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DIFFERENCES IN CARBON STORAGE BETWEEN TEMPERATE AND TROPICAL FORESTS

Diploma Thesis

Academic year: 2014 - 2016 **Bc. Rolling Richard Loayza Fernandez**

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Abstract

Rolling Richard Loayza Fernandez

Differences in carbon storage between temperate and tropical forests.

Over the years a concern about climate change has shown up, affecting the natural conditions in many ways. Terrestrial biomes are part of the carbon cycle, storing and releasing carbon according to natural and anthropogenic factors. In this case, Temperate and Tropical forests are showing predictable tendencies. This diploma thesis is comparing these two biomes, factors which are influencing carbon storage, the differences between Temperate and Tropical forests, such as characteristics of the stands, forest management, and also external factors like deforestation and forest degradation, and finally proposing practical recommendations how to manage forests to improve carbon storage.

Key words: Allometric equation, Aboveground biomass, Carbon content, Tropical Forest, Temperate Forest.

Abstrakt

Rolling Richard Loayza Fernandez

Rozdíly v ukládání uhlíku mezi lesy mírného pásu a tropickými lesy

V průběhu let se objevily obavy ohledně změny klimatu, která ovlivňuje přírodní podmínky v mnoha ohledech. Suchozemské biomy jsou součástí koloběhu uhlíku, ukládají a uvolňují uhlík podle přírodních a antropogenních faktorů. V tomto případě lesy mírného pásu a tropické lesy vykazují předvídatelné tendence. Tato diplomová práce porovnává tyto dva biomy, faktory, které ovlivňují ukládání uhlíku, rozdíly mezi lesy mírného pásu a tropickými lesy, jako například vlastnosti lesních porostů, hospodářská úprava lesa a také externí faktory jako odlesňování a degradace lesů, a konečně navrhuje praktická doporučení ohledně spravování lesa s cílem zlepšení ukládání uhlíku.

Klíčová slova: alometrická rovnice, nadzemní hmota, obsah uhlíku, tropický les, les mírného pásu.

Table of contents

Table of figures

Tables

I. Introduction

The development of many parts on the world has been done through natural evolution. This evolution has been tainted by human activities. Nowadays we are seeing to the results of the natural evolution mixed with anthropogenic impact displayed by changing climatic conditions. We are globally feeling the climate change and how it influences our own evolution and limits our natural resources.

The development of society in the world has been through natural resources; us taking advantage of them in an excessive manner. It was the industrial revolution that rushed the development. This starting point was the beginning of the problems we are now experiencing.

Terrestrial forest biomes of the world are important for nature balance. Forests cover approximately 30 % of the world's land surface (Carlowicz & Simmon, 2012). That is over 4 billion hectares (FAO, 2010). Tropical forests, with astounding biodiversity, but unfortunately with high rate of deforestation, are just about able to supply needed resources and services. On the other hand, temperate forests in Europe have very good forest management, but compared to Tropical forests have quite low biodiversity. In both cases these forests play an important role in the climate change mitigation.

Carbon is one of the most important elements after the oxygen (Weathers et al., 2013) as well as the main component of the greenhouse gases. To understand the carbon cycle and its behavior in the ecosystem, we turn to biogeochemistry, explaining the major transformation flows in the carbon cycle, how it works and its behavior in the ecosystem. It should be part of the elementary knowledge to understand the carbon storage.

The structure of forests differs among biomes. Every single tree has a fundamental way of growth, its belowground part and aboveground part and both gather mass, which is known as below and aboveground biomass. These are extremely important features to assess carbon sinks. We can just do so with suitable allometric equations that we have developed according to ecosystems and tree growth. Tree allometry is a critical point in assessment of carbon sinks as it is in the accuracy of the results. In practical forest inventory have been obtaining the information from traditional methods at different kinds of technological levels. This study utilized the Field-Map Technology, developed by Czech scientists, for all data collections.

II. Literature review

2.1. Ecoregions and carbon sinks

WWF defines an ecoregion as a "large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (Olson et al., 2001) (WWF, 2016).

The first attempt to achieve representation of habitat types on a global scale was the introduction of the Global 200 with the primary objective to promote the conservation of terrestrial, freshwater, and marine ecosystems; harboring globally important biodiversity and ecological processes (Olson & Dinerstein, 1998). Over the years this system became the tool of looking at biodiversity loss in new ways as well as global threats of the climate change. It has a wide span ranging from oil exploration, mining, road development to logging. All facilitated by this detailed map of ecoregions (Olson et al., 2001).

In the world, there are 867 terrestrial ecoregions, classified into 14 different biomes such as forests, grasslands, or deserts (WWF, 2012) and eight biographical realms (Figure 1).

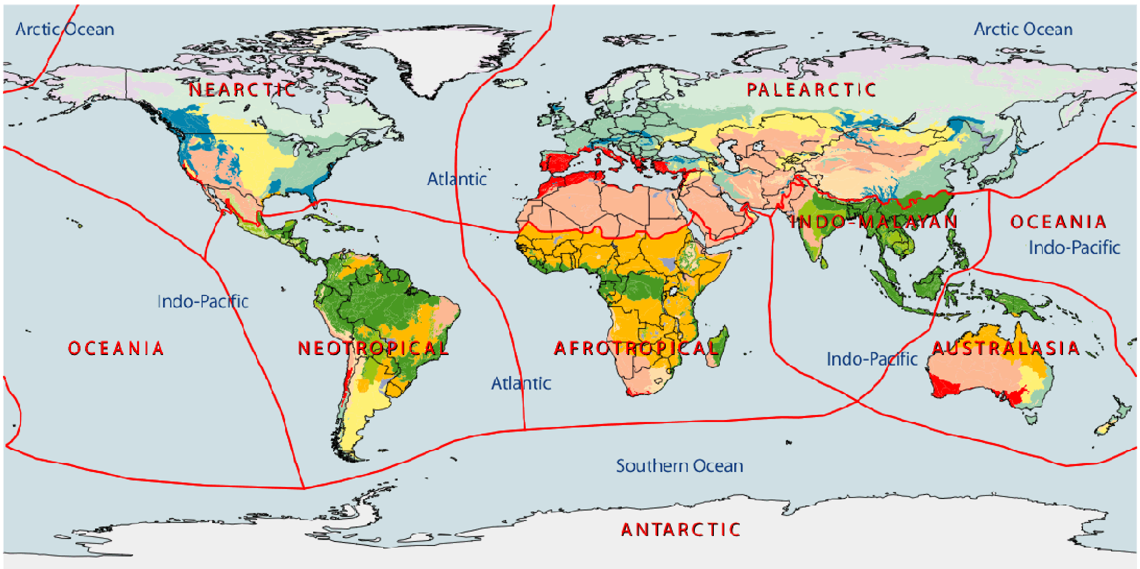

Figure 1.The ecoregions are categorized within 14 biomes and eight biogeographic realms to facilitate representation analyses. (Source from WWF)

The Terrestrial ecosystems store almost three times as much carbon as is in the atmosphere (Trumper et al., 2009), geographically, 471 ± 93 PgC (55%) is stored in tropical forests, with 272 ± 23 PgC (32%) in boreal and 119 ± 6 PgC (13%) in temperate forests (Pan et al., 2011).

Tropical forests occupy large areas of central and northern South America, western Africa, South-East Asia and northeastern Australia. Such forests have extremely high levels of plant, mammal, insect, and bird diversity and are considered to host the greatest biodiversity of all the Earth's biomes. Boreal forests occupy large areas of the northern hemisphere and are mainly found in Canada, Russia, Alaska and Scandinavia. Biodiversity in these forests is generally low. Temperate forests occupy large areas of Asia, Europe and North America and are mostly found in developed countries. (Trumper et al., 2009)

2.2. Carbon cycle

Element cycling is the transport and transformation of chemicals (Figure 2) within and among ecosystems. Elements are required by all living things, and element cycles thus link the living and nonliving part of ecosystems (Weathers et al., 2013). The most important thing to know to understand the carbon cycle is the difference between a stock and a flow of carbon. In forests the Stock carbon is represented by the biomass stored in the different components of the forest. Flows are all processes that affect stock (Cruzado Blanco, 2010)

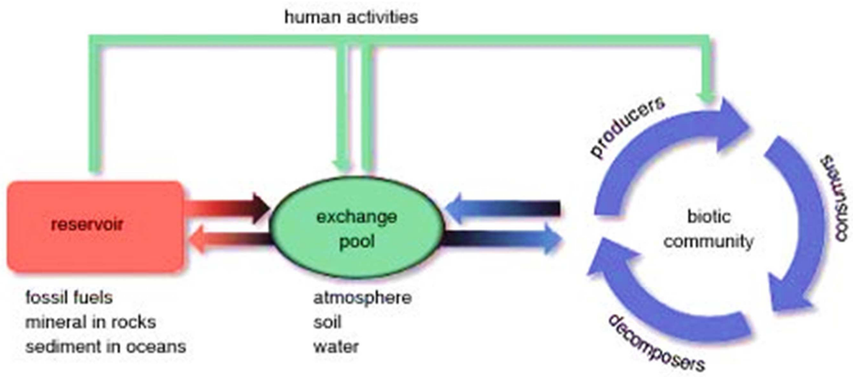

Figure 2. Biogeochemical cycles. (Source from The McGraw-Hill Companies)

The carbon cycle is fundamental to the functioning of the earth's biosphere (Brown et al., 2013) and is the second most important element by mass (after oxygen). In organism, carbon is chemically versatile and can form a diverse array of organic and inorganic compounds (Weathers et al., 2013). Carbon, in the form of carbon dioxide (CO_2), is one of the greenhouse gas emitted by human activities (WMO, 2013).

Carbon is exchanged, or "cycled" among Earth's oceans, atmosphere, ecosystem, and geosphere. All living organisms are built of carbon compounds. It is the fundamental building block of life and an important component of many chemical processes. It is present in the atmosphere primarily as carbon dioxide (CO2), but also as other less abundant but climatically significant gases, such as methane (CH4) (ESRL, 2016).

Conceptually, one can distinguish two domains in the global carbon cycle. The first is a fast domain with large exchange fluxes and relatively 'rapid' reservoir turnovers, which consists of carbon in the atmosphere, the ocean, surface ocean sediments and on land in vegetation, soils and freshwaters (IPCC, 2013).

The rate of change in atmospheric CO2 depends, however, not only on human activities but also on biogeochemical and climatical processes and their interactions with the carbon cycle (Falkowski et al., 2000).

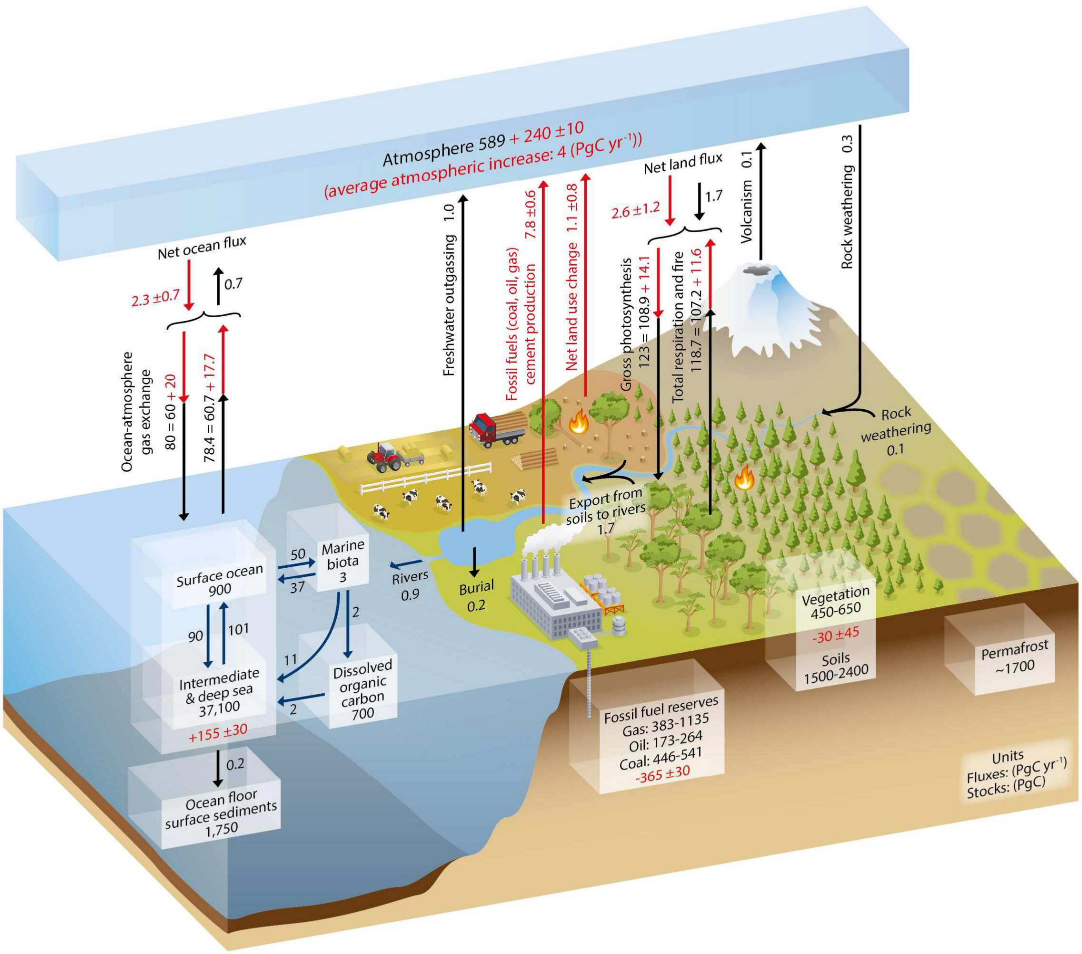

Figure 3.The carbon cycle from IPCC AR5

2.3. Climate change

Climate change is one of the most complex issues we are facing today. It involves many dimensions – science, economics, society, politics and moral and ethical questions – and is a global problem, felt on local scales, that will be around for decades and centuries to come. Carbon dioxide, the heat-trapping greenhouse gas that has driven recent global warming, lingers in the atmosphere for hundreds of years, and the planet (especially the oceans) takes a while to respond to warming. So even if we stopped emitting all greenhouse gases today, global warming and climate change will continue to affect future generations. In this way, humanity is "committed" to some level of climate change (NASA, 2016).

Climate change is one of the major challenges of our time and adds considerable stress to our societies and to the environment. From shifting weather patterns that threaten food production, to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale. Without drastic action today, adapting to these impacts in the future will be more difficult and costly (UNEP, 2010).

The radiative properties of the atmosphere are strongly influenced by the abundance of admixed GHGs, mainly carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), which have substantially increased since the beginning of the Industrial Era (defined as beginning in the year 1750), primarily due to anthropogenic emissions (IPCC, 2013).

2.4. Allometric equations

The term allometry means 'the relationship between a part of an organism and its entirety (West, 2009). This relationship stems from the ontogenic development of all individuals, which is the same for all throughout the history of life related variability (Picard et al., 2012). Allometry, therefore, refers to the relative growth of individuals (Gayon, 2000). The use of allometric regression models is a crucial step in estimating aboveground biomass (Chave et al., 2005). Calculations are performed from equations with general form.

$$M = aD^b$$

Where:

M : Oven-dry weight of the biomass component of the tree (Kg).

D : Is the DBH (cm).

a,b : are the parameters

This general equation has gained popularity because it provides a reasonable balance between accuracy and low requirements, but it can still incorporate additional independent variables (Larocque, 2015).

However, uncertainties in tropical forest carbon stocks remain high because it is costly and laborious to quantify standing carbon stocks. Carbon stocks of tropical forests are determined using allometric relations between tree stem diameter and height and biomass (Hunter et al., 2013).

When trunk diameter, total tree height, and wood specific gravity were included in the aboveground biomass model as covariates, a single model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors. The mean percent bias and variance of this model was only slightly higher than that of locally fitted models. Wood specific gravity was an important predictor of aboveground biomass, especially when including a much broader range of vegetation types than previous studies. The generic tree diameter–height relationship depended linearly on a bioclimatic stress variable E, which compounds indices of temperature variability, precipitation variability, and drought intensity. For cases in which total tree height is unavailable for aboveground biomass estimation, a pantropical model incorporating wood density, trunk diameter, and the variable E outperformed previously published models without height (Chave et al., 2014).

Brown (1997) proposed a classification of tropical forests into three forest types, dry, moist, and wet, following the Holdridge life zone system (Chave et al., 2014).

The Chave et al. (2005) models represented a major step forward in tropical forest carbon accounting, and they are currently being proposed for inclusion in the IPCC Emission Factor Database also used by REDD protocols. However, the quality of these allometric models represents one of the most important limitations in assessing AGB stocks. Tree height has often been ignored in carbon-accounting programs because measuring tree height accurately is difficult in closed-canopy, water stress is important in predicting the shape of local allometric equations, we also extracted monthly values of reference evapotranspiration (ET), as computed by the FAO Penman–Monteith equation (Chave et al., 2014).

2.5. Field-Map Technology

Field-Map is a system for computer aided field data collection with primary emphasis to forestry. It is a highly flexible system. Its use starts from the level of single tree measurement, through the level of research or inventory plot, up to the landscape level. Field-Map has been designed primarily for the purposes of forest inventory but it has functionality for a number of different field data collection tasks like forestry mapping, attributing forest stands for forest management planning, carbon offset monitoring, landscape mapping, standing volume assessment, measurement of research plots, inventory and monitoring of nature reserves, etc. Field-Map product line combines flexible real-time GIS software with electronic equipment for mapping and dendrometric measurement (IFER, 2014).

In Figure 4, all the basic programs are shown (FM Project Manager, FM Data Collector, FM Stem Analyst and FM Inventory Analyst) as well as tools; each one of them has been develop according the workflow such as project design, data collection and results analysis. Field-Map also features other platforms and its script is basically a piece of program written using Field-Map Object Pascal scripting language. Field-Map Object Pascal is a subset of Borland Object Pascal (used in Delphi programming environment). Knowledge of only a few basic construction commands is sufficient for most scripts (IFER, 2011), that allows for high project flexibility with high efficiency.

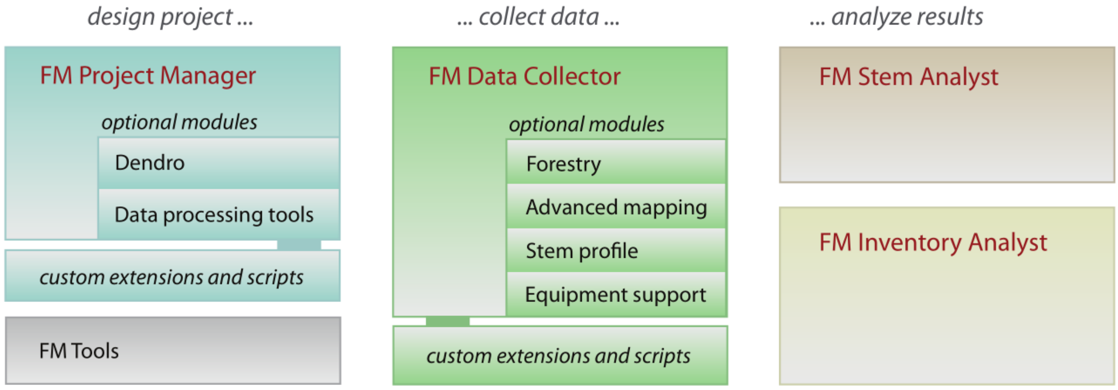

Figure 4. Field-Map software and its applications. (source from Field-Map)

Field-Map hardware consists of several parts. A field computer running the Field-Map software is the heart of the system. The software provides smooth communication with external devices. The hardware is usually delivered in sets designed to suit a particular need and can be divided into the following basic categories.

Field-Map hardware set categories:

- Rugged field tablet computers, Range-finders with inclinometer

- Electronic compasses or angle encoders, GPS / GNSS and Accessories

III. Materials and Methods

3.1. Study area

The study is focused onto two specific biomes. Data have been collected from Temperate and Tropical forests. Temperate forest study site is located in The Training Forest Enterprise Masaryk Forest Křtiny (TFE) (http://www.slpkrtiny.cz/en/), that it is an organizational part of Mendel University (MENDELU) in Brno - Czech Republic, TFE was founded in 1923. In the case of the Topical Forest, the plot was set up in the National Agrarian University of the Jungle (UNAS) in Tingo María – Perú. UNAS it is owner of the UNAS (BRUNAS) forest reserve, which was established in 1971 (Puerta & Cardenas, 2012).

This study was performed on two study plots, Hády and Soběšice, located in TFE, in the southeastern Czech Republic. Each plot has an area of 4 ha. The elevation of the study areas is 401 m.a.s.l. in Hády and 355 m.a.s.l. in Soběšice. The bedrock is chalk in Hády and granodiorite in Soběšice, and the soils are brown forest soils in Hády and cambisols in Soběšice. The average annual rainfall is 510 mm, and the average annual air temperature of both plots is 8.4°C. The average temperature in July (the warmest month) is 18.4°C, and the average temperature in January (the coldest month) is −2.1°C, based on data from 1960–2010 from the Brno climatic station (the nearest climatic station for both plots) (Matula et al., 2015).

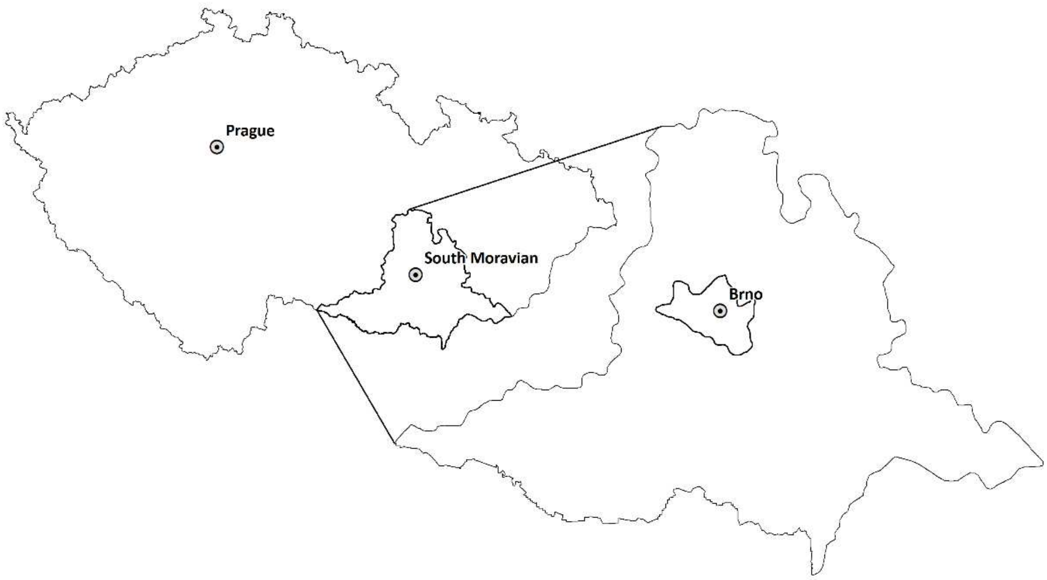

Figure 5. Location map of the study area in Czech Republic, Temperate Forest.

The study area was an active coppice stand for at least 200 years in the eighteenth and nineteenth centuries and was documented as an active coppice as late as 1898 (Kadavý et al. 2011). However, from 1902 to 1920, the coppice underwent a transformation to a high forest (Kadavý et al. 2011) and in 2009, the original old growth forests in both plots were harvested, with an intention to restore a short-rotation coppice system (Matula et al., 2015).

The study area in the tropical forest averages an annual rainfall of 3428.8 mm. Precipitations is mostly distributed between September and April and reaches the highest numbers in January, with an average monthly rainfall of 483.6 mm. Relative humidity is around 87% and the average annual temperature is 24°C. According to life zones system developed by Holdridge (1982) BRUNAS the plot is located in Subtropical Premontane Wet Forest (Puerta Tuesta , 2007).

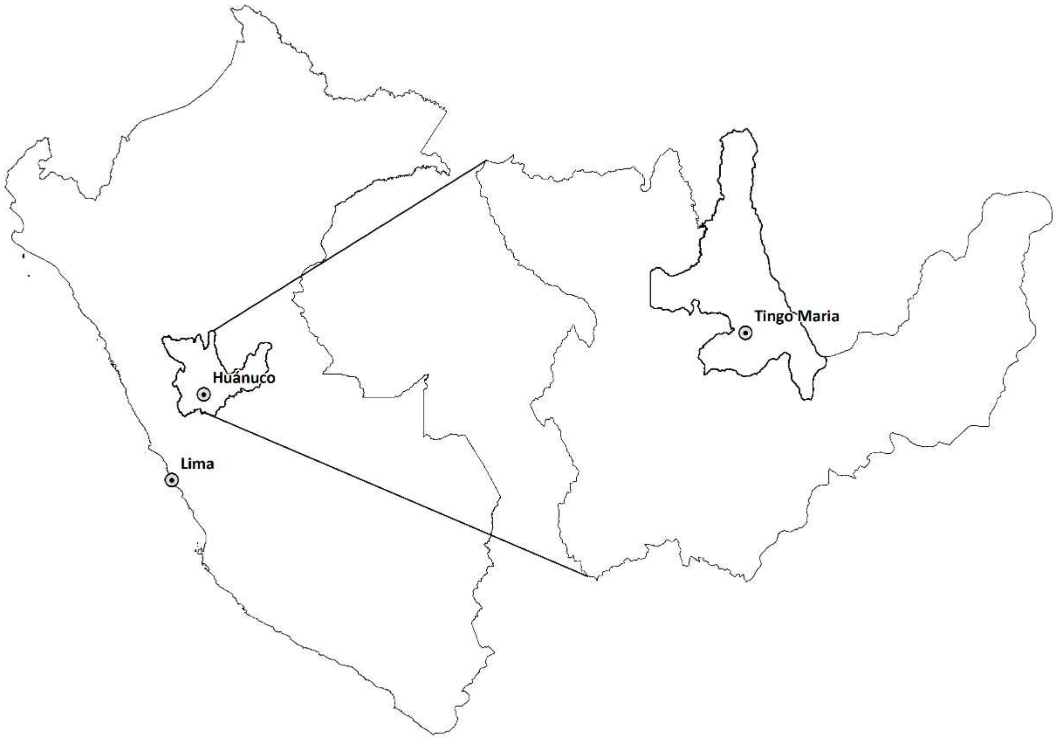

Figure 6. Location map of the study area in Perú, Tropical Forest.

Many plantations with native and introduced species have been established in the BRUNAS. They are most notably the plantings of "Screw", installed in 1950 by Ing. Jose Burgos Lizarzaburu during his operation of Tingo Maria Agricultural Experiment Station. The plantations were established by opening sashes oriented from east to west in the area of forest high hill between 720 and 760 m.a.s.l., using around 1-year-old saplings of *Cedrelinga cateniformis*. Trans-plantation of natural regeneration was made on bare root to ensure engraftment. 108 plants of *Cedrelinga cateniformis* and 108 plants *Swietenia macrophylla* were also established in the strips covering an area of one hectare. Unfortunately, mahogany plants were unsuccessful and virtually disappeared after the third year (Burgos, 1955). This plantation is considered the oldest of its kind in the South America screw (Wadsworth, 2000)

Table 1. Description of the study sites included in this study.

Biomes	Country	Site	Latitude	Longitude	Rainfall (mm)	Altitude (m.a.s.l)
Temperate Forest						
	Czech R.	Hády	49°13'30"N	16°40'55"E	510.00	401.00
	Czech R.	Soběšice	49°14'43"N	16°35'59"E		355.00
Tropical Forest						
	Perú	Low T. M.	09°18'58"S	75°59'31"W	3428.80	730.00
	Perú	High T. M.	09°18'54"S	75°59'09"W		870.00

3.2. Variables

The data collected from the forest inventory are made from certain areas. Temperate and tropical forests generally use different methodology to gather the information according to specific classification, limits of evaluation, and other parameters. In the case of the temperate forest all individuals from 7cm of DBH were evaluated.

The methodology differs in Tropical forest as only individuals over 10 cm of DBH are evaluated. The DBH < 10 cm class is considered as regeneration evaluation (evaluating from 30 cm of height in seedlings). It has to be noted that all the calculation in reference to tropical forest will be bigger than 10 cm of DBH.

3.3. Materials

All the data collections was performed with Field-Map Technology; license acquired from Mendel University, Universidad Nacional Agraria de la Selva (national Peruvian university) and Map Geo-Solutions Consult. This Technology was developed by the Institute of Forest Ecosystem Research (IFER), integrating hardware and software with principal feature to collect real-time data. The hardware consists of Laser Technology, rugged computer and accessories interconnected with the software. Field-Map Data Collector (one of the applications of Field-Map) that allow location of the trees, measure of height, diameter and attribute for each map layer.

3.4. Methodology

3.4.1. Creation of database

The database framework has been designed in the application called Field-Map Project Manager, which allows the field workflow process to take place with high efficiency due to features for information records. The parameters of the design were set up according to variables that should be collected such as species list, dendrometric parameters, size of the plot, geographical information and other attributes.

The following steps have been done on desktop computer with a hardlock that contains sufficient license. It is up to the user to select between the Standard or Lite version. Figure 7 shows the procedures of Field-Map LT (Lite) and the import and export of the project and data.

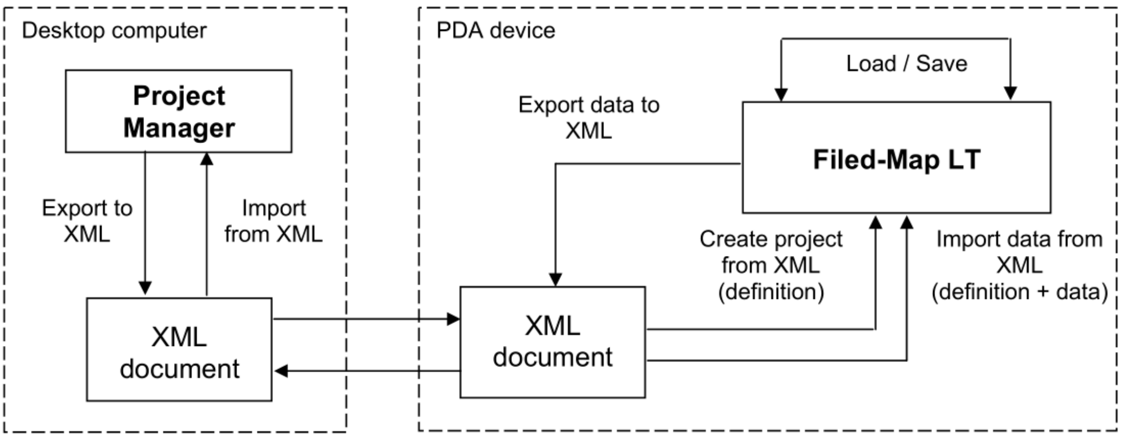

Figure 7.The workflow among Field-Map's applications. (Source from Field-Map)

The internal structure of the Field-Map database is based on Paradox or MS Access tables or MSSQL database for storage of attributes and ArcView shapefiles for storage of geographical entities. It is easily possible to convert the attribute tables to dBase, excel, XML and other formats by using the export utility of Field-Map Project Manager (IFER, 2011).

3.4.2. Data collection

The study area was identified according the target biome, and located by Global Navigation Satellite System (GNSS) through a device, that works in a Global Coordinate System (GCS[1]). GCS[1] was later changed to a Local Coordinate System (LCS[2]) in a specific spot (corner of the plot) with Field-Map equipment. The Field-Map equipment was first located in 0,0 coordinate, than we started to measure trees around in the equipment range. Trees were first located with the laser rangefinder and electronic compass, obtaining their locations by polar coordinate (distance and azimuth). Dendrometric parameters, except diameter, were obtained remotely by Field-Map. Field-Map is capable to calculate height from the tree stem and measures it by rangefinder through geometric relationships (Figure 8). All of the above data are gathered in the computer. The Field-Map interface of the FM Data collector allowed us to note other attributes as well.

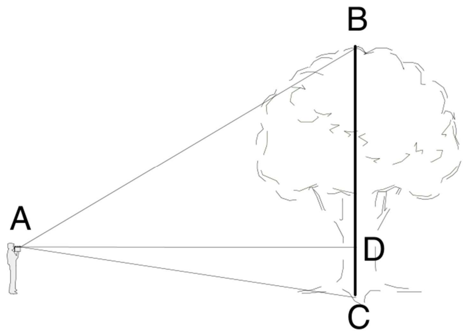

Figure 8. Height measurement: The instrument first calculates AD, then measures angles CAD and DAB. It then calculates BD and DC. The height is the sum of BD and DC (source from Laser Technology Inc.).

According to Phillips et al. (2009) the standard diameter at reference height (DRH) is measured at 1.3 m if possible. In cases where we could not use the 1.3 m as the Point of Measurement (POM) in order to avoid deformities or buttress roots, the height of the POM at the alternate DRH was recorded.

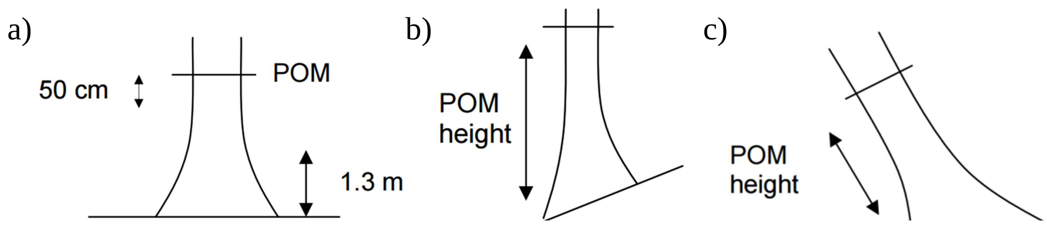

Figure 9. Standard measurement of diameter at breast height.

[1] The global position is expressed in relation to the scene's origin
[2] The local position is expressed in terms of the center of the object's parent

3.4.3. Information preprocessing

The raw data collected in the field, were computed in R software with Exploratory Data Analysis procedures in order to get a broad overview of the data. A species composition table was created so that wood density for each species could be added and subsequently used for allometric equation calculations.

3.4.4. Information processing

The basal area of a tree is defined as the cross-sectional area of the stem, either at breast height or at a specified height above the base of the tree (Laar & Akça, 2007).

$$BA = \frac{\pi \times D^2}{4}$$

Where:

BA: Basal area (m2)

D : Diameter Breast Height (m)

The focus for many studies has been the use of attributes related to the size of tree stems such as tree diameter, height, and volume (McElhinny et al., 2005). Volume of wood is a widely used parameter in the forestry field.

$$V = BA \times H \times f$$

Where:

V : Volume (m3)

BA : Basal Area (m2)

H : Height Total (m)

f : Form Factor (Tropics 0.65, Temperate 0.5)

Abundance usually refers to the relative number of individuals belonging to different species (Pagel et al., 1991). Relative abundance or density appears to be an important value to understand the amount of individual by special area (biome) and explains how is this species distributed.

$$rA = \frac{Ns}{Nt} \times 100$$

Where:

rA : Relative Abundance or density (%)

Ns : Number of individuals per specie

Nt : Number of total individuals

Dominance, also called degree of coverage of species, is the expression of the space occupied by specific species. It is defined as the sum of the horizontal projections of the trees on the ground. The relative dominance is calculated as the ratio of one species of the total area evaluated, expressed as a percentage (Melo & Vargas , 2003). Dominance expresses the quality of a species on a specific site of the forest stand.

$$rD = \frac{BAs}{BAt} \times 100$$

Where:

rD: Relative dominance (%)

BAs : Basal Area per specie

BAt : Basal Area total

The IVI is commonly used in ecological studies as it shows ecological importance of a species in a given ecosystem. The IVI is also used for prioritizing species conservation, whereby species with low IVI value need high conservation priority compared to the ones with high IVI (Kacholi, 2014). Simplified importance value index is modified using relative abundance and dominance (Lamprecht, 1989). The tropical forest has a big biodiversity and this index helps to identify important species in the accountable of carbon storage.

$$sIVI = \frac{rA + rD}{2}$$

Where:

$sIVI$: Simplified importance value index (%)

rA : Relative abundance or density

rD : Relative dominance

Chave et al., (2014), found the best-fit pantropical model for above ground biomass calculations, this model (bellow) performed well across forest types and bioclimatic conditions.

$$AGB_{est} = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where:

AGB_{est}: Above Ground Biomass (Kg)

ρ : Density (g cm^{-3})

D : Diameter Breast Height (cm)

H : Height (m)

Allometric equations for used for estimation of aboveground biomass of forest ecosystems across Europe (for species found in the study area) are listed in Table 2. The listed allometric equations were collected by the Finnish Forest Research Institute by Zianis et al., 2005 and by GlobAllomeTree (http://www.globallometree.org) that is the first international web platform to share and provide access to tree allometric equations, created in 2013 by the Food and Agriculture Organization of the United Nations (FAO).

Table 2. Allometric equation for estimation of aboveground biomass in the temperate forest.

Scientific Name	Common Name	Equation Model	a	b	c	Author
Acer campestre	Field Maple	LN(ABW)=a+b*ln(D)	-2.7606	2.5189		Zianis, D. et al. 2005
Acer platanoides	Norway maple	LN(ABW)=a+b*ln(D)	-2.7606	2.5189		Zianis, D. et al. 2005
Acer pseudoplatanus	Sycamore maple	LN(ABW)=a+b*ln(D)	-2.7606	2.5189		Zianis, D. et al. 2005
Betula pendula	Silver birch	AB=a*(D*10)^b	0.00087	2.28639		Zianis, D. et al. 2005
Carpinus betulus	Hornbeam	AB=(a*(D)^2*(H))+b	0.0485	5.4		Hoellinger, G. 1987
Cornus mas	Cornelian cherry	LOG(AB)=-a+b*(LOG((D)^(1)))	-1.339	2.73		Martin, J. et al. 1998
Fagus sylvatica	European Beech	AB=a*D^b	0.453	2.139		Zianis, D. et al. 2005
Fraxinus excelsior	Ash	LN(ABW)=a+b*ln(D)	-2.4598	2.4882		Zianis, D. et al. 2005
Larix decidua	Larch	AB=a*D^b*H^c	0.1081	1.53	0.9482	Zianis, D. et al. 2005
Malus sylvestris	European crab apple	AB=a*((D)^(b))*((H)^(c))	0.0547	2.1148	0.6131	Hung, N.D. et al. 2012
Picea abies	Norway spruce	AB=a*D^b	0.57669	1.964		Zianis, D. et al. 2005
Pinus nigra	Black pine	AB=(a*(D)^2*(H))+b	0.0662	4.9		Laurier, J.P. 1987
Pinus sylvestris	Scots pine	LN(AB)=a+b*ln(D)	-1.954	1.988		Zianis, D. et al. 2005
Prunus avium	Wild cherry	AB=a*D^b	0.1142	2.4451		Hung, N.D. et al. 2012
Pseudotsuga menziesii	Douglas fir	LN(AB)=a+b*ln(D)	-1.957	2.2996		Zianis, D. et al. 2005
Pyrus sp.	Pear	AB=a*((D)^(b))*((H)^(c))	0.0547	2.1148	0.6131	Hung, N.D. et al. 2012
Quercus petraea	Sessile oak	AB=(a*(D)^2*(H))+b	0.0379	6.2		Hoellinger, G. 1987
Sorbus torminalis	Wild service tree	AB=a*((D)^(b))*((H)^(c))	0.0547	2.1148	0.6131	Hung, N.D. et al. 2012
Tilia cordata	Small leaved lime	LN(ABW)=a+b*ln(D)	-2.6788	2.4542		Zianis, D. et al. 2005

D (Diameter at breast height), H (Total height), ABW (Aboveground woody biomass), AB (Aboveground biomass)

The carbon content is usually close to 50% of the biomass and generally varies little between species or in different parts of the tree (MacDicken, 1997;Emmer, 2004;West, 2009).

$$Carbon_{est} = AGB_{est} \times 0.5$$

Where:

Carbon_{est} : Carbon content (Mg C ha^{-1})
AGB_{est}: Above Ground Biomass (Mg ha^{-1})
0.5 : Factor

IV. Results

4.1. Characteristics of the forest stand

The forest stands characteristics (Table 3) were obtained from temperate and tropical forest. They consist of two samples for each biome.

Hády and Soběšice (representing temperate forest) showed slight differences between samples. Temperate forest stands compared to tropical (Low Tingo Maria and High Tingo Maria) mainly differ in the number of individuals per hectare (average of number of tree per ha). Temperate stands have 13.4% less individuals per ha compared to tropical forest (even with 8 ha of evaluation area). We could expect an increase in the number of individuals per hectare due to the high complexity of tropical forest stands. The average number of individuals of the Tropical forest sample was 229 Ind. ha^{-1} that is almost 3 times more than Temperate forest.

There was not variability in the height averages (Table 3) between these biomes. Temperate and Tropical forest stand stood equal with 16.94 ± 3.77 m and 16.53 ± 5.27 m of mean tree height respectively, however, difference in the range of tree height was found. Tropical forest canopy reached 37.7 m of height maxima and showed that they were taller than Temperate forest on average by 8.2 m. Nevertheless, studied temperate zone sites presented low variability in tree heights ranging from 2.73 (Hády) to 4.60 (Soběšice).

Table 3. Stand characteristics by Biomes.

Plot	Area (ha)	No. of trees (ha)	Range of tree height (m)	Mean tree height (m)	Standard deviation of tree heights
Temperate forest					
Hády	4.00	574.00	4.6 - 29.5	17.63	4.60
Soběšice	4.00	655.00	2.7 - 25.0	16.33	2.73
Tropical forest					
Low Tingo Maria	1.00	595.00	5.7 - 37.7	16.28	5.72
High Tingo Maria	1.00	824.00	4.9 - 37.4	16.78	4.93

Distributions of heights by study areas are shown in Figure 10. Height class of less than 10 meters for Hády and Soběšice consists of 6.97 % and 4.01 % respectively compared to 10.25 % and 6.1 for Low Tingo María (highest percentage in this class) and High Tingo María respectively. Soběšice has 90.3% of the individuals belonging to 10 to 20 m height class and that with the lowest standard deviation of all study areas (Table 3). Hády has 54.42 % if individuals in this class and is followed by Low and High Tingo María with 67.22 % and 70.99 % respectively, all without considerable variation. The next class from 20 to 30 m, as was expected, was represented in the Soběšice site with the lowest percentage of individuals with 5.68 %. That is low even compared to the Hády plot with 38.60 %. Low and High Tingo Maria display signs of sites best distributed forest canopy and do not show any big differences in this class ranging from 20.00% to 21.70%. The third height class of 30 m and taller was measured only on tropical forest sites. Low Tingo María is composed of trees higher than 30 m by 2,52 % and the High Tingo María site by 1.09 %.

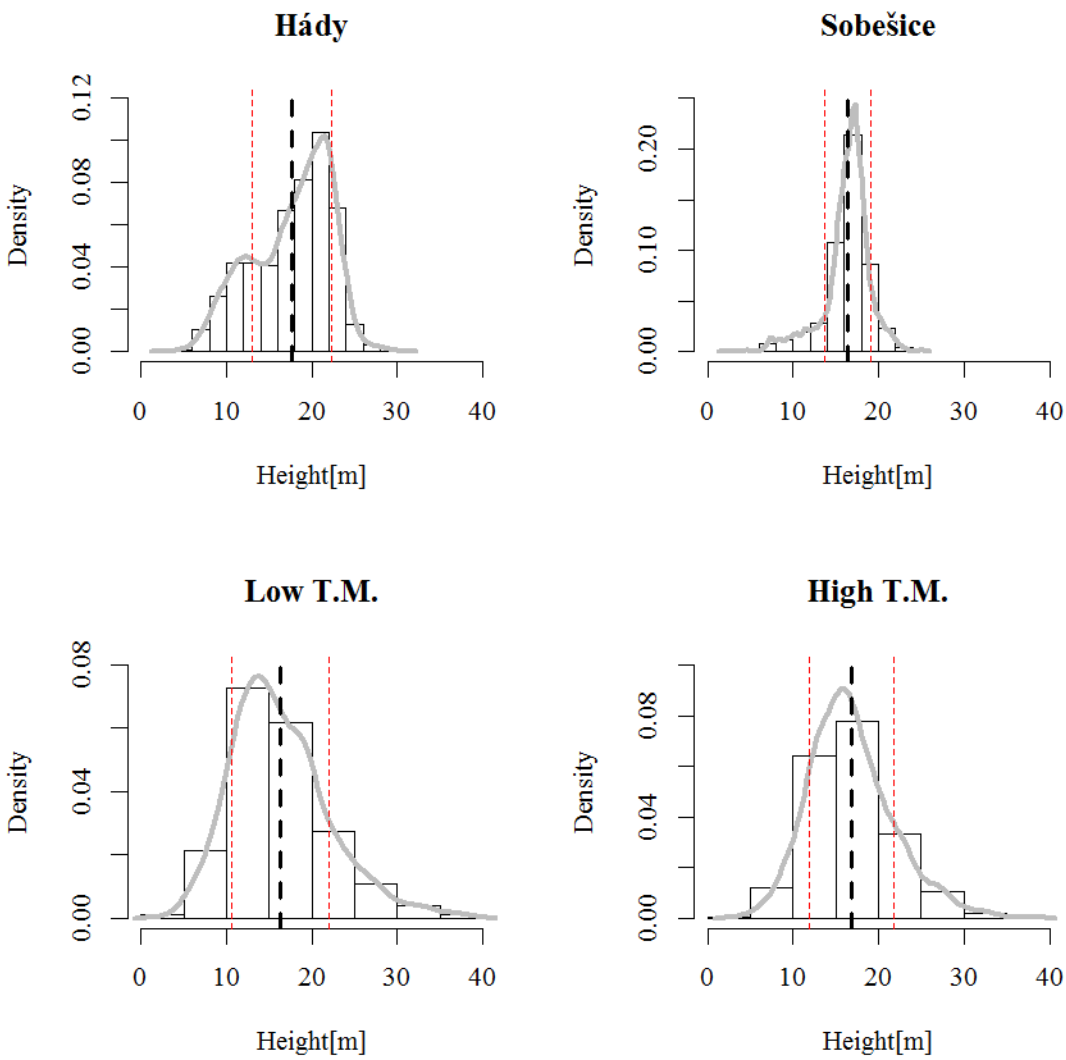

Figure 10. Density of class height by study areas (< 10, 10to 20, 20 to 30 and ≥ 30), mean (black dashed lines) and standard deviation (red dashed lines).

The diameter distribution illustrated in the Figure 11 as number of tree per unit area by DBH class for both biomess show a growth behavior as an even-aged stand in Temperate forest and Tropical Forest presenting reverse J-shaped distribution being uneven-aged stand, concerning to the amount of tree by class Soběšice has highest frequency in DBH from 20 to 30 cm and in Hády does not has the same frequency in that DBH class but particularly has more frequency from 30 to 40 DBH class than Soběšice, Hády is well spreading for all the DBH class but with a trend to decrease starting in 50 to 60 DHB class, no value found in the class 70 to 80, and in the class major than 80 appears 0.25 Trees per ha according to this plot sample unlike in Soběšice with any value major than 60 cm DBH. Tropical Forest display a balanced pattern indirectly proportional being the 10 to 20 DBH class with more frequency in both of plot sample, High Tingo María presents a shift to up in its curve comparing with Low Tingo María, matching in the DBH class 40 to 50 cm and over than 50 cm there are values corresponding to 4 DBH class left that it was not found in Temperate forest, reaching an average of 10.00, 6.00, 3.50, 2.0 Trees per ha respectively starting from 50 to 60 DBH class.

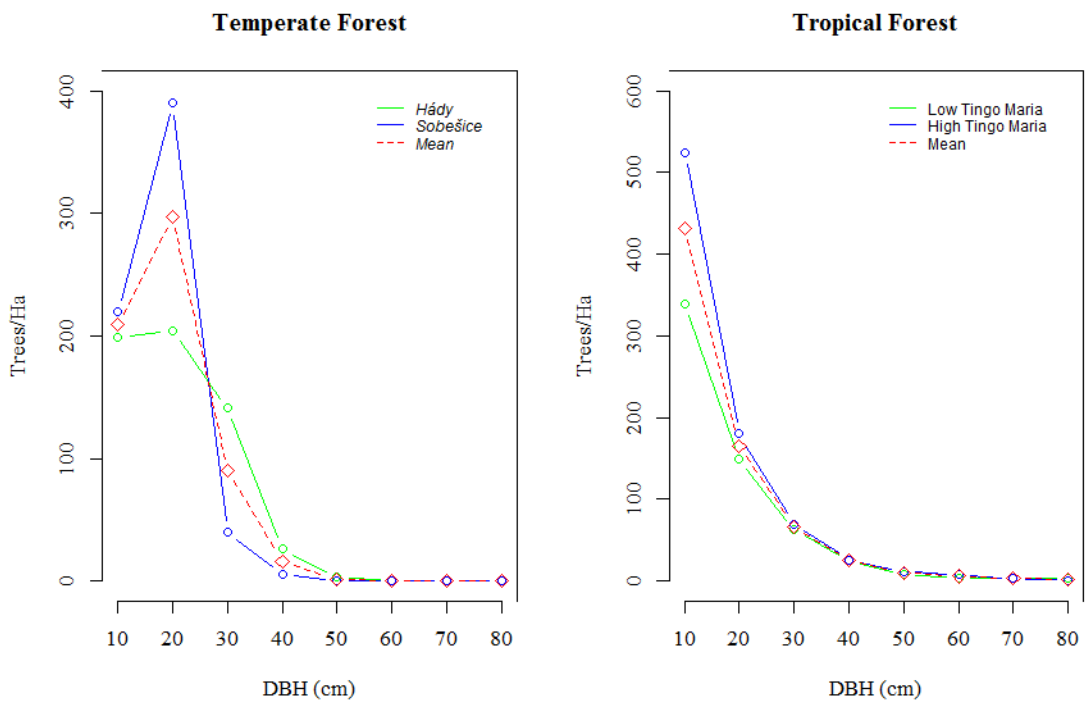

Figure 11. Number of individuals per hectares.

Total of 19 species in 8 families was encountered in the temperate forest biome, compared 72 species in 22 families counting NN (nomen nudum) species as well in the Tropical forest, thus becoming out the high amount of species composition.

The most common tree species in the forest were ranked based on the Simplified Importance Value Index (sIVI) in both biomess as shown in Table 4. Each biome was represented by at least 10 species, temperate forest by e.g. *Quercus petraea* 77 %, *Carpinus betulus* 11 %, *Sorbus torminalis* 4 %. Relative abundance of this three species is high and contribute to species composition with 92 %.

Table 4. Simplified importance value index.

Species	Family	Abun.	rA (%)	D (m^2)	rD (%)	sIVI (%)
Temperate forest		614		29.02		100%
Quercus petraea	Fagaceae	470	77%	24.06	83%	80%
Carpinus betulus	Betulaceae	66	11%	1.41	5%	8%
Sorbus torminalis	Rosaceae	22	4%	0.77	3%	3%
Tilia cordata	Malvaceae	14	2%	0.64	2%	2%
Larix decidua	Pinaceae	9	2%	0.84	3%	2%
Acer campestre	Sapindaceae	19	3%	0.35	1%	2%
Pinus sylvestris	Pinaceae	8	1%	0.65	2%	2%
Pinus nigra	Pinaceae	2	0%	0.10	0%	0%
Acer platanoides	Sapindaceae	1	0%	0.05	0%	0%
Fagus sylvatica	Fagaceae	1	0%	0.05	0%	0%
Other species	9	2	0%	0.10	0%	0%
Tropical forest		710		31.50		100%
Senefeldera macrophylla	Euphorbiaceae	83	12%	1.90	6%	9%
Virola elongata	Myristicaceae	48	7%	1.77	6%	6%
Protium amazonicum	Burseraceae	36	5%	2.18	7%	6%
Pourouma bicolor	Urticaceae	47	7%	1.49	5%	6%
Schefflera morototoni	Araliaceae	29	4%	1.92	6%	5%
Parkia igneiflora	Fabaceae	24	3%	1.82	6%	5%
Parkia nitida	Fabaceae	36	5%	1.25	4%	4%
Inga pezizifera	Fabaceae	32	5%	1.26	4%	4%
Cedrelinga cateniformis	Fabaceae	7	1%	2.00	6%	4%
Cecropia sp	Urticaceae	14	2%	1.19	4%	3%
Other species	62	355	50%	14.72	47%	48%

Tropical forest is represented mainly by *Senefeldera macrophylla* 12 %, *Virola elongate* 7 %, *Pourouma bicolor* 7 %, *Protium amazonicum* 5 %, *Parkia nitida* 5 %, *Inga pezizifera* 5 %, *Schefflera morototoni* 4 %, *Parkia igneiflora* 3 % of relative abundance, these species belong to 48% of the species composition pointing out that in this ecosystem the abundance is very spread out among species. When comparing the amount of individuals of temperate forest to tropical we get to numbers 614 against 710 (trees per ha). *Quercus petraea* predominates in studied temperate forest with 83 % of relative dominance and there is a clear trend to move forward from the rest of species such as *Carpinus betulus* 5 %, *Sorbus torminalis* 3 %, *Larix decidua* 3 % and *Pinus sylvestris* 2 %. Whether this is caused intentionaly or not the relative abundance of some species is very low in the studied areas of the temperate zone. Tropical forest seems more proportionally distributed with no huge difference of the relative dominance: *Protium amazonicum* 7%, followed by *Schefflera morototoni* 6%, *Senefeldera macrophylla* 6%, *Parkia igneiflora* 6%, *Virola elongate* 6% and others. Another special case is *Cedrelinga cateniformis* with 6% of relative dominance taking place close enough to *Protium amazonicum* surprisingly with only 1% of relative abundance.

The wood density (oven dry mass/fresh volume) distribution (Figure 12) in temperate forest has an average of 0.56 ± 0.05 g cm^{-3}, and in Tropical forest 0.55 ± 0.15 g cm^{-3}. There are very similar values between the temperate and tropical but the temperate forest keeps a narrow margin ahead with smaller standard deviation. This is caused by high frequency of the *Quercus petraea* species with density of 0.559 g cm^{-3} (77% of relative abundance) but also *Carpinus betulus* with the highest found density value of 0.706 g cm^{-3}.

There is a big variability between the species of the tropical forest sites distributed from 0.232 g cm^{-3} (*Cecropia obtusifolia*) to 0.929 g cm^{-3} (*Pouteria guianensis*). Other species, such as *Senefeldera macrophylla* (0.86 g cm^{-3}) with 12% of relative abundance have been measured for densities e.g.: *Virola elongata* 0.523 g cm^{-3}, *Pourouma bicolor* 0.31 g cm^{-3}, *Protium amazonicum* 0.599 g cm^{-3}, *Parkia nitida* 0.383 g cm^{-3}, *Inga pezizifera* 0.606 g cm^{-3}, *Schefflera morototoni* 0.448 g cm^{-3} and *Parkia igneiflora* 0.47 g cm^{-3}, this named species make up to 48 % of the species composition.

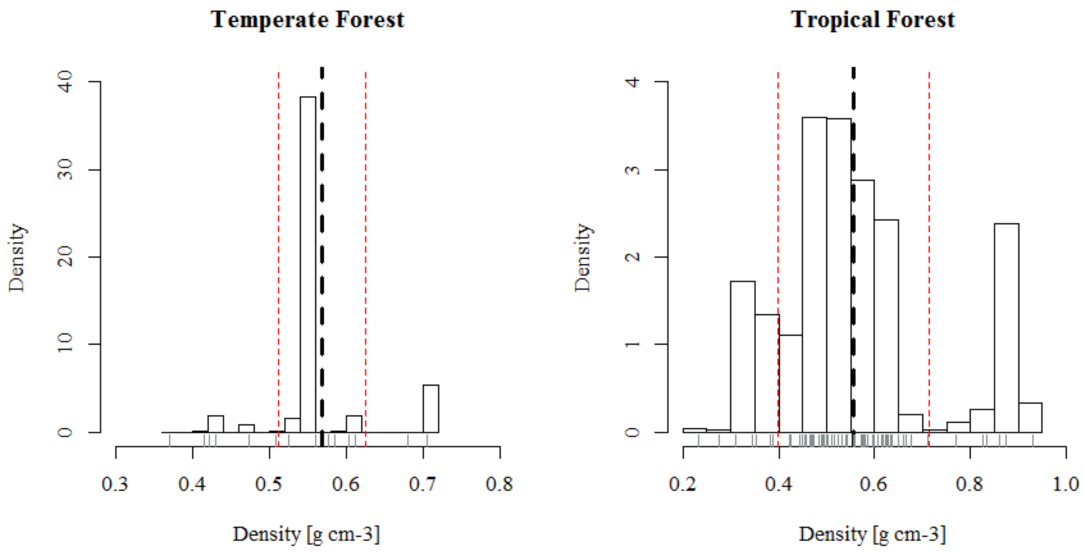

Figure 12. Wood density distribution (extracted from Global wood density database (Zanne et al., 2009))

4.2. Above ground biomass analysis

The higher aboveground biomass content was found in temperate forest with 250.6 Mg ha^{-1}, this is compared to tropical forest with 235.54 Mg ha^{-1} being 15,6 Mg ha^{-1} of difference among these biomes, in carbon stock 124.57 Mg C ha^{-1} and 117.77 Mg C ha^{-1}, respectively. The aboveground biomass was sorted into tree size classes (Table 5). The influence of AGB content in the DBH class from 10 to 30 cm taking up 60% of AGB was found in the temperate forest sites. The rest of the classes with 39.7% in 30 to 60 DBH class and 0.3% in the last class were less important. In tropical forest the two first classes are around 41% and 40% of AGB content, respectively, and 19 % in the 60 and bigger DBH class.

Surprisingly in other scenarios tropical forest take advantage of temperate forest related to the timber volume 420.53 m^3 ha^{-1} and 270.78 m^3 ha^{-1}, respectively. That is a mere 149.75 m^3 ha^{-1} of difference among them. Temperate forest with timber volume sorted according to t tree size class has more timber stock in 10 to 30 DBH class 57.5 %, followed by 41.9% in the next lower class; that with a difference of 42.27 m^3 ha^{-1}. 60 and bigger DBH is unimportant with 1.18 m^3 ha^{-1} (0.4 % from all timber stock). On the other hand, most biomass in timber of the tropical forest site is stored the 10 to 30 DBH class (38.5 %) and in the 30 to 60 DBH class (41.6 %) of all timber stock and that despite the fact that the over 60 DBH class reached 19.7 %.

Table 5. Tree aboveground biomass (AGB), carbon content and volume in temperate and tropical forest.

Tree size class (DBH)	Temperate Forest			Tropical Forest		
	AGB (Mg ha^{-1})	Carbon (Mg C ha^{-1})	Vol. (m^3 ha^{-1})	AGB (Mg ha^{-1})	Carbon (Mg C ha^{-1})	Vol. (m^3 ha^{-1})
10 - 30 cm	150.16	74.68	155.94	97.82	48.91	162.12
30 - 60 cm	99.60	49.47	113.67	93.58	46.79	175.22
≥ 60 cm	0.85	0.42	1.18	44.13	22.07	83.20
Total	250.60	124.57	270.78	235.54	117.77	420.53

Table of contribution by species to each biome can be found in the appendices. There is a graph of the sample studies that were taken. *Quercus petraea* provided 88.3 % of the AGB in the temperate forest, if we added *Carpinus betulus* to that the total number reached 93.5 %. This means most of the AGB contribution in the temperate forest sites is on behalf of two species. The tropical forest sites show different behavior because just to reach 70% of the AGB 15 species are need. It was also found that the 7th species with values of AGB content between 21.08 to 11.71 Mg ha^{-1}: *Protium amazonicum*, *Senefeldera macrophylla*, *Cedrelinga cateniformis*, *Clarisia racemosa*, *Parkia igneiflora*, *Schefflera morototoni* and *Virola elongata* were taking up 47 % of the AGB in this biome, and the other species are responsible for 9.16 to 0.04 Mg ha^{-1} AGB content, however are taking more than 50 % of it.

The aboveground biomass contribution by species (Figure 13) according to trend fitted by a power model, constrained to the most common tree species in the forest ranked based on the Simplified Importance Value Index (sIVI) showed that *Quercus petraea* appears as species that could gather most AGB content in the Temperate forest (8.86 Mg per tree, estimation base on natural forest stand). *Fagus sylvatica* is the second one providing 2.75 Mg per tree, *Pinus nigra* 1.62 Mg per tree, and *Carpinus betulus, Tilia cordata*, *Larix decidua* between 1.34 to 1.31 Mg per tree. The other species with less than 0.94 Mg per tree. In the tropical forest *Protium amazonicum* and *Cedrelinga cateniformis* contribute between 5.75 and 5.61 Mg per tree, respectively, becoming two of the species with the perquisites to store AGB in the conditions of this forest stand. They are followed by *Parkia igneiflora* 3.83 Mg per tree, *Schefflera morototoni* 2.59 Mg per tree, *Cecropia sp* 2.16 Mg per tree, *Inga pezizifera* 2.13 Mg per tree, *Senefeldera macrophylla* 1.76 Mg per tree and *Virola elongata* 1.55 Mg per tree and other species with less than 1.02 Mg per tree.

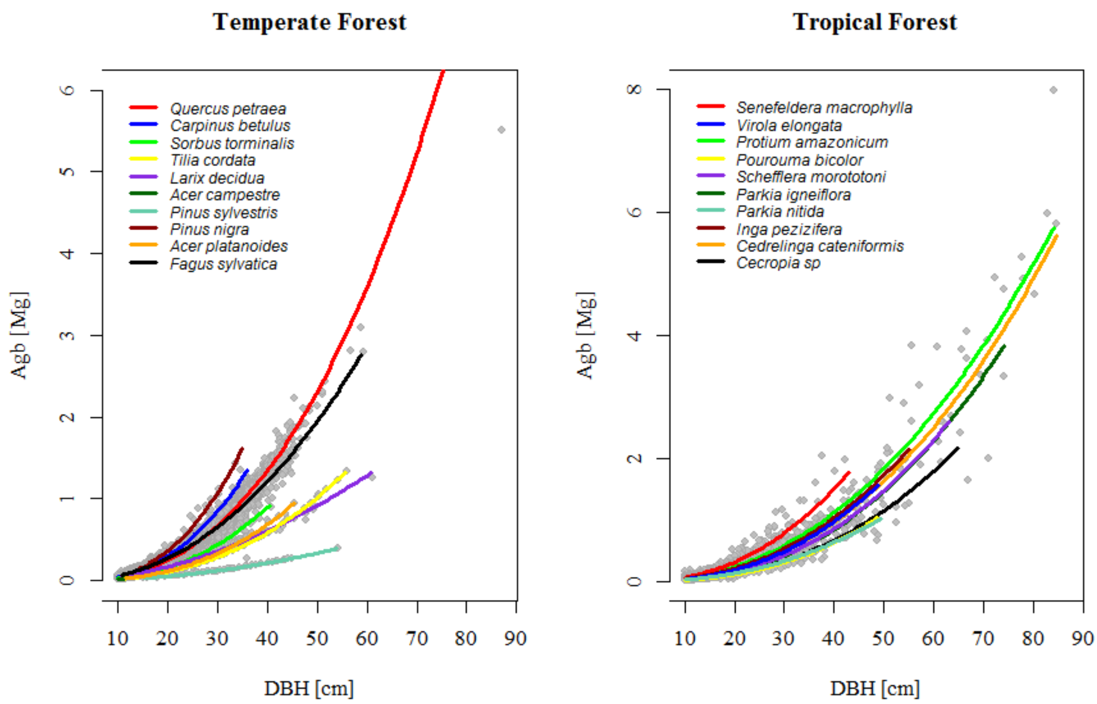

Figure 13. Predicted aboveground biomass in relation to DBH for 10 sIVI, constrained for each biomes.

V. Discussion

In natural stand in central Europe, the above ground biomass varied from 169 to 536 Mg ha^{-1} (Szwagrzyk & Gazda, 2007). In the temperate forest, the average aboveground biomass content was around 270 Mg ha^{-1} (Houghton| et al., 2009), in this study case average AFB of 250.60 Mg ha^{-1} was found, corresponding with temperate forest average from the study of Houghton et al. (2009). Carbon content usually accounts for 50% of the aboveground biomass, however, according to Lamlon and Savidge (2003), the results of the study indicates that very little research has actually been done.

Carbon contents in heartwood of 41 softwood and hardwood species were determined. Hardwood species ranged from 46.27% to 49.97%, softwood, mainly conifers ranged from 47.21% to 55.2%. The higher C content in conifers agrees with their higher lignin content (~30%, versus ~20% for hardwoods) (Lamlom & Savidge, 2003). Despite that 50% is widely accepted as a constant factor for conversion of biomass to C stock. That is why it was applied in this case. Results, therefore, reached 124.57 Mg C ha^{-1} of carbon content. Taking other studies into consideration; the carbon content per hectare in Germany is in the range of 120 - 190 Mg C ha^{-1}, depending on age class and tree species (Dieter & Elsasser, 2002). When comparing results of those studies, they do not show big differences. The tropical forest surprisingly accounted for 235.54 Mg ha^{-1} of AGB, lesser aboveground biomass and carbon content (117.77 Mg C ha^{-1}). Similarly, the usual numbers for tropical forest stands reaches around 170 - 250 Mg C ha^{-1} (Trumper et al., 2009). Moist tropical forests can vary considerably in their carbon stocks depending on the abundance of large, densely wooded species that store the most carbon (Baker et al., 2004). The sample plot wood densities varied from 0.232 g cm^{-3} (*Cecropia obtusifolia*) to 0.929 g cm^{-3} (*Pouteria guianensis*). We have to take into consideration that 57% of the species abundance were of less than 0.55 g cm^{-3} (average wood density). Standard forest inventory data (DBH, tree heights, and basal area) have been shown to be strongly correlated with tree biomass (Bettinger et al., 2009). Bigger range of tree height that was found in the tropical forest stands, that has the dominance of the forest canopy height reaching maxima of 37.7 m with an average of 16.53 ± 5.27 m (high variability). In Manaus, Brazil 30 m of height average canopy was found reaching to 330 - 370 Mg ha^{-1} of aboveground biomass (Malhi et al., 1999). This is much higher than the study area. This would influence the carbon stock of the site. In the tropical forest in Singapore carbon stocks were measured in primary and 60-year-old secondary forest plots located on infertile Ultisols in Bukit Timah Nature Reserve, one of the few remaining areas of forests in Singapore, finding 334.98 and 209.04 Mg ha^{-1} of above ground content respectively. The contribution of these pools to the total carbon stocks varied markedly between the primary and secondary forests (Ngo et al., 2013); The literature on tropical secondary forests, defined those as resulting from human disturbance (e.g. logged forests and forest fallows). Secondary forests are extensive in the tropics (Brown & Lugo, 1990), that being the outcome of the vulnerability of large reserves of carbon and through perturbation linked to human activities including deforestation and climate change. An article published by the CIFOR (Che Piu & Menton, 2014) states that the destruction of the Peruvian Amazon is rising and expanded over more than 145,000 hectares in 2014 (Doleac, 2015). Sharma (1992) categorized causes of deforestation into direct and underlying causes. Direct causes include urbanization, agricultural land expansion, commercial logging and conflict underlying causes of deforestation are typically population pressure coupled with poverty (Rahma et al., 2015); all these pressure on Tropical forest is not just purely of anthropogenic origin. Biodiversity also plays an important role, however, it is also consequently declining. 72 species was identified in the study area according sIVI and 10 most important of them were ranked, finding *Protium amazonicum* and *Cedrelinga cateniformis* to have more contribution to aboveground biomass content in natural conditions of the area that others, reaching between 5.75 and 5.61 Mg per tree, respectively. Thus, *Protium amazonicum* and *Cedrelinga cateniformis* becoming two important species, within the terms that: “the carbon storage depends on species composition” and on the mode and manner in which species are lost (Bunker et al., 2005). *Cedrelinga cateniformis* is especially selected for wood production and it is a popular commercial species of which was 239,971.53 m^3 logged. More than all commercial species in Peru combined (MINAG, 2013). Peru is facing selective logging, species with high wood density being the target and that implies to the aboveground biomass and carbon storage in the tropical forest: one of the reasons why the tropical forests are constantly decreasing in mass.

The temperate forest has a different scenario due to increment of biomass density and a substantial increase in forest area. Those are consequences of an intensive national afforestation/reforestation programs in the past few decades. An example lies in China’s forests (Pan et al., 2011). Another reason being that forest management has a rich and long history and that there was a fundamental change in the society's view of forests in the 18th century. Forest uses that were diminishing yields and degrading the production potential were restricted, and forest management regulations were introduced, including procedures adopted from the German forestry school (Jongepierová et al., 2012). This clearly showed in the graph of number of tree per unit area by DBH class the type of management that was performed on the example of Soběšice and Hády. The two plots with a growth behavior of an even-aged stand and most frequency in both 20 to 30 cm and 10 to 20cm of DBH class (60% of AGB content), present *Quercus petraea* with around 77 % of the relative abundance as well as *Carpinus betulus* with 11 %. It also appears that *Quercus petraea* is a species that can gather most AGB content in the study area of around 8.86 Mg per tree (estimation base on natural forest stand). Also, *Quercus petraea* provided 88.3 % of the AGB adding *Carpinus betulus* the number reached 93.5 %, so that means all the AGB contribution in the study area was mostly on behalf of only two species. In mixed stands of *Quercus petraea* and *Fagus sylvatica* biomass productivity exceeded that in pure stands by 1.7 Mg ha^{-1} year^{-1}, as the growth of both species was beneficial. Such stand composition usually takes over 112 years to get to 191.7 7 Mg ha^{-1} of AGB (Pretzsch et al., 2013). Fortunately, with silviculture practice such as free growth thinning, results show mean DBH of 39.0 cm with an estimated mean tree volume of 0.98 m^3, compared to 29.3 cm and 0.52 m^3 for equivalent crown thinned trees by less than 100 years (Kerr, 1996). Wood production methods were changed in 1902 in the area of study, a coppice underwent a transformation to a high forest. In 2009, when was harvested, trees were 107 years old and provided 270.78 m^3 ha^{-1} of stock. I would like to throw a comparison at this time and point out that the studied tropical forest site in some cases reached 420.53 m^3 ha^{-1} in just 66 years without any silvicultural practice. As inadequate as it may seem, comparing these two biomes is important in terms of the carbon storage, and hopefully will bring some advantages in the wood production of the tropical forest.

VI. Conclusions

Forest biomes are major reserves for terrestrial carbon, divided into three groups: Tropical, Temperate and Boreal forest (the last is not taken into account for this study). Tropical forests store large amounts of carbon, but we could say, that their carbon stocks depend on the abundance of their large, densely wooded species that store most of the carbon. An important role in the temperate zone plays forest management applied on its forest. Following these facts and the data we evaluated we find out that the forest structure is highly related to the aboveground biomass content. The studied tropical forest sites, despite their bigger height, are a subject to lower carbon stock (117.77 Mg C $ha^{-1)}$. Temperate forest are differently structured and even with mean canopy height of 16.94 ± 3.77 m and maximal height of 29.5 reached 15,6 Mg ha^{-1} more aboveground biomass and 124.57 Mg C ha^{-1} of carbon stock than tropical forest. This was due to the high abundance of two hardwood species: *Quercus petraea* and *Carpinus betulus* consisting of 88 % AGB of the plots and contributing by 93.5% to total carbon stock in the study area. The biodiversity of tropical forests plays an important role. 72 species were found, unlike in the temperate zone, where the number reached 19. The wood density distribution of studied tropical forest sites respected species variation ranged from 0.232 g cm^{-3} (*Cecropia obtusifolia*) to 0.929 g cm^{-3} (*Pouteria guianensis*). This fact has a strong influence on the carbon stock of the stands. Knowing that density is directly proportional to aboveground biomass, one of the major problems is presented by selective logging and the fact that people usually look for high wood density in the tropical forest., There are about 40 native tree species in temperate forest zone, but in Central Europe the managed forests are dominated by a few tree species, mostly *Pinus sylvestris*, *Picea abies*, and *Fagus sylvatica* (Szwagrzyk & Gazda, 2007). This could be ways of the forest management helping to improve the potential carbon storage by suitable commercial species composition. Such as in the case of *Quercus petraea* that could potentially reach 8.86 Mg per tree (predicted value form natural conditions of the study area). Modification of the silviculture treatment could improve the quality of the stands and wood in both biomes with an advantage in the tropical forest that requires shorter rotation periods than temperate forest; and at the same time store carbon.

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Appendices

A- Table of aboveground biomass and wood volume by species in Temperate forest

Scientific Name	Units	10 to 19.9	20 to 29.9	30 to 39.9	40 to 49.9	50 to 59.9	60 to 69.9	70 to 79.9	80 to more	Sub Total
Acer campestre	Mg ha^{-1}	0.846	0.374	0.000	0.000	0.000	0.000	0.000	0.000	1.220
	m^3 ha^{-1}	1.583	0.746	0.000	0.000	0.000	0.000	0.000	0.000	2.329
Acer platanoides	Mg ha^{-1}	0.019	0.000	0.047	0.207	0.000	0.000	0.000	0.000	0.273
	m^3 ha^{-1}	0.034	0.000	0.093	0.399	0.000	0.000	0.000	0.000	0.527
Acer pseudoplatanus	Mg ha^{-1}	0.000	0.047	0.053	0.000	0.000	0.000	0.000	0.000	0.100
	m^3 ha^{-1}	0.000	0.109	0.124	0.000	0.000	0.000	0.000	0.000	0.233
Betula pendula	Mg ha^{-1}	0.000	0.028	0.057	0.000	0.000	0.000	0.000	0.000	0.085
	m^3 ha^{-1}	0.000	0.052	0.105	0.000	0.000	0.000	0.000	0.000	0.158
Carpinus betulus	Mg ha^{-1}	7.770	4.644	0.679	0.000	0.000	0.000	0.000	0.000	13.094
	m^3 ha^{-1}	6.052	3.715	0.547	0.000	0.000	0.000	0.000	0.000	10.314
Cornus mas	Mg ha^{-1}	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.047
	m^3 ha^{-}	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.064

	1									
Fagus sylvatica	Mg ha^{-1}	0.019	0.000	0.083	0.000	0.350	0.000	0.000	0.000	0.452
	m^3 ha^{-1}	0.013	0.000	0.089	0.000	0.481	0.000	0.000	0.000	0.583
Fraxinus excelsior	Mg ha^{-1}	0.006	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.148
	m^3 ha^{-1}	0.009	0.289	0.000	0.000	0.000	0.000	0.000	0.000	0.298
Larix decidua	Mg ha^{-1}	0.168	0.567	1.876	1.135	0.260	0.157	0.000	0.000	4.162
	m^3 ha^{-1}	0.269	1.107	4.238	2.921	0.706	0.465	0.000	0.000	9.708
Malus sylvestris	Mg ha^{-1}	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
	m^3 ha^{-1}	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Picea abies	Mg ha^{-1}	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
	m^3 ha^{-1}	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Pinus nigra	Mg ha^{-1}	0.065	0.721	0.727	0.000	0.000	0.000	0.000	0.000	1.513
	m^3 ha^{-1}	0.038	0.425	0.429	0.000	0.000	0.000	0.000	0.000	0.892
Pinus sylvestris	Mg ha^{-1}	0.030	0.333	0.433	0.276	0.049	0.000	0.000	0.000	1.122
	m^3 ha^{-1}	0.158	1.876	2.543	1.693	0.309	0.000	0.000	0.000	6.579
Prunus avium	Mg	0.021	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.051

	ha^{-1}									
	$m^3\ ha^{-1}$	0.027	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.071
Pseudotsuga menziesii	$Mg\ ha^{-1}$	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	0.045
	$m^3\ ha^{-1}$	0.000	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.077
Pyrus sp.	$Mg\ ha^{-1}$	0.000	0.057	0.000	0.000	0.000	0.000	0.000	0.000	0.057
	$m^3\ ha^{-1}$	0.000	0.086	0.000	0.000	0.000	0.000	0.000	0.000	0.086
Quercus petraea	$Mg\ ha^{-1}$	17.903	112.243	69.331	19.167	1.880	0.000	0.000	0.689	221.214
	$m^3\ ha^{-1}$	17.825	114.593	71.334	19.780	1.943	0.000	0.000	0.713	226.189
Sorbus torminalis	$Mg\ ha^{-1}$	1.091	2.018	1.015	0.205	0.000	0.000	0.000	0.000	4.329
	$m^3\ ha^{-1}$	1.578	3.012	1.539	0.300	0.000	0.000	0.000	0.000	6.429
Tilia cordata	$Mg\ ha^{-1}$	0.330	0.624	0.755	0.377	0.589	0.000	0.000	0.000	2.675
	$m^3\ ha^{-1}$	0.685	1.538	1.855	0.790	1.372	0.000	0.000	0.000	6.239
Total	$Mg\ ha^{-2}$	28.278	121.877	75.101	21.367	3.128	0.157	0.000	0.689	250.598
	$m^3\ ha^{-2}$	28.279	127.656	82.975	25.884	4.811	0.465	0.000	0.713	270.784

B- Table of aboveground biomass and wood volume by species in Tropical forest

Scientific Name	Units	10 to 19.9	20 to 29.9	30 to 39.9	40 to 49.9	50 to 59.9	60 to 69.9	70 to 79.9	80 to more	Sub Total
Alchornea latifolia	Mg ha^{-1}	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036
	m^3 ha^{-1}	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.066
Alchornea triplinervia	Mg ha^{-1}	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.160
	m^3 ha^{-1}	0.310	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.310
Anaxagorea dolichocarpa	Mg ha^{-1}	0.132	0.000	0.285	0.000	0.000	0.000	0.996	0.000	1.413
	m^3 ha^{-1}	0.208	0.000	0.466	0.000	0.000	0.000	1.678	0.000	2.351
Aniba amazonica	Mg ha^{-1}	0.374	1.972	0.984	1.686	0.000	1.302	0.000	0.000	6.318
	m^3 ha^{-1}	0.609	3.322	1.659	2.930	0.000	2.287	0.000	0.000	10.807
Aniba perutilis	Mg ha^{-1}	0.402	0.726	0.000	1.912	0.000	0.000	0.000	0.000	3.040
	m^3 ha^{-1}	0.726	1.354	0.000	3.670	0.000	0.000	0.000	0.000	5.751
Aniba sp	Mg ha^{-1}	0.000	0.000	0.208	0.000	0.000	0.000	0.000	0.000	0.208
	m^3 ha^{-1}	0.000	0.000	0.294	0.000	0.000	0.000	0.000	0.000	0.294
Apeiba membranacea	Mg ha^{-1}	0.026	0.000	0.192	0.000	0.000	0.000	0.000	0.000	0.217

	$m^3\ ha^{-1}$	0.084	0.000	0.652	0.000	0.000	0.000	0.000	0.000	0.736
Aspidosperma macrocarpon	$Mg\ ha^{-1}$	0.000	0.000	0.000	0.000	0.000	0.000	2.373	0.000	2.373
	$m^3\ ha^{-1}$	0.000	0.000	0.000	0.000	0.000	0.000	3.336	0.000	3.336
Batocarpus orinocensis	$Mg\ ha^{-1}$	0.118	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.190
	$m^3\ ha^{-1}$	0.200	0.123	0.000	0.000	0.000	0.000	0.000	0.000	0.323
Bellucia pentamera	$Mg\ ha^{-1}$	0.222	0.000	0.000	0.603	0.000	0.000	0.000	0.000	0.825
	$m^3\ ha^{-1}$	0.375	0.000	0.000	1.077	0.000	0.000	0.000	0.000	1.452
Brosimum alicastrum	$Mg\ ha^{-1}$	0.000	0.000	0.000	0.536	0.000	0.000	0.000	0.000	0.536
	$m^3\ ha^{-1}$	0.000	0.000	0.000	0.825	0.000	0.000	0.000	0.000	0.825
Brosimum rubescens	$Mg\ ha^{-1}$	0.453	1.317	1.463	0.000	1.489	0.000	0.000	0.000	4.722
	$m^3\ ha^{-1}$	0.499	1.529	1.723	0.000	1.781	0.000	0.000	0.000	5.533
Brosimum utile	$Mg\ ha^{-1}$	0.090	0.177	0.393	0.731	0.000	0.000	0.000	0.000	1.391
	$m^3\ ha^{-1}$	0.160	0.325	0.736	1.390	0.000	0.000	0.000	0.000	2.610
Cariniana multiflora	$Mg\ ha^{-1}$	0.837	1.322	0.000	0.000	0.000	0.000	0.000	0.000	2.159
	$m^3\ ha^{-1}$	1.353	2.207	0.000	0.000	0.000	0.000	0.000	0.000	3.560

Caryodendron orinocense	Mg ha^{-1}	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.071
	m^3 ha^{-1}	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100
Cecropia obtusifolia	Mg ha^{-1}	0.059	0.072	0.000	0.000	0.000	0.000	0.000	0.000	0.131
	m^3 ha^{-1}	0.228	0.284	0.000	0.000	0.000	0.000	0.000	0.000	0.512
Cecropia sciadophylla	Mg ha^{-1}	0.147	0.749	0.283	0.379	0.000	0.000	0.000	0.000	1.558
	m^3 ha^{-1}	0.340	1.820	0.692	0.935	0.000	0.000	0.000	0.000	3.788
Cecropia sp	Mg ha^{-1}	0.290	0.991	1.579	1.732	0.598	1.208	0.000	0.000	6.399
	m^3 ha^{-1}	0.759	2.664	4.305	4.794	1.667	3.429	0.000	0.000	17.617
Cedrelinga cateniformis	Mg ha^{-1}	0.077	0.159	0.289	1.767	0.000	3.379	5.100	8.218	18.990
	m^3 ha^{-1}	0.140	0.295	0.543	3.384	0.000	6.574	10.123	16.342	37.401
Ceiba pentandra	Mg ha^{-1}	0.000	0.000	0.000	0.480	0.000	0.000	0.000	0.000	0.480
	m^3 ha^{-1}	0.000	0.000	0.000	1.307	0.000	0.000	0.000	0.000	1.307
Chimarrhis sp	Mg ha^{-1}	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125
	m^3 ha^{-1}	0.164	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.164
Cinchona pubescens	Mg ha^{-1}	1.114	1.201	0.000	0.000	0.000	0.000	0.000	0.000	2.315

	$m^3\ ha^{-1}$	1.863	2.064	0.000	0.000	0.000	0.000	0.000	0.000	3.927
Cinchona sp	$Mg\ ha^{-1}$	0.340	0.980	0.770	0.000	0.000	0.000	0.000	0.000	2.089
	$m^3\ ha^{-1}$	0.573	1.699	1.350	0.000	0.000	0.000	0.000	0.000	3.622
Clarisia racemosa	$Mg\ ha^{-1}$	0.183	0.407	2.470	2.250	4.632	3.693	0.000	0.000	13.636
	$m^3\ ha^{-1}$	0.286	0.655	4.054	3.729	7.764	6.259	0.000	0.000	22.747
Couma macrocarpa	$Mg\ ha^{-1}$	0.420	0.246	0.793	0.000	0.000	0.000	0.000	0.000	1.459
	$m^3\ ha^{-1}$	0.763	0.461	1.517	0.000	0.000	0.000	0.000	0.000	2.741
Dendropanax arboreus	$Mg\ ha^{-1}$	0.306	0.686	0.000	0.000	0.000	0.000	0.000	0.000	0.992
	$m^3\ ha^{-1}$	0.659	1.502	0.000	0.000	0.000	0.000	0.000	0.000	2.161
Didymopanax morototoni	$Mg\ ha^{-1}$	0.313	1.193	1.266	0.000	0.000	0.000	0.000	0.000	2.772
	$m^3\ ha^{-1}$	0.499	1.959	2.106	0.000	0.000	0.000	0.000	0.000	4.564
Diplotropis martiusii	$Mg\ ha^{-1}$	0.098	0.318	0.000	0.000	0.000	0.000	0.000	0.000	0.416
	$m^3\ ha^{-1}$	0.140	0.477	0.000	0.000	0.000	0.000	0.000	0.000	0.617
Garcinia macrophylla	$Mg\ ha^{-1}$	0.364	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.460
	$m^3\ ha^{-1}$	0.431	0.115	0.000	0.000	0.000	0.000	0.000	0.000	0.546

Guarea guidonia	Mg ha^{-1}	0.087	0.191	0.000	0.000	0.000	0.000	0.000	0.000	0.278
	m^3 ha^{-1}	0.140	0.308	0.000	0.000	0.000	0.000	0.000	0.000	0.448
Guatteria elata	Mg ha^{-1}	0.447	1.116	1.855	0.000	0.000	0.000	0.000	0.000	3.418
	m^3 ha^{-1}	0.745	1.928	3.244	0.000	0.000	0.000	0.000	0.000	5.916
Hevea brasiliensis	Mg ha^{-1}	0.000	0.189	0.000	0.000	0.000	0.000	0.000	0.000	0.189
	m^3 ha^{-1}	0.000	0.360	0.000	0.000	0.000	0.000	0.000	0.000	0.360
Hevea guianensis	Mg ha^{-1}	0.441	0.293	1.727	0.000	0.000	0.000	2.462	0.000	4.922
	m^3 ha^{-1}	0.780	0.530	3.207	0.000	0.000	0.000	4.771	0.000	9.287
Inga pezizifera	Mg ha^{-1}	1.708	4.332	2.490	0.000	0.633	0.000	0.000	0.000	9.162
	m^3 ha^{-1}	2.566	6.702	3.926	0.000	1.007	0.000	0.000	0.000	14.202
Inga punctata	Mg ha^{-1}	0.071	0.632	0.663	0.510	0.000	0.000	0.000	0.000	1.877
	m^3 ha^{-1}	0.115	1.055	1.127	0.876	0.000	0.000	0.000	0.000	3.173
Iryanthera juruensis	Mg ha^{-1}	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.067
	m^3 ha^{-1}	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096
Iryanthera laevis	Mg ha^{-1}	0.662	0.360	0.000	0.000	1.444	0.000	0.000	0.000	2.466

	m^3 ha^{-1}	0.985	0.549	0.000	0.000	2.315	0.000	0.000	0.000	3.849
Jacaranda copaia	Mg ha^{-1}	0.236	0.425	0.469	0.000	0.476	0.000	0.000	0.000	1.606
	m^3 ha^{-1}	0.607	1.121	1.252	0.000	1.291	0.000	0.000	0.000	4.271
Licania octandra	Mg ha^{-1}	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.101
	m^3 ha^{-1}	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
Manilkara bidentata	Mg ha^{-1}	0.236	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.236
	m^3 ha^{-1}	0.248	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.248
Miconia barbeyana	Mg ha^{-1}	0.258	0.607	0.000	0.000	0.000	0.000	0.000	0.000	0.865
	m^3 ha^{-1}	0.382	0.917	0.000	0.000	0.000	0.000	0.000	0.000	1.299
Miconia poeppigii	Mg ha^{-1}	0.829	0.235	0.000	0.000	0.000	0.000	0.000	0.000	1.064
	m^3 ha^{-1}	1.267	0.365	0.000	0.000	0.000	0.000	0.000	0.000	1.632
NN	Mg ha^{-1}	1.295	1.551	0.849	0.000	0.000	0.000	0.000	0.000	3.695
	m^3 ha^{-1}	2.339	2.911	1.608	0.000	0.000	0.000	0.000	0.000	6.857
Ocotea aciphylla	Mg ha^{-1}	0.092	0.536	0.815	0.000	0.000	0.000	0.000	0.000	1.443
	m^3 ha^{-1}	0.163	0.984	1.526	0.000	0.000	0.000	0.000	0.000	2.673

Ormosia amazonica	Mg ha^{-1}	0.000	0.000	0.796	0.000	0.000	0.000	0.000	0.000	0.796
	m^3 ha^{-1}	0.000	0.000	1.241	0.000	0.000	0.000	0.000	0.000	1.241
Osteophloeum platyspermum	Mg ha^{-1}	0.055	0.317	0.000	0.000	0.000	0.000	0.000	0.000	0.371
	m^3 ha^{-1}	0.105	0.637	0.000	0.000	0.000	0.000	0.000	0.000	0.742
Otoba parvifolia	Mg ha^{-1}	0.000	0.000	0.320	0.000	0.907	0.000	0.000	0.000	1.227
	m^3 ha^{-1}	0.000	0.000	0.714	0.000	2.076	0.000	0.000	0.000	2.790
Parkia igneiflora	Mg ha^{-1}	1.044	0.553	1.310	2.168	4.451	0.000	3.624	0.000	13.149
	m^3 ha^{-1}	2.007	1.097	2.637	4.444	9.231	0.000	7.647	0.000	27.064
Parkia nitida	Mg ha^{-1}	1.936	0.908	1.080	2.029	0.000	0.000	0.000	0.000	5.954
	m^3 ha^{-1}	4.571	2.180	2.655	5.093	0.000	0.000	0.000	0.000	14.499
Pourouma bicolor	Mg ha^{-1}	1.535	2.177	1.580	0.685	0.000	0.000	0.000	0.000	5.977
	m^3 ha^{-1}	4.434	6.489	4.806	2.103	0.000	0.000	0.000	0.000	17.832
Pourouma minor	Mg ha^{-1}	0.160	0.132	0.000	0.364	0.000	0.000	0.000	0.000	0.656
	m^3 ha^{-1}	0.324	0.277	0.000	0.780	0.000	0.000	0.000	0.000	1.380
Pouteria guianensis	Mg ha^{-1}	0.776	2.792	2.928	0.000	1.912	0.000	0.000	0.000	8.408

	$m^3\ ha^{-1}$	0.774	2.865	3.027	0.000	2.043	0.000	0.000	0.000	8.709
Protium amazonicum	$Mg\ ha^{-1}$	2.812	1.719	1.673	2.048	3.222	5.616	0.000	3.994	21.083
	$m^3\ ha^{-1}$	4.294	2.681	2.658	3.312	5.267	9.305	0.000	6.742	34.260
Protium plagiocarpium	$Mg\ ha^{-1}$	0.121	0.307	0.000	0.000	0.000	0.000	0.000	0.000	0.428
	$m^3\ ha^{-1}$	0.187	0.495	0.000	0.000	0.000	0.000	0.000	0.000	0.682
Pseudolmedia laevigata	$Mg\ ha^{-1}$	1.037	1.550	1.918	0.000	0.000	0.000	0.000	0.000	4.504
	$m^3\ ha^{-1}$	1.499	2.302	2.915	0.000	0.000	0.000	0.000	0.000	6.716
Pseudolmedia macrophylla	$Mg\ ha^{-1}$	0.247	0.163	0.000	0.000	0.000	0.000	0.000	0.000	0.410
	$m^3\ ha^{-1}$	0.342	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.573
Rinorea lindeniana	$Mg\ ha^{-1}$	0.295	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.295
	$m^3\ ha^{-1}$	0.394	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.394
Schefflera morototoni	$Mg\ ha^{-1}$	0.678	3.554	3.662	2.400	0.930	1.340	0.000	0.000	12.564
	$m^3\ ha^{-1}$	1.375	7.405	7.747	5.174	2.023	2.944	0.000	0.000	26.668
Senefeldera macrophylla	$Mg\ ha^{-1}$	11.230	6.316	0.000	1.731	0.000	0.000	0.000	0.000	19.277
	$m^3\ ha^{-1}$	12.026	6.939	0.000	1.960	0.000	0.000	0.000	0.000	20.925

Sterculia sp	Mg ha^{-1}	0.313	0.232	0.000	0.000	0.000	0.000	0.000	0.000	0.545
	m^3 ha^{-1}	0.586	0.445	0.000	0.000	0.000	0.000	0.000	0.000	1.031
Symphonia globulifera	Mg ha^{-1}	1.509	1.305	0.000	0.000	0.000	0.000	0.000	0.000	2.814
	m^3 ha^{-1}	2.223	1.988	0.000	0.000	0.000	0.000	0.000	0.000	4.211
Tachigali cavipes	Mg ha^{-1}	0.044	0.249	0.375	0.000	0.000	0.000	0.000	0.000	0.668
	m^3 ha^{-1}	0.072	0.423	0.645	0.000	0.000	0.000	0.000	0.000	1.140
Tachigali polyphylla	Mg ha^{-1}	0.150	0.811	0.495	0.000	0.000	0.000	0.000	0.000	1.455
	m^3 ha^{-1}	0.216	1.196	0.746	0.000	0.000	0.000	0.000	0.000	2.158
Tapirira guianensis	Mg ha^{-1}	0.521	1.131	3.011	2.064	0.000	0.000	0.000	0.000	6.728
	m^3 ha^{-1}	1.037	2.314	6.258	4.346	0.000	0.000	0.000	0.000	13.955
Theobroma subincanum	Mg ha^{-1}	0.920	0.776	0.000	0.000	0.000	0.000	0.000	0.000	1.696
	m^3 ha^{-1}	1.758	1.531	0.000	0.000	0.000	0.000	0.000	0.000	3.289
Virola calophylla	Mg ha^{-1}	0.111	0.119	0.520	0.000	0.000	0.000	0.000	0.000	0.750
	m^3 ha^{-1}	0.218	0.234	1.042	0.000	0.000	0.000	0.000	0.000	1.493
Virola elongata	Mg ha^{-1}	2.669	3.675	2.928	2.442	0.000	0.000	0.000	0.000	11.714

	$m^3\ ha^{-1}$	4.631	6.568	5.323	4.512	0.000	0.000	0.000	0.000	21.034
Virola flexuosa	$Mg\ ha^{-1}$	0.570	1.777	1.522	0.000	0.000	0.000	0.000	0.000	3.869
	$m^3\ ha^{-1}$	1.014	3.266	2.849	0.000	0.000	0.000	0.000	0.000	7.129
Virola pavonis	$Mg\ ha^{-1}$	0.046	0.457	0.000	0.000	0.000	0.000	0.000	0.000	0.503
	$m^3\ ha^{-1}$	0.071	0.727	0.000	0.000	0.000	0.000	0.000	0.000	0.798
Virola sebifera	$Mg\ ha^{-1}$	0.913	0.413	0.000	0.409	0.000	0.825	0.000	0.000	2.561
	$m^3\ ha^{-1}$	1.828	0.840	0.000	0.858	0.000	1.762	0.000	0.000	5.288
Vismia macrophylla	$Mg\ ha^{-1}$	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050
	$m^3\ ha^{-1}$	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.092
Ziziphus cinnamomum	$Mg\ ha^{-1}$	0.000	0.217	0.000	0.000	0.000	0.000	0.000	0.000	0.217
	$m^3\ ha^{-1}$	0.000	0.244	0.000	0.000	0.000	0.000	0.000	0.000	0.244
Total	$Mg\ ha^{-1}$	43.026	54.798	43.962	28.926	20.692	17.364	14.555	12.213	235.536
	$m^3\ ha^{-1}$	68.157	93.959	81.253	57.499	36.465	32.559	27.555	23.084	420.530

C- Photos

Location spatial of *Cedrelinga cateniformis* Tingo Maria.

Field-Map equipment form Mendel University-Brno