer of this report is grateful to Fiedel and Jérémie Nzorara because of their help during fieldwork in Nyungwe forest. It was thanks to them the measurements were possible! Fiedel did most of the work regarding accessibility throw small of one’s own making paths in the forest, by using a machete in a handy way. Fiedel also did the majority of the DBH measurements and assisted with the Transponder T3 during height and slope calculations. Jeremias took notes and was responsible for the name identification of the trees, both in Kinyarwanda and Latin names. In addition, Jeremias did some of the GPS positions and appreciated a few of the height values from the Vertex III, when uncertainty rose to the surface. Besides, Fiedel and Jérémie did an exacting work during the establishment of the 10×10 quadrats. The conditions during fieldwork, regarding the slope of the ground, the thickness of the vegetation and the sometimes heavy rain, made the effort quite difficult.

In a Respectful Way;
Hearty Thanks
The Writer of this Report;
Johan Cohn
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*For finding Wood Density (WD) values were the following sources used:*

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http://cdm.unfccc.int/UserManagement/FileStorage/B7Y5L3VPMSJN0ODWU2HARC41Z9XG8I

*Internet Sources:*


*Personal Communication:*

Uddling Fredin, Johan, University of Gothenburg, Department of Plant and Environmental Science, phone number +46 – (0)31-786 37 57, e-mail: johan.uddling@dpes.gu.se

Wallin, Göran, University of Gothenburg, Department of Plant and Environmental Science, phone number: +46 – (0)31-786 26 20, e-mail: goran.wallin@dpes.gu.se