Carbon research at Maquipucuna biological reserve

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Preface

This paper is written as a thesis report for the Bachelor Forest and Nature management, major Tropical Forestry at Van Hall Larenstein University of applied sciences. The field research was conducted at Maquipucuna biological reserve in North-West Ecuador during the months July and August 2010.

The process of doing field research at this magnificent montane forest reserve has been a great experience. For the support in this process I would like to thank Carlos, Rufus, Arsenio, Cristina and all the other people of the Maquipucuna foundation. For the support with writing this report I would like to thank my supervisor Jaap de Vletter and for providing technical assistance to the carbon calculations I would like to thank Eric Arets.

Prologo

Este documento es el tesis para mi bachelor gestion de los bosques y de la naturaleza, mayor forestales tropicales de la universidad para las ciencias aplicadas Van Hall Larenstein. La investigacion ha realizado en la reserva biologica Maquipucuna situado en el norte-oeste del Ecuador durante los meses Julio y Agosto de 2010.

El proceso de investigar en este reserva bosque nublado fue una experiencia magnifica. Por el apoyo en este proceso quisiera dar las gracias a Carlos, Rufus, Arsenio, Cristina y toda otra gente de la Fundacion Maquipucuna. Por el apoyo para el escribir de este documento quisiera dar las gracias a mi revisor Jaap de Vletter, y para proporcionar asistencia tecnica con los calculos de las cantidades de carbon quisiera dar las gracias a Eric Arets.

Summary
Andean montane forests are one of the biologically richest places on the planet. In North-West Ecuador these forests face many threats as pressure on land is rising. Maquipucuna biological reserve protects over 5500 ha of Andean montane forest of which over 80% is in primeval condition. It is protected by the Fundacion Maquipucuna, the first non-profit organization of Ecuador founded in April 1988. Safeguarded well by this organization from agricultural needs, these forests might face another threat: global climate change. The severity of this threat and the array of possible consequences for the biological state of Andean montane forests will be explained in a literature study that is included in this report. In the context of this background information the living tree carbon stocks of Maquipucuna are determined in the case study of this report. Biomass equations using dbh (diameter at breast height) as the only input are used to estimate the carbon quantities present. To obtain better estimations the forest is divided in three different zones: the secondary lower montane forest, the primary lower montane forest (the official name of this forest type: western Andes lower montane evergreen forest) and the primary upper montane forest (the official name of this forest type: western Andes montane cloud forest). Also several structural characteristics of the forest are correlated with differences in forest type and altitude to gain more information about the forests in the reserve. The amount of living tree carbon in the reserve is approximately 1 million tons of which about 85% can be found aboveground. Significant differences between the forest types can be observed in terms of carbon and biomass quantities. The primary lower montane forest has the largest amount of carbon per ha. In the secondary forest the amount is lower due to anthropogenic reasons, in the primary upper montane forest the amount is lower due to natural climatic change. The comparison between the primary lower and upper montane forest might give long term valuable information regarding shifting vegetation zones due to global climatic change. In this context the several structural characteristics of the forest were correlated with altitudinal differences. Significant negative correlations were observed between biomass per ha, average dbh of all large trees (dbh >=50cm), height of the crown layer, crown density and altitude. Furthermore a discussion is included in this report to discuss the results of the case study, to obtain better insight in the used carbon quantity calculations and to put the report as a whole in context.

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1. Introduction

1.1 Objectives of the research

This research has five main objectives.

- To estimate the possible impacts of climate change on the biodiversity of the Andean montane forests of Ecuador.
- To assess the possibilities for REDD and sustainable forestry in Ecuador.
- To determine the living tree carbon quantities of Maquipucuna biological reserve and for each of the different forest types.
- To compare the different forest types present in Maquipucuna reserve on the following structural characteristics: living tree biomass, no of trees per ha, height of crown layer, crown density and average dbh.
- To assess whether there is a correlation between these characteristics and altitude.

1.2 A literature study and a case study

1.2.1 A double approach, a single goal

The objectives of the research ask for a double approach. The first two objectives demand a literature study, while the other three can not be answered by a literature study but only by a case study conducted at Maquipucuna biological reserve. These two studies are interrelated in both directions and therefore can not be regarded as separate entities. Ultimately the research has one goal and that is to provide valuable information on the structural characteristics of an Andean montane forest with the emphasis being laid on the structural characteristic carbon quantity because of its current global environmental and monetary value. The two studies melt together in the discussion where the results from the case study is linked with the information given in the literature study.

1.2.2 Purpose of the literature study

This literature study serves not only to provide an answer on the first two research objectives. It also has the purpose of providing background information for the case study. The main purpose of the first objective and consequently of the first part of the literature study is to validate the need for protection of intact Andean montane forests like Maquipucuna biological reserve in this time of rapid climatic change. This first part of the literature study therefore discusses the observed and expected impacts of a global problematic phenomenon on a local situation. The second objective's main purpose is to give information on sustainable forestry and REDD in the country Ecuador and by doing so it provides background information for both the case study and the discussion.

1.2.3 Purpose of the case study at Maquipucuna biological reserve

The case study is conducted at Maquipucuna biological reserve in North-West Ecuador. This reserve protects a relatively small Andean montane forest environment but nonetheless it is a forest reserve with an outstandingly great biological value. The forest is for over 80% in primeval condition (Tian *et al*. 2007) and has an extraordinarily high plant species diversity of almost 2000 species which have been documented so far (Webster and Rhode 2007).

Unfortunately forests in the area have been under threat for quite a number of reasons. Pressure on land for mainly agricultural but also other purposes like the exploitation of bauxite has resulted in heavy deforestation in the region. This makes a well preserved and largely intact native forest complex like can be found in Maquipucuna reserve a very important place for nature conservation. But recently a different threat which is not directly connected to land area is evolving; global climate change. Recent evidence already shows that this global phenomenon is having its effects on the South American continent and montane forests in particular.

The primeval forests of Maquipucuna reserve provide an excellent opportunity to study the structural characteristics of the two different (native) forest types present due to the intactness of the forest. The altitude differences are impressive and are the cause for practical difficulties concerning large scale field measurements but also result in field data that are easy to correlate with altitude differences.

The secondary forest is included mainly for the carbon quantity measurements. Carbon quantity is the most important characteristic of the forest at the moment. With global climate change having its impacts on Andean montane forests, the need for positive economic incentives concerning the mitigation of climate change are also on the rise. Chiu (2009) from the government of Ecuador indicates that GHG monitoring is highly necessary in this country.

Picture 1: Secondary lower montane forest at Maquipucuna biological reserve

2. Literature study

2.1 Climate change and the biodiversity of neo-tropical montane forests

2.1.1 Climate change; evidence for temperature rise caused by anthropogenic production of CO_2

Climate change has quite recently become an important issue for the international governmental community. Reason for this is that there is evidence for a radically rising global temperature over the past couple of decades and that this rise is expected to increase over the next century. The main causes for this phenomenon are becoming increasingly recognized as being mainly of anthropogenic origin. But are these concerns based on valid problem analysis or is this an overrated hype from environmentalists?

First let's have a look at changes in global surface air temperature. There has been an observed temperature rise at least since 1880 (Henson 2008) and. Global surface air temperature has risen approximately 0.7 degrees in the 20^{th} century (Henson 2008). According to IPCC temperature rise has been most severe over land and on the northern hemisphere. Temperature rise in Ecuador has been above global average at least since 1976. A map of IPCC indicates an average rise of 0.6 degrees per decade over the period 1976-2000. The total warming up of this planet is estimated at about 3.0 degrees since pre-industrial times within a range of 2.0-4.5 degrees according to the 2007 IPCC report.

These temperature rises in the past are strongly correlated with an exponential rise of atmospheric CO_2 (Berendsen 2005; Groom *et al.* 2006). The first time that an increase in CO_2 in the atmosphere was recognized as causing global warming was in 1896 by Svante Arrhenius. In 1938 Guy Callender delivers the first prove of a rise in CO_2 in the atmosphere but his findings are being neglected. Twenty years later Charles Keeling starts his measurements by which a rise in atmospheric CO_2 is proved. It is now becoming clear that already since the 1850s the amount of CO_2 in the atmosphere has been on an exponential rise (Smil 1997), and that since the 1970s the process of global warming has been starting to escalate (Pearce 2007). That it concerns a very exponential growth is emphasized by the fact that over half of all the carbon released into the atmosphere between 1850 and 1995 is released in the last 20 years of this time period (Smil 1997).

CO_2 is considered one of the two most important greenhouse gasses (GHGs), the other being H_2O (Berendsen 2005). One of the major reasons why CO_2 is considered the most important and notorious greenhouse gas is that it stays in the atmosphere for over a century (Groom *et al.* 2006). Methane is a much stronger GHG but it stays usually for less than a decade in the atmosphere. Thanks to these and other GHGs the earth temperature is 33 degrees higher than without them and the temperature differences between day and night are being tempered (Berendsen 2005). So we should be grateful for CO_2 being in the atmosphere. Though too much CO_2 leads to problems. On Venus (a planet in size comparable with the earth) the atmosphere consists for approximately 98% out of CO_2 and this GHG alone can there be attributed to a rise in surface temperature of at least 285 degrees. Due to cloud cover, high gravitational forces and other factors the surface temperature on Venus is a stunning 466 degrees on average.

GHGs are not the only factors contributing to the current climatic changes, but are considered the most important. Other important factors causing climatic changes include ocean currents resulting in thermohaline circulation, volcanism, albedo, cloud development (obviously strongly linked to the GHG atmospheric H2O) and solar activity.
Many critics of the climate change debate emphasize the fact that global temperature has never been very stable. At the end of the Permian age, the amount of CO2 was approximately five times the current amount, while near the end of the Cretaceous period the amount of CO2 was two to three times the amount today (Berendsen 2004). But that it has never been stable and that fluctuations are natural does not mean to say that change in CO2 levels cannot have dramatic consequences or not at least partly be of anthropogenic origin. The dramatic consequences of changes in CO2 levels were made clear by a research of D.J. Beerling (2002).
According to this research, the amount of atmospheric CO2 reached a record high for the Phanerozoicum period (from 542 million years ago until today) near the end of the Trassic period. The end of the Triassic period is considered to be one of five mass extinction periods of life. During this extinction era, approximately 205 million years ago, 23% of all families and 48% of all genera went extinct (Baez 2006). This dramatic event can be attributed largely due to extreme temperature rise caused by high levels of CO2. So even if the current global warming is natural than still there is reason to be worried about the consequences.
Though there is evidence that this rise in temperature can at least partly be attributed to the interaction of the human species with their environment. The rise in CO2 in the atmosphere since the 1850s correlates with the start of the industrial revolution and therefore also to the start of the burning of fossil fuels on a large scale (Smil 1997). Groom *et al.* (2006) notes that since the industrial revolution, burning of coal, oil, and natural gas has increased levels of greenhouse gases by about 30% and global temperature rise (1860-1998) by at least 0.6 degrees. Also the sheer magnitude of the rise in atmospheric CO2 indicates an unnatural situation. Atmospheric carbon dioxide rose 36% since 1910 (280 ppm to 380 ppm) (Groom *et al.* 2006). This is definitely outside the bounds of past natural fluctuations.

2.1.2 Consequences of climate change in general

So it is now clear that climate change is occurring at a disturbing pace and that it is caused at least partly by human behavior, but is this change of the climatic condition of the earth actually a problem? The first thing one has to realize is that this phenomenon has a global impact. Though the sort of impact it has differs significantly per region. And although globally on average there is a strong rise in temperature, there are regions that are cooling down (especially oceanic regions on the Southern Hemisphere). The effects of a changing climate, whether economically, ecologically, or socially speaking, are numerous and impossible to fully comprehend. Fact is that there are advantages as well as disadvantages concerning the consequences of global warming (and regional cooling). Though it has become more and more clear that the problems will heavily outweigh the benefits. The problems are numerous. Much of the following information comes from Henson (2008).
Drought related concerns have particularly devastating effects on subtropical regions like Southern Africa, parts of Australia, the Mediterranean, the Caribbean and the South-West USA and Mexico. These subtropical regions are already by nature arid regions and thus the

climatic conditions will become more extreme. The same pattern can we observe for relative wet regions like monsoon climates in South and South-East Asia as well as across the Northern Hemisphere from 50 degrees N. Monsoonal rains across South Asia are likely to increase over the next century by 11% and estimates go up as high as 23%. Ironically there has been a decrease in average monsoon rainfall of 5-10% since the 1950s. This however is probably due to sulphate pollution. Globally precipitation will increase and it has already increased by approximately 1% over the 20th century. This is partly explainable by the simple fact that a rise in air temperature and consequently ocean water temperature results in a rise in evaporation which results in a rise in precipitation.
Another well-known problem is the big melt. This problem is particularly severe in the Artic and on the Antarctic peninsula. Temperature rise has been very strong in these regions already, while at the contrary an average drop in temperature can be observed in much of the rest of Antarctica. In western Canada and Alaska winter temperatures have been on a rise of 4 degrees since the 1950's. With that in mind it is not very surprising that the Arctic sea ice has been decreased up to 40% over the time period late 1950s to late 1990s. The problematic result of the melting polar ice is sea level rise.
Glacial melt is also considered a problem. 99% of the world's tropical ice is located in the Andes. This provides vital freshwater and is an important source for hydrological power for much of the Andes region. The pacific-coastal areas of Peru, Bolivia and Ecuador are particularly dry. In Peru 80% of the water supply for the pacific region is gained from ice melt (mainly indirect by rivers that are sustained by melting ice). The pacific coast of Peru, Bolivia and Ecuador is influenced heavily by the dynamic El Niño. El Niño is one of the most important climatic happenings in the world and it is of major influence on Ecuador and surrounding countries. El Niño's have been occurring for the past 6.000 years in an average frequency of once every 6 years and the phenomenon itself is even much older than that (Pearce 2007). This was proved by research concerning the water levels of a lake in Southern Ecuador by Donald Rodbell (Pearce 2007). But after 1976 El Niño's occurred on average every 3.5 years (Pearce 2007). The problem of El Niño's is that they cause huge droughts in East Asia and Australia and heavy rains in the pacific region of the tropical and subtropical Americas (like the major part of Ecuador). It also causes fish populations in the Ecuadorian waters to decrease immensely.
The most important environment with regard to CO_2 are tropical forests. Tropical forests contain approximately 40% of the carbon stored as terrestrial biomass. A research by Philips *et al.* indicated that biomass gain exceeded losses from dead trees in 38 out of 50 plots on neo-tropical sites. An average annual increase of 0.71(±0.34) tC/ha was observed in these plots over the past couple of decades. Consequently these forests are probably a huge carbon sink, a positive aspect. Mature humid forests (excluding lowland sites) in the neo-tropics, like can be found at maquipucuna reserve, have an average increase of 1.11(±0.54) tC/ha. This accounts for the most rapid increase of all natural forest ecosystems in the neo-tropics.

2.1.3 Biological impacts of climate change

As this thesis report is set up for a nature conservancy, the biological impacts of climate change are being emphasized. The biological impacts of climate change are like the economical and social consequences very numerous and diverse. Even though the effects of climate change are not well investigated but for what is known so far the consequences are very dramatic.

Many evolutionary and morphological changes have been observed among flies as a result of climate change. One of the major biological impacts is the disturbance in the phenology of species. Phenological shifts are already occurring in several species within a very wide array of taxa; from Mexican Jays, *Aphelocoma ultramarina* (Brown *et al.* 1999) to Tree swallows, *Tachycineta bicolour* (Dunn and Winkler 1999). At Maquipucuna biological reserve changes are recently being observed in the time of arrival of the spectacled bears (spectacled bear season) possibly due to a phenological shift in the flowering time of trees. Whether the cause is climate change or not, is well worth to investigate.

Other observed biological impacts of climate change include population and species abundances, community reassembly, range shifts, sea level rise, and the direct consequences of more carbon dioxide.

A case of a species whose range is changing due to global warming is the red fox, *Vulpes vulpes*, in Canada. This species is expanding northward for the past 70 yrs (Parmesan and Yohe 2003). But not only the range of species and populations can shift, also entire ecosystems and vegetation zones can move. The problematic part of this movement is that much of the natural habitats or areas of the world are very fragmented and therefore species are often trapped into changing island environments. This problem can partly be solved by building corridors between natural areas. Maquipucuna reserve is located within the Choco-Andean corridor and connects two regions of global biodiversity significance, the lowland Choco and the Andean tropical montane forests.

The direct effects of an increase of atmospheric carbon dioxide are one of the most important and yet underestimated effects of the current climatic changes. $CO2$ acts like a fertilizer with an atmospheric concentration of 850 ppm resulting in increase of photosynthesis by 60%, the growth of young trees by 70% and the growth per unit of leaf area by 27% (Keeling and Worff 1999). Chave, Condit, Muller-Landau *et al.* (2008) mentions recent evidence of an increase in aboveground biomass and primary productivity in South America as well as a shift in plant species composition favouring fast-growing plants over slow-growing plants. Also changes within plants due to an increase in atmospheric carbon occur, like a shift in the C:N ratio favouring the carbon molecule (reviewed by Cotrufo *et al.* 1998; Bezemer and Jones 1998).

Parmesan and Yohe (2003) investigated all-round on the biological impacts of global warming by examining changes of 1700 spp. world-wide; approximately 50% of those showed a significant response to climate change over the past 10-140 years by a change in phenology or a spatial shift in direction of either higher latitudes or altitudes.

Root *et al.* (2003) made a study using data from 143 different studies on changes in species trait changes and compared that with climate driven predictions. This study indicated that 80% of the species investigated showed trait changes consistent with climate-driven predictions.

Furthermore Hansen *et al.* (2003) showed that it is likely that a 2 degrees surface air temperature rise over pre-industrial levels will result in that several species will get lost but many possible management options still exist to minimize the loss. A 4 degrees rise is expected to vanish many species and few management will remain that are able to control the extinction rate. With a 6 degrees rise climate change will have a dire impact on global biodiversity levels.

2.1.4 Biological consequences of climate change on neo-tropical montane forests

Maquipucuna biological reserve consists of neo-tropical montane (cloud) forest. These forests are particularly sensitive for climate changes. Research on the biological impacts of climate change on these kind of environments is quite rare. Though a very extensive study on this topic was conducted by Masters *et al.* in Groom *et al.* (2006). This research was organized by the golden toad laboratory for conservation of the monteverde cloud forest preserve and tropical science centre in Costa Rica. The Monteverde cloud forest preserve is located in a different ecoregion than Maquipucuna reserve but both concern neo-tropical cloud forests that are influenced by El Niño.

Changes in species abundances and occurrence were observed. Many birds like the Keel-billed Toucan (*Rhamphastos sulfuratus*) were unknown in the Monteverde cloud forest and used to live in lowland rainforest are migrating recently uphill to this cloud forest. Herpetologists observe negative trends in populations of lizard species and notice disappearances in many frog and toad species of which two were endemic; golden toad (*Bufo periglenes*) and Monteverde harlequin frog (*Atelopus sp.*). These changes are attributed to climate change and therefore these two amphibian species are the first animal species known to get extinct due to modern day global warming. Since 1872 (start of collecting weather data in the area) the frequency of days with little or no precipitation has increased during the dry or windy-misty season (December to May). This is attributed to the increased frequency of El Niño events. El Niño frequency increases due to global sea surface and air temperature rise. Also an increase in cloud cover has been observed. Cloud cover is suspected of preventing frogs (by raising body temperature) to kill the deadly chytrid fungus *Batrachochytrium dendrobatidis*.

This problem of frogs that are being killed by this chytrid fungus seems to be far greater than a Costa Rican locality. According to a different study conducted by Pounds *et al.* (2006), 67% of the approximately 110 species of the genus *Atelopus*, of which all are endemic to the American tropics, also vanished due to this chytrid fungus. There is a high confidence (>99%) that this can be attributed to changes in sea surface and air temperature.

Neo-tropical cloud forests are known for their high diversity of endemic frog species, epiphytes and orchids. In Monteverde reserve 500 species of orchids are present and a lot of them inhabit narrow altitudinal belts. These species among other very spatially limited species are of extraordinary high abundance in cloud forests and are especially vulnerable for climate change. This in combination with the overall biological richness of neo-tropical cloud forests makes these environments a focus area of global warming related concerns and nature protection.

2.1.5 Biodiversity of Ecuador and Maquipucuna reserve itself

Maquipucuna reserve is part of the WWF ecoregion North-Western Andean montane forest and part of the biome tropical and subtropical moist broadleaf forest. It is listed under the global 200, a system set up by WWF to protect the most important ecoregions with regard to

conservation. This ecoregion is considered one of the richest ecoregions of the world and a center of endemism, with about half of its flora being endemic.
Furthermore globally the highest endemism levels of bird species can be found here. At low elevations this ecoregion suffers heavy losses, but it is often relatively well preserved at higher altitudes (like in maquipucuna). Next to deforestation, hunting is considered a significant problem.
Maquipucuna is also part of the tropical Andes biodiversity hotspot, and is nicknamed the ‘global epicenter of biodiversity’. Biodiversity hotspots are the most biologically rich and most endangered terrestrial ecosystems of the world. The tropical Andes is even the most richest and diverse region on earth and it contains about one sixth of all plant life while it is stretched out over less than 1% of the world’s land area.
According to the website of the rainforest rescue organization, Ecuadorian cloud forest or low montane humid forest and humid montane forest is the single richest biodiversity hotspot on the planet, with 15-17% of global plant species diversity and one-fifth of the world’s bird species diversity.
A research by Balslev (1988) indicated that middle range Andean montane forests (between 900 and 3000 m.) cover only about 10% of the land surface of Ecuador while harboring about half of its plant species. Maquipucuna reserve lies approximately between 1000 and 2800 m. and thus entirely within the middle-range of Andean montane forests. The same research showed that much higher levels of endemism can be found in montane forests than in lowlands (red. 39% against 16%).
According to the GTZ Ecuador is the country with the greatest biodiversity for its surface area. Representing only 0.2 % of the earth’s land surface it is home to 18% of all bird and orchid species, 10% of all amphibians and 8% of all mammals (Carrion 2010). It is also one of the seventeen so-called mega-diverse countries in the world concerning the total biodiversity of the country according to Conservation International.
Unfortunately much of this biodiversity is under threat. According to IUCN records Ecuador holds the largest number of red listed species with a total of 2151 (Groom *et al.* 2006). Second is the USA with only 1143, just over half of Ecuador’s total. Plants form the biggest group (81% of total number of species in Ecuador) with amphibians on second place in Ecuador (Groom *et al.* 2006). These groups are known to have high species diversity and endemism levels in tropical montane forest ecosystems. Though the large number of threatened species is not only due to the fact that a lot of nature is under threat but also that Ecuador has a huge biodiversity and a long and very extensive history of documenting the condition of species and populations.
Maquipucuna reserve itself harbours about 10% of Ecuador’s plant diversity and over 20% of the country’s bird species diversity. This reserve is located within the Choco-Andean corridor. This corridor connects the coastal forests in the north of Ecuador near the border with Colombia with the Andean montane forests. This corridor is ranked as the fifth most bio-diverse in the world with over 8,000 plant species present, including 458 species listed in the IUCN Red Book. Most famous though is this corridor for its bird diversity, with 800 species which account for approximately 10% of the world’s total.

2.2 Forest policy and management in Ecuador

2.2.1 Andean montane forests in Ecuador

Over 80% of all forest in Ecuador is lowland rainforest, while Andean montane forests only have a tiny shear. All forest in Maquipucuna reserve is Andean montane forest. Montane forest and cloud forest are terms which are often used the same. In short all cloud forest is montane forest, but not all montane forest is cloud forest. It is however difficult to determine when a forest is actually a cloud forest. According to Bubb *et al.* (2004) only 8.4% of all neo-tropical forest in mountainous areas and 1.2% of all neo-tropical forest can be considered cloud forest. In reality however people tend to call much of all moist or wet tropical mountainous forest cloud forest. In Maquipucuna there are officially two types of natural forest, western Andes montane cloud forest and western Andes lower montane evergreen forest (Tian *et al.* 2007). Over 80% of this forest is in primeval condition. Western Andes cloud forest occurs in Maquipucuna on high elevation. It is however unclear where the boundary exactly is. In this report I use altitudinal boundaries that approach the division between the two forest types. For clarity and because of the insecurity of the division I will call the western Andes cloud forest ‘upper montane forest’ and the western Andes lower montane evergreen forest ‘lower montane forest’.

Andean montane forests and especially cloud forests are important resources for many reasons. Two of the most appealing reasons are their extraordinary biodiversity and their hydrological function. The biological richness has been discussed in the previous chapter. Andean montane forest augment a critically large amount of water for the capital of Ecuador, Quito (Bubb *et al.* 2004). World-wide many large cities depend on cloud forests for their water supply; Mexico city for instance depends partly on cloud forest supplies while Dar es Salaam (Tanzania, 2.5 million inhabitants) depends during the dry season for 100% on water from cloud forests (Bubb *et al.* 2004).

2.2.2 Forest development in Ecuador

With the alarming state of biodiversity in Ecuador and the enormous biological richness of the forest ecosystems in this country it is not very surprising that forest cover and intactness have been declining for decades. Annual deforestation rates were negative at least from 1990 on. Between 1990 and 2000 -1.5% forest cover development annually, between 2000 and 2005 -1.55% and between 2005 and 2010 -1.7%. The deforestation is thus still increasing. According to UN sources each year Ecuador loses almost 200,000 hectares of forest. This results in a release of 55 million tons of GHGs. In 2010 36% of Ecuador’s land surface area was forested. About half of this forest is primary forest, while the other half consists mainly out of naturally regenerated forest. Actual plantations only cover 2% of the total land area.

2.2.3 Forest policy and management in Ecuador

The agricultural sector is not very large in Ecuador, only about 7.4% when measured in GDP in 2005. Within this sector though forestry is one of the most important contributing to about 4% of Ecuador’s GDP in 1989. This does not only include wood, but also cinchona bark (for quinine), ivory palm nuts (for buttons) and kapok from the ceiba tree (for mattress stuffing) are important forestry products.

By far most important for the economy of Ecuador is the production of petroleum. 40% of the export's earnings and a quarter of the central government budget can be accounted to petroleum. The search for petroleum is however not a major threat for cloud forests like Maquipucuna and the petroleum reserves can mainly be found in the oriente (and therefore threatening lowland rainforest).
The government does not invest that heavily in forestry or nature conservation but still has made some remarkable progress concerning nature conservation. According to GTZ, about 18% of the land surface of Ecuador falls under some form of protection. This is especially surprising considering the poor economic state of the country for many decades and especially today. Over 60% of the populations currently lives in poverty, while 27% are counted as extremely poor. This poverty often leads to unsustainable use of land and short-term gains are sometimes necessary for survival with intense forest exploitation as a result. The situation is worsened by a poor legal framework especially on a regional and local level. Consequently illegal cutting and other forms of exploitation of natural areas are very widespread. Holopainen *et al.* (2008) therefore also concludes that sustainable forest management of natural and semi-natural ecosystem, planted forests and agro-forestry systems has not yet been achieved.
A very solid document concerning sustainable forest management in South America is written by van Dijk and Savenije (2008). Much of the following information comes from this source. To enable sustainable management, public microcredit financing has been proved effective in Ecuador. The foundation CODEAMA manages a microcredit fund for forestry and agro-forestry. Only 10% is used for forest management. They pay smallholders (farmers, landowners) to make the management of their land more sustainable. This is likely to be a more effective method than large scale governmental initiatives, because of the many smallholders in the central/Andean part of Ecuador where also Maquipucuna reserve is located.
Ecotourism in combination with cooperation with local people can be very effective in protecting nature and culture. A good example in Ecuador is Cuyabeno reserve, an over 600,000 ha reserve in the Amazon region of Ecuador which is inhabited by five indigenous communities and threatened by oil companies. Thanks to a well structured ecotourism program the forest is well protected and the communities have kept much of their traditional way of living while gaining extra money as tour guides (who I think are doing their jobs more than excellent).
PROFAFOR is an Ecuadorian enterprise created in 1993 with the help of the Dutch FACE foundation. The objective of this enterprise is to fixate CO_2 from the atmosphere. They work by establishing plantations. This organization provides direct payments to the landowner but they also have a clause with a penalty if the plantation is not established.

Other important companies in Ecuador:

- Ecofondo: Was created in 2005 with a capital of 16.93 million US$ for projects of conservation and development. Of all the project money, 60% was used for conservation, 35% for capacity building and between 15% and 25% was used for research purposes. It is clear that many projects have more purposes, as the total comes out higher than 100%.

- SNAP: Sistema Nacional de Areas Protegidas. This consists out of 33 protected areas throughout Ecuador. Among this are 9 national parks and 10 ecological reserves. These form the most important nature protection system in the country. Maquipucuna however is a reserve owned by the Maquipucuna organization.

Furthermore by Ecuador, as in 1st of January 2010, the following agreements were ratified (only those relevant for Maquipucuna):

- Convention of biological diversity
- UNFCCC
- Kyoto protocol
- CITeS.

2.3 <u>REDD and Ecuador</u>

2.3.1 REDD, the system

REDD stands for 'reduced emissions from deforestation and forest degradation'. It is a PES system concerning the trade in carbon credits. The initial idea came to provide an answer on the problems of deforestation and forest degradation with regard to climate change. The idea was formed by the Conference of the Parties in Bali. They formulized the concept as follows: "Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries."
There is sufficient reason to stress the importance of creating a system like REDD. Deforestation accounts for approximately 20% of global greenhouse gas emissions (IPCC 2007), making it one of the major drivers for anthropogenic climate change. Tropical forests are the most important terrestrial biome concerning carbon storage containing a quarter of all CO2 stored on land (Parker *et al.* 2008). Surprisingly emissions from deforestation are not integrated into CDM. Besides, REDD is not, nor is it likely to become, a part of CDM (Clean development mechanism).
There are two major questions concerning REDD; when to initiate the REDD system and how to release it. On when to start the REDD system there was achieved consensus in Bali by the UNFCCC. It was decided that REDD would be part of a post-2012 (post-Kyoto) protocol. But recently, in Cancun it was decided that the Kyoto protocol will not end in 2012. Therefore it is now questionable whether REDD will be released by 2012.
How REDD will function as a system is mainly a debate on how much control we want. Whether the system is fund based or market based are key elements in this debate. Arguments not just to release a plain REDD system on the market is that it increases the potential value of natural forest areas, irrespective of timber quality or accessibility, and thus tempts the public and private sector to appropriate areas previously considered uneconomic. This is likely to disadvantage forest-dependent peoples. On the other hand SFM restricted to profits from the production of timber is economically less attractive than other land uses. REDD could make an important contribution and increases the opportunity costs also for local people. Conclusively REDD is often considered to be a driver for and against forest decentralization and social equity. Michael Richards (2008) formulizes the problematic situation as follows: "REDD is not inherently pro-poor and could be anti-poor. Market-based

REDD could end up compensating wealthy developers who are threatening to cut down the rainforest rather than communities that have conserved forests for centuries. It will need a lot of donor and NGO support to ensure the poor do not lose out again." The difficulties of REDD with poverty are globally very large as approximately 90% of the 1.2 billion people living in extreme poverty in the world depend at least partly on forest resources.
Next to social problems there are also economic concerns for a market based approach. One of the major concerns is that when at once a market based REDD system is launched, the credits will flood the market. Another problem is that the potential supply of avoided deforestation (AD) credits is way higher than the demand with consequently the risk of market flooding. The demand of AD credits in 2008 was estimated at 400 million against a potential supply of 7.2 billion (Paul Leach in Holopainen *et al.* 2008). This situation is unlikely to change unless Annex 1 countries (first world countries) commit to gigantic GHG reductions on short terms. However, avoided deforestation credits that would be included in post-Kyoto protocols are very promising for halting tropical forest destruction and especially for nature conservancies like Maquipucuna reserve.
In order to combat the range of different problems surrounding REDD, a REDD-plus system was proposed. About the content of a REDD+ program, four international forest dialogues were held between April and September 2009 at Yale university. The main outcomes were:

- REDD+ finance mechanisms should be sufficiently robust to deal with in-country and international leakage, use credible baselines, must achieve verifiable additionality, and result in value for money.
- REDD+ should lead to real reductions in CO_2, enhance forest ecosystem functions and the supply of critical ecosystem services, protect and respect the rights of Indigenous Peoples and local communities, and ensure equitable benefit sharing.
- In addition to reducing emissions from deforestation and forest degradation REDD+ finance mechanisms should also create incentives for additional actions in forest conservation, sustainable forest management, and the enhancement of carbon stocks.
- REDD+ processes should allow the broad participation of all stakeholders, on equitable terms, at the national and international levels.

An interesting development is furthermore that private investment is already creating a market for REDD credits (voluntary-based) independent of both UNFCCC negotiations and the FCPF. And although there are a lot of problems involved, the potential of REDD, whether measured in monetary terms or in combating climate change, are enormous.

2.3.2 NGO or enterprise based REDD and other PES schemes in Ecuador

The very poor state of forest management due to lack of finance and pressure on land in Ecuador ask for faster and more cost-effective action from the public and private sectors to support sustainable programs like PES. Most PES (payments for ecosystem services) in Ecuador are in their initial stages and are related to watershed protection. Schemes related to carbon sequestration, reducing emissions from deforestation and degradation (REDD), landscape beauty/recreation and biodiversity also exist but not many have been established. The country does not have an extensive public policy or legislation with regard to PES. And even the hydrological PES programs are troubled with their development. Often there is a lack

of hydrological data regarding the effect of forests on watershed services and consequently decision-makers work under difficult circumstances and often use the precautionary principle, aiming at protecting water quality alongside other ecosystem services.
The Bilsa and PROFAFOR are two projects that plant and protect trees for carbon sequestration in Ecuador. Bilsa is a local reforestation project on the Pacific coastal region. PROFAFOR is owned by the Dutch face foundation. PROFAFOR is much larger and reforested between 1994 and 2002 more than 22000 ha on degraded lands all over the Andean highlands in collaboration with private landowners and native communities. The land-owners harvest the timber, forest products and non-forest products; they have to replant to maintain the stock.
The face foundation also owns the 'Fundacion Bosques para la Conservacion' which develops REDD projects. These projects mainly focus on maintaining forest carbon storage and avoiding deforestation. It has been developed in cooperation with both private landowners and the environmental ministry of the government. Though the area which is protected in this way is small and covers in total only 5800 ha (only slightly larger than the maquipucuna reserve) divided over two sites, one in the Andes and the other in the Amazon region.
PES income concerning landscape beauty and recreation is generated mainly by ecotourism which is well developed in many of the protected areas of Ecuador, while the Galapagos is now even has a surplus on tourists with negative consequences for environment of the island group.
A biodiversity related PES scheme is developed by GTZ for 7000 ha on the Ecuadorian coast. GTZ only provided technical assistance and aid in capacity building, but furthermore it is completely dependent on international funding. Surprisingly the world famous pop/rock band Coldplay donated to this project.

2.3.3 The governmental approach to REDD

So far only NGO and enterprise initiatives have been discussed. The government of Ecuador has developed a plan to control the deforestation in the country (Chiu 2009). An important development concerning REDD in this plan was the initiation of the Socio Bosque program (PSB) in September 2008. PSB is an initiative of the ministry of environment and it is also financed fully by public funds. According to the ministry of environment the program can be defined in December 2010 as "Economic incentives for farmers and indigenous communities who decide voluntarily to conserve their forest". To my idea it is a sort of combination of a national sustainable forestry program and a REDD+ program with an emphasis on the "plus". It has four main goals:

- To conserve approximately 4 million ha of native forest and especially the forests that are in danger.
- Protection of environmental services provided by these forests.
- Contribute to the improvement of the livelihoods of rural people.
- To position the country avant-garde in the reduction of carbon emissions by avoided deforestation.

The target groups for these economic incentives are smallholders and indigenous communities. This is understandable as these groups often lack the financial capacity to protect and/or sustainably manage their forests. Also is there relatively much forest owned by these groups. On farms 3.8 million ha of forest can be found, while 3 million ha of forest stands on indigenous territories. Unfortunately Maquipucuna reserve is not a farm neither is it communal land. But furthermore the area qualifies for many of the selection/priority criteria. Depending on the number of selection criteria that are appropriate a land owner can receive up to 30 US$/ha/yr. This under the pre-condition that the forest is protected for a period of 20 years. Even though sanctions are included if the targets are not met and 30 US$ a year can't be considered a goldmine, from the initiation in 2008 to May 2010 already 400.000 ha of forest have been conserved in this way benefitting more than 40.000 people (Carrion 2010).

2.3.4 REDD and Maquipucuna reserve

When proposing a REDD program one should take in mind the scope of the project, the reference level, the distribution and financing according to Parker *et al.* (2008).

The scope is about what kind of REDD scheme is applicable and what kind of carbon pool. Ecuador promotes a REDD+ scheme and thus for Maquipucuna REDD+ is probably the best scheme. In this research only living tree carbon is measured.

The reference level consists of the spatial scale and reference period. This research uses a local scale, the Maquipucuna reserve. The reference period is the current state of the forest. It aims at providing REDD possibilities for avoided deforestation. Therefore the current situation (present carbon amounts in maquipucuna reserve) is the reference line.

The distribution concerns the kind of assets and the scale of distributing the credits. It concerns carbon assets. The scale of distributing the credits can regional, national or international/global.

The financing method can be divided into three areas; direct-market, hybrid / market-linked, or voluntarily by a fund.

Maqui-carbon credits already exist and can be purchased. This concerns carbon from land set aside by local people for conservation in the surroundings of Maquipucuna reserve.

3. Case study

3.1 Hypothesis

The following hypothesis comes directly from the research proposal:
I expect that the biomass and carbon stocks will be negatively correlated with altitude. According to GOFC-GOLD (2009) for lowland rainforest one can expect 133 tC/ha, while for the montane forest this is 110 tC/ha. This can be explained mainly by a decrease in temperature. Also do I expect a decrease in BA/ha when altitude increases, but a positive correlation between altitude and stem density.

3.2 Methods

3.2.1 Study area

This research was conducted in Maquipucuna biological reserve in North-West Ecuador and it is located only 50 miles (80 kilometers) outside Quito and within the Metropolitan district of Quito (00º02'N-00º08'N and 78º35'W-78º38'W). The reserve is managed and owned by the Maquipucuna foundation (Fundacion Maquipucuna). This foundation was founded in April 1988 and is the first non-profit organization in Ecuador.
The reserve protects approximately 5700 ha of Andean montane forest (Svenning 2001). The relief in the reserve is impressive and the altitude ranges from about 1000 meters to almost 2800 meters at the Cerro Montecristi (Tian *et al*. 2007). Typical for tropical montane forests, the annual precipitation is high and differs per altitudinal zone. At the lowest parts of the reserve the annual precipitation is about 2500 mm. while near the highest peak it is usually between 3300 and 3700 mm (Stephenson *et al.* 2007). According to Blondin Landivar (1977) the area has a subtropical rainfall climate. Annual temperature averages between 18ºC at 1200 m. and 10ºC close to the summit of the Cerro Montecristi (Webster and Rhode 2007).
The geological formations in the reserve were mainly formed in the Pleistocene and are highly determined in composition by volcanic activity of the Pichincha volcano (Webster and Rhode 2007). The formations are rich in Bauxite and the reserves present were exploited on small scale in the past. According to a USDA taxonomy in 1992 the soils in the region were mainly Andisols (Tian *et al*. 2007). These soils developed about 2500 years from andesitic volcanic ash deposits (Rhoades *et al*. 2000).
Two primary forest types can be distinguished in the reserve, western Andes montane cloud forest and western Andes lower montane evergreen forest – red. upper montane forest and lower montane forest (Tian *et al.* 2007). Primary forest covers over 80% of the reserve (Tian *et al*. 2007). In the lower parts of the reserve near the Northern entrance, secondary forest occurs. The history of this secondary forest differs spatially. According to Carlos (one of the guides of Maquipucuna who lives in the area for many decades) agriculture with mainly maize (*Zea mays*) and sugar cane (*Saccharum spp.*), and also yuca (or manioc) (*Manihot esculenta*) and banana (*Musa spp.*) followed by pastures with cows was the main land use in the area. This system resulted sometimes in shifting agricultural practices with fallow periods included. Some parts of the secondary forest are not in use for about 25 years while other parts that are located on steep slopes or at very wet places are not used for over 50 years. The information concerning age of the secondary forest is confirmed by Rhoades and Coleman

(1999). Rhoades *et al*. (2000) gives an extensive history of land use practices in the area. They indicate that sugar cane production has dominated the region for much of the 20th century. Next to sugar cane, pasture sites were established that underwent 3 to 4 months periods of maize and with a 2 to 4 years fallow period.
Webster and Rhode (2007) conducted a very extensive research on the flora of the reserve. The vascular flora present consists of 157 families, 663 genera and approximately 1960 species. Of these 356 species belonging to 169 genera are trees. To compare, the Netherlands has 1536 species of vascular plants. The dominating families are Araceae, Bromeliaceae, Orchidaceae, Ericaceae, Gesneriaceae and many ferns. The number of exotics is low (47) and the flora can be regarded as the southern terminus of the Choco flora.

3.2.2 Dividing the area in different zones
The area is divided in different zones to compare the amounts of carbon and the structural characteristics. In maquipucuna reserve three different forest types can be distinguished. Secondary lower montane forest, primary lower montane forest and primary upper montane forest. Where the boundaries between these three zones are located is hard to find out and thus is it also difficult to determine precisely the surface area per forest type. Webster and Rhode (2007) use altitude difference to indicate the location and boundaries of the different forest types. They don't use one single altitude as a boundary but use an altitudinal range. In this report a single altitude figure is taken as a boundary between two forest types, because many objectives of this research (like the amount of carbon per ha) demand calculations that are surface-related. Using the division of Webster and Rhode (2007) and local oral sources (Carlos, a guide of maquipucuna) I decided to make the following differentiation for the different forest types in the reserve:
The lowest parts of the reserve, up to 1500 m, are almost completely covered with secondary lower montane forest or heavily alterated (primary) lower montane forest, the zone from 1500-2000 meters is covered mostly with primary lower montane forest, while at 2000 m. a different zone starts consisting of primary upper montane forest. These zones cover respectively 16,22% (849,56 ha), 48,07% (2517,65 ha) and 35,71% (1870,37 ha) of the total surface area of the maquipucuna reserve (5237,58 ha).

3.2.3 Setting out of the plots
To set out the plots I used Pearson *et al.* (2005). First about the shape and the size of the plots. The plots are square and measure 35 by 35 m. In this large plot all trees with dbh (diameter at breast height = approximately 1.3 m.) > 50 cm will be measured. Within this large plot, an intermediate plot of 25 by 25 m is set out for all trees with dbh 20-50 cm, while a small plot of 7 by 7 m is used for all trees with dbh 5-20 cm. The plots were often located in very hilly terrain and therefore the area of the plot was slope-corrected by measuring the angle of the slope and cosines.
Next is to determine how many plots are necessary to make a good estimation of the carbon amounts and to compare the structural characteristics of the different forest types present. To measure the amounts of carbon, Pearson *et al.* (2005) gives a multi-strata equation (multi-strata refers in the case of maquipucuna to more forest types) to estimate the total number of plots necessary: $n = (\Sigma N_h * s_h)^2 / (N^2 * E^2 / t^2 + (\Sigma N_h * s_h^2))$.

Where:
E = allowable error or the desired half-width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10% precision, or 0.2 for 20% precision).
t = the sample statistic from the t-distribution for the 95 per cent confidence level. t is usually set at 2 as sample size is unknown at this stage.
N_h = number of sampling units for stratum h (= area of stratum in hectares or area of the plot in hectares).
n = number of sampling units in the population.
s_h = standard deviation of stratum h.
Additionally, the following equation can be used to determine the number of plots for each stratum (forest type): $n_h = n * ((N_h * s_h) / (\Sigma N_h * s_h))$.
When applied for the situation at maquipucuna the total number plots is 26 when using a precision level of 10% and 12 for 15% precision level. The results of the equation for each stratum are 5 for the secondary forest, 12 for the primary lower montane forest and 9 for the primary upper montane forest. This is respectively 2, 6 and 4 plots for a 15% precision level. For this equation I used information concerning the average carbon stocks/ha and the coherent standard deviation for tropical montane forests from the sourcebook of GOFC-GOLD; the same average for tropical montane forests was made available on the website of the environmental sciences division of the oak ridge national laboratory.
The problem though with this equation is that it focuses entirely on measuring the carbon amounts and my research also has the objective of comparing the structural characteristics of the different forest types. In order to investigate the latter an equal number of plots per forest type is preferable. This in combination with the practical difficulty of doing research in the upper montane forest and the fact that the secondary forest differs strongly per locality in age (which would indicate that more plots in the secondary forest are necessary) made me decide to take 6 plots in each forest zone. 6 plots is also set as a commonly used minimum by Pearson *et al.* (2005) to measure variance. More about making decisions on the number of plots that are necessary for this kind of research can be found in the discussion.
The location of the plots was selected randomly but not with completely equal chance for the whole area of being selected due to inaccessibility. It was virtually impossible to gather data at some extremely steep hills. Also locations far from the trail were avoided as the forest was really dense at certain places and (except for the secondary forest) never without steep hills. Furthermore the highest parts of the reserve near the summit of the Cerro Montecristi were avoided due to the fact that it was only possible to get there by a very long and hardly accessibly trail.

3.2.4 The monitoring methodology

Of each tree that is being monitored, the dbh is measured using a dbh-tape. The height of the canopy layer is obtained by measuring the height of all trees with dbh > 50 cm if trees in this dbh-class are present and if not present than half of all the trees with dbh between 20 and 50 cm are being measured. To monitor the height of trees, a clinometer to calculate the angle was used and a meter tape to measure the distance to the tree. By using tangent the height of the tree was obtained. Next to the height of the crown layer, the crown density was measured. The

crown density is an estimated percentage of the shear of leaf cover vs. the shear of air gap in the canopy. Also the number of trees were counted for each plot, and for each tree the family, genus and if possible the species was identified. For the determination of the tree I got help from the guides Carlos and Rufus and also used (for the scientific name when only the local name was known by the guides) Webster and Rhode (2007).
Furthermore the location and elevation was recorded using GPS. The slope of the area (by using a clinometer) and the aspect of the slope was determined. The aspect was measured in down-hill direction by using a compass.

3.2.5 The methodology of the analysis of the results

To determine the amount of aboveground living tree carbon present it is necessary to first calculate how much aboveground living tree biomass there is in the area. For this I used the following biomass equation from Brown (1997, updated) in Pearson *et al.* (2005):
$Biomass = \exp(-2.289+2.649*\ln(dbh)-0.021*\ln(dbh)^{\wedge}2)$. This equation can be used for tropical moist environments (1500-4000 mm of rainfall annually) and for trees of up to 148cm.
Cecropia has a remarkably low wood density and thus for the measured Cecropia's of up to 40cm the following alternative equation of Winrock in Pearson *et al.* (2005) was used:
$Biomass = 12.764+0.2588*dbh^{\wedge}2.0515$.
The amount of belowground living tree biomass is determined by using the following regression model from Pearson *et al.* (2005):
$belowground\ biomass = \exp(-1.0587+0.8836*\ln(aboveground\ biomass))$.
These biomass equations all use dbh as the only variable. As this equation is exponential, for every tree the biomass has to be determined individually in order to get the overall results of the different plots and consequently of the different forest types.
The amounts of carbon are obtained by simply dividing the biomass results by two. This is a valid approach according to Pearson *et al.* (2005).
To assess the significance of the observed differences between the carbon stocks of the different zones I used a one-way ANOVA test followed by a Tukey test. By using a t-test, the measured averages of the carbon stocks of maquipucuna are compared with an expected amount of carbon of 110 t/ha for tropical montane forest from the sourcebook of GOF-GOLD (2009).
An ANOVA and a tukey test were also used to assess the structural characteristics of the different forest types. The structural characteristics that are being assessed are no of trees per ha, average height of the crown layer, crown density, average dbh (>=5cm) and average dbh (>=50cm) between the zones.
Pearson's correlation was used to determine the correlation between altitude and the following structural characteristics: biomass, no of trees per ha, average dbh(>=5cm), average dbh(>=50cm), average height of crown layer and crown density. The correlations are tested on their significance. Only the plots from the two primary forest zones are used for these correlation tests. If secondary forest plots would be included it might give a bias.

3.2 Results

3.3.1 The carbon quantities of the different forest types

The average amount of aboveground living tree carbon present in the secondary forest zone was rather low at 88.8(±39.7) tC/ha (figure 1) with relatively large differences between the plot results (figure 2) which is indicated by a CV of 45%. This in contrast to the primary lower montane forest zone which has an average of 215.4(±31.8) tC/ha (figure 1) and a low CV of only 15% (figure 3). The upper montane primary forest zone has an average amount of carbon of 125.7(±49.2) tC/ha (figure 1) with a CV of 39% and thus large differences between the plots (figure 4). The expected amount of carbon is 110 tC/ha according to GOFC-GOLD (2009). There is a highly significant difference ($P<0.0005$) between the primary lower montane forest and the expected amount of carbon for this area. The other two forest types do not differ significantly from the expected amount of carbon. This is partly due to high variation between the plots of these forest types, which is indicated by a high CV. The amount of aboveground living tree carbon present in the whole maquipucuna reserve is 852,812.3 tons of carbon. The average amount is 162.8 tC/ha with a CV of 41%. This results in a significant difference with the expected amount of 110 tC/ha ($P<0.005$).

The belowground amounts of carbon are 16.9(±6.6) tC/ha for the secondary forest, 36.9(±4.8) tC/ha for the primary lower montane forest and 22.9(±7.9) tC/ha. The total amount of belowground living tree carbon for Maquipucuna is 150,035.8 tons of carbon. The total carbon quantity for the whole Maquipucuna reserve (aboveground and belowground) is 1,002,848 tons. This is divided over a total of 3,506,874 trees if assumed that the measured no of trees in the plots account as standard for the whole area.

Significant differences between the aboveground living tree carbon stocks of the different zones have been observed ($P<0.01$). The difference between the secondary forest zone and the primary lower montane zone is considered highly significant ($P<0.01$). A highly significant difference can also be observed between the primary forest lower and upper montane zone. However, no significant difference in the amounts of living tree carbon is there between the secondary lower montane and upper montane forest zones. This sounds weird as these two zones are spatially separated and share few ecological or functional characteristics. Though not only the amount of carbon is comparable for these two zones but also several other structural characteristics.

For the belowground the same patterns can be observed as for the aboveground carbon amounts as the belowground is determined by an equation of Pearson *et al.* (2005) using the aboveground amounts as only input.

3.3.2 The structural characteristics of the different forest types

Important structural characteristics are dbh, biomass, no of trees/ha, average height of crown layer and crown density (Table 1). The average dbh for all measured trees (>=5cm dbh) is highest in the primary lower montane forest and lowest at the secondary lower montane forest (Table 1).

The dbh-graphs (figure 6 and 7) indicate a natural “reversed J” shape at the upper primary forest, but an unnatural shape at the primary lower montane forest. The unnatural shape is due to an outstandingly high number of trees with a dbh between 15 and 20 cm. Whether this is

due to a sampling error or a natural error due to the relatively low number of plots (6 in total in the primary lower montane forest zone) or that it is an indication of alteration of the forest at certain plot sites will be investigated in the discussion. The same dbh class of 15 to 20 cm also has a number of trees per ha above expected at the secondary lower montane forest (figure 5). Surprisingly the severity of this interruption of the natural shape is less than at the primary lower montane forest. Furthermore a scarcity of trees with high diameters can be observed at the secondary lower montane forest. This is a logical consequence of the relatively young age of this forest zone.
Biomass patterns and significances concerning the comparison between the different forest types equal those concerning carbon as the amount of carbon is derived from the amounts of biomass (aboveground living tree carbon ≈ aboveground living tree biomass / 2).
Number of trees per ha is highest in the secondary lower montane forest and lowest in the primary lower montane forest (Table 1). This difference is mainly due to a higher number of small trees (dbh < 20cm) in the secondary forest compared to the primary forest types. For the number of large trees (dbh >=50cm) one can observe the reverse order of magnitude, but this is of little significance for the total number of trees as the number of large trees overall is low compared to the number of small trees. These results confirm the expected results.
Both crown density and height of crown layer are highest in the primary lower montane forest and lowest in the primary upper montane forest with a negligible small difference between the secondary lower montane forest and the primary upper montane forest (Table 1).
A statistical analysis was used to make a comparison between the different forest types for the no of trees per ha, average height of the crown layer, crown density, average dbh (>=5cm) and average dbh (>=50cm). A significant difference was observed for average dbh(>=5cm) between the secondary lower montane forest and the primary lower montane forest ($P<0.5$). For the very large trees (dbh>=50cm) more clear differences can be observed; between the secondary lower montane forest and the primary lower montane forest $P<0.1$, and also between the secondary lower montane forest and the upper montane primary forest $P<0.1$. Concerning no of trees per ha, average height of crown layer and crown density no significant differences were observable for the different forest types.

3.3.3 The structural characteristics of the forest correlated with altitude

The major structural characteristics of the 12 plots from the two primary forest zones are correlated with altitude. A highly significant negative correlation can be found between biomass and altitude ($P<0.01$, figure 8). Negative correlations concerning altitude can also be found for average dbh of large trees (dbh>=50cm, $P<0.02$, figure 9) and average height of crown layer and crown density (both $P<0.05$, figure 10 and 11).

Table 1	**secondairy lower montain forest**	**primary lower montain forest**	**primary upper montane forest**
average dbh >=50cm	56,00	77,81	62,22
average dbh 20-50cm	30,30	31,78	31,95
average dbh 5-20cm	10,06	11,83	9,97
average dbh total (>=5cm)	15,26	21,90	17,67
average height crown layer trees (in m)	22,83	26,17	22,00
no of trees per ha dbh >50cm	3	34	17
no of trees per ha dbh 20-50cm	181	165	184
no of trees per ha dbh 5-20cm	578	408	510
no of trees per ha total (dbh >=5cm)	762	607	711
elevation in feet	4492	5697	6482
elevation in meters	1369	1736	1976
crown density	54%	71%	50%

Figure 1

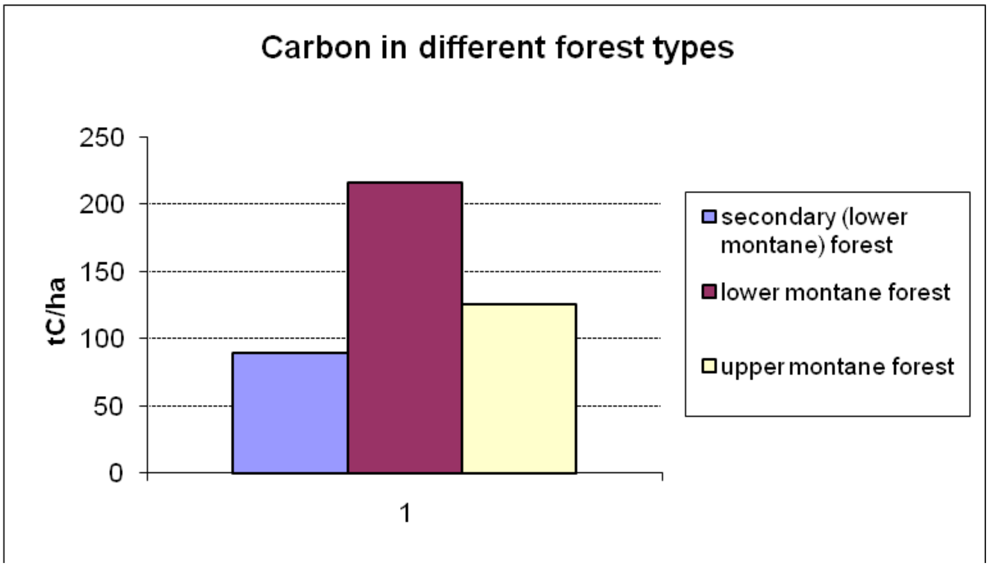


Figure 2

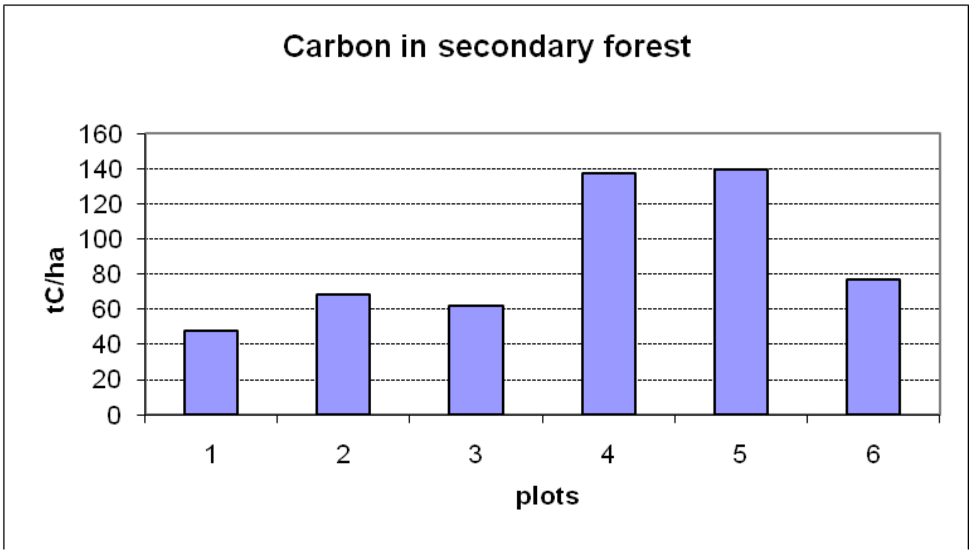


Figure 3

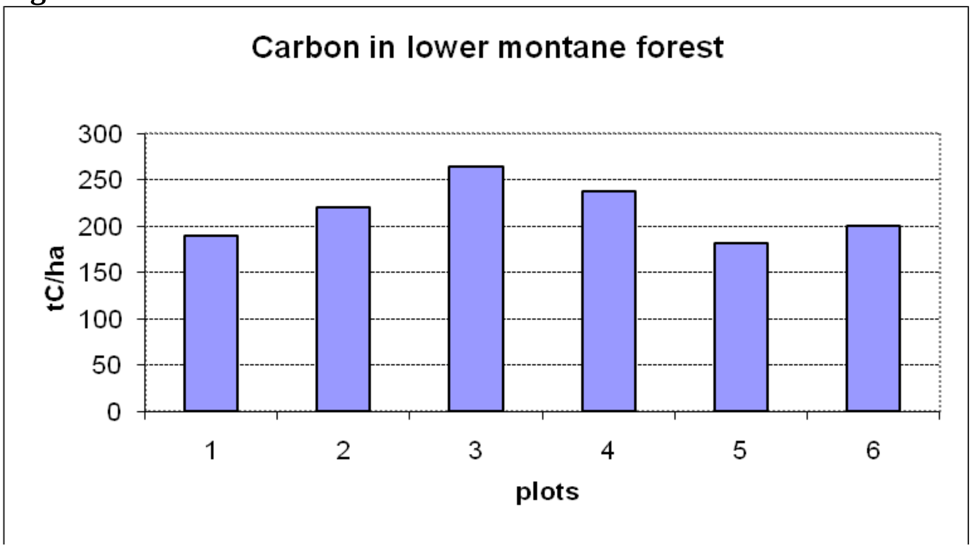


Figure 4

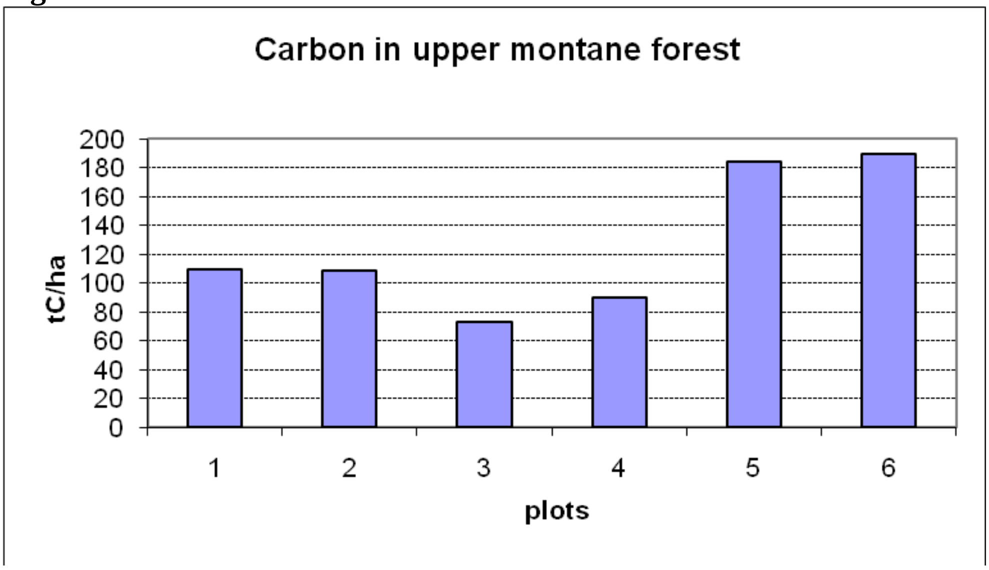


Figure 5

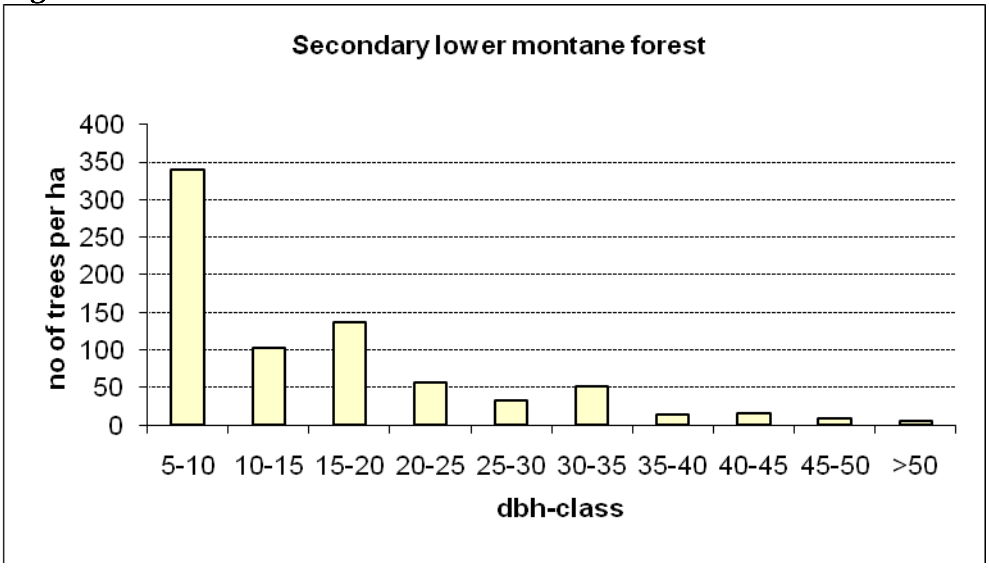


Figure 6

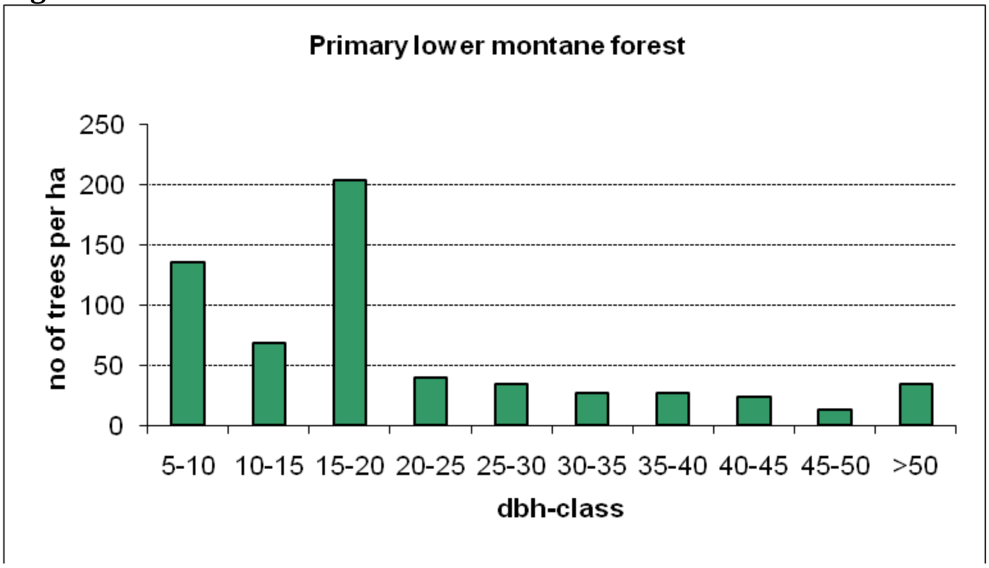


Figure 7

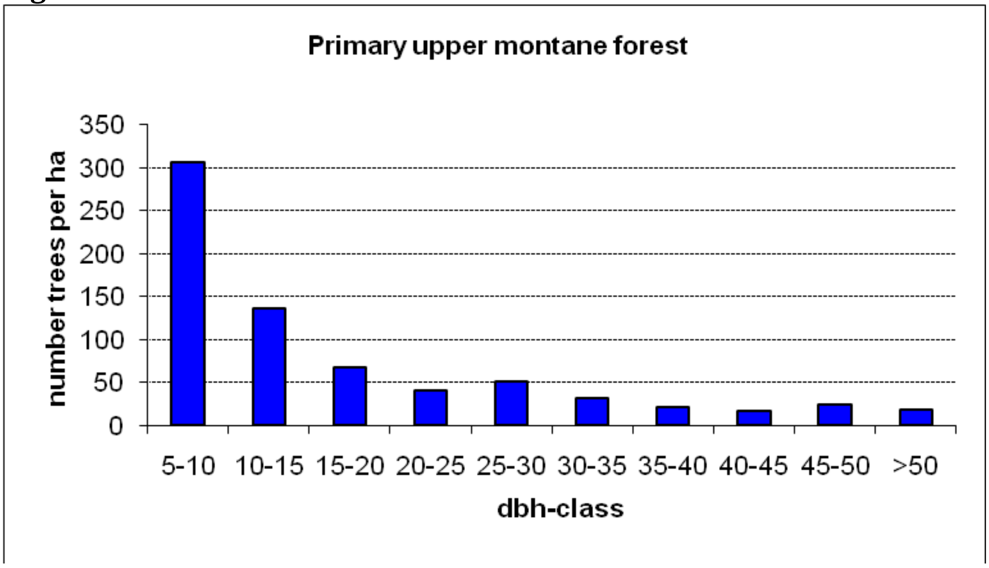


Figure 8

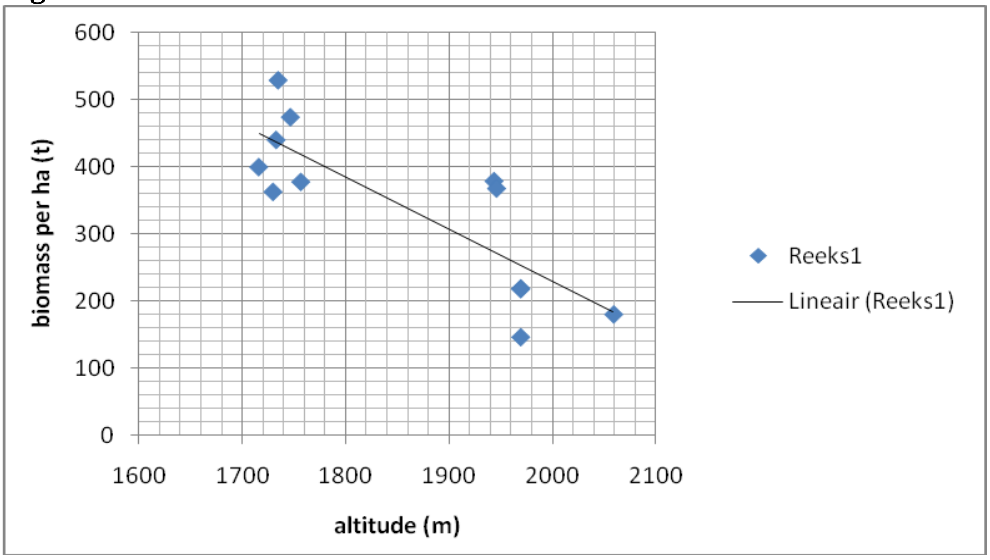


Figure 9

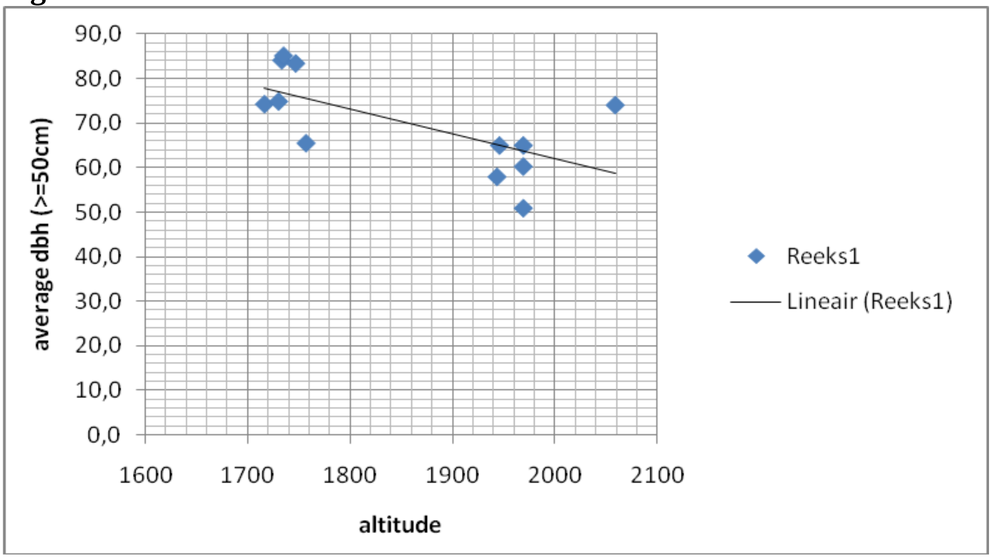


Figure 10

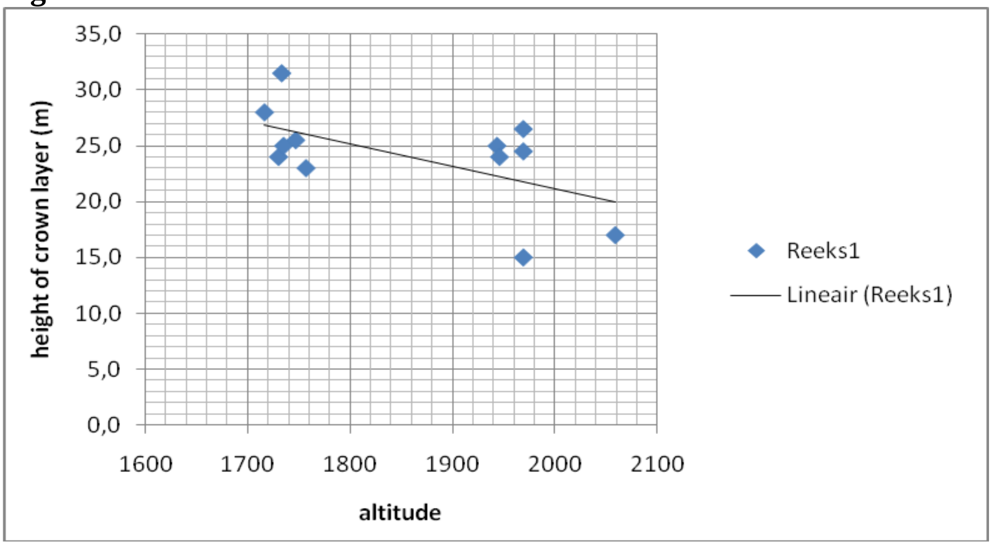
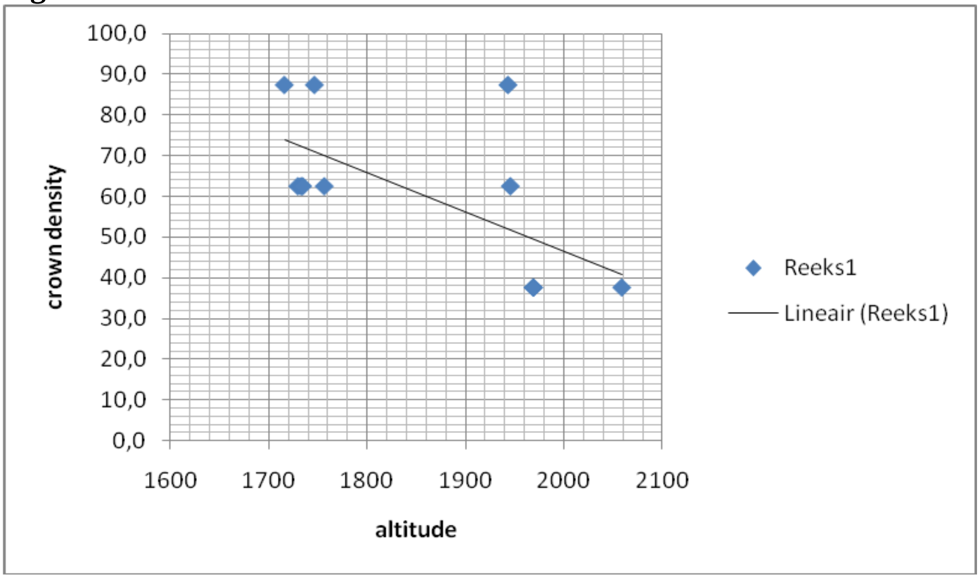


Figure 11


100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
crown density
1600
1700
1800
1900
2000
2100
altitude
Reeks1
Lineair (Reeks1)

4. Discussion

4.1 <u>About the case study results</u>

4.1.1 Review on the expected results vs. the actual results

The expected results are formulized in the hypothesis of paragraph. 3.1. This hypothesis comes directly from the research proposal which was written before in the orientation phase and long before the field measurements were obtained. It includes the following statements:

- Biomass/carbon quantities are negatively correlated with altitude
- Negative correlation between BA and altitude
- Positive correlation between stem density and altitude

No statements were made about the different forest types present and all statements include the aspect altitude. This is due to the fact that in the time of formulizing this hypotheses I didn't had yet all the information about the area including detailed information about the different forest types in the area. Much of that information was available in Quito. Therefore initially the idea was to focus on altitude correlations but when a lot of information appeared to be available in Quito I adapted the plan and shifted the emphasis on the differences between the forest types.

The unit BA (basal area) when correlated with altitude is replaced by dbh as BA is derived from dbh with dbh being the only variable. BA mainly has additional value for wood quantity calculations of plantation forests or (like will be discussed later in this report) for more precise biomass or carbon estimations. Also the unit stem density is replaced by number of trees per ha.

When the observed biomass results are correlated with altitude one can conclude that there is indeed a significantly negative correlation (paragraph 3.3.3; figure 8). In figure 8 it seems as though there are 11 plots, but in fact there are 12 plots. Plot 13 has a value of 218.5625 and plot 11 has a value of 217.468. This difference is so small that it is hardly visible on the correlation graph.

For the dbh and altitude also negative correlations were observed but less strong correlations than with altitude. As the biomass is derived completely from dbh when using biomass equations with dbh as the only input one can expect a comparable sort of correlation. As will be explained more thoroughly in paragraph 4.3.3, the unit biomass is determined by three factors: BA, height and the allometric coefficient (a correcting constant to indicate the cone-like shape of a tree). Which of these factors contribute and to what extent these factors contribute to the stronger correlation of biomass than the correlation of dbh is difficult to find out. If all factors except dbh are equal for the whole than still a stronger correlation could be expected as BA is exponentially derived from dbh. Though according to the results there is a negative correlation ($P<0.05$) between the height of trees in the canopy layer and altitude (figure 10).

For stem density or number of trees per ha, no significant correlation could be found with altitude. The hypotheses can thus only in the case of stem density be rejected.

Furthermore the results are logical and quite self-explainable, except for two points: 1) the extraordinarily high number of trees with dbh 15-20 cm in the primary lower montane forest and 2) the outlying amounts of carbon for plot 4 and 5 of the secondary forest.

4.1.2 The extraordinarily high number of trees with dbh 15-20 cm

There are basically three possible reasons to explain the high number of trees with dbh 15-20 cm in the primary lower montane forest. The first possibility is that it concerns an error due to the low number of plots per forest type, the second possibility is that at one plot an unfortunate sampling error has occurred, while the third possibility is that the forest is damaged at certain places. If the forest is damaged than the next question is whether this damage is caused by human interference or due to a natural process (storm, fire etc.).

An interesting feature in this case is whether the high number of trees is due to an outstandingly high number of trees in one plot or that more plots have a lot of trees in this dbh-class. Out of the 6 plots in the lower montane forest zone, 4 (n = 6) contained trees in this dbh-class. This indicates a structural phenomenon and thus can be concluded that certainly this is not due to damage at one single place and that a sampling error has occurred.

Other interesting aspects are altitude and the spatiality of the plots. The altitude differences between the six plots in the primary lower montane forest are limited; the elevation ranges between 1716 m. and 1757 m. Also are the plots located on quite a distance from each other but still in roughly in the same part (Northern part) of the reserve. Besides they are never located very far from the central (and only) trail or on extremely steep slopes. This indicates two aspects of the plots. First is that the difference between the several plots in terms of altitude and in terms of location is limited. Second is that the area chosen for sampling is relatively well accessible.

One has to realize that the boundaries between the forest types are determined in my research by altitude and thus there is an uncertainty included. The most logical conclusion is than that the forest is altered by human interference in this part of the reserve and therefore can not be considered entirely primary forest. This is an indication that this altitude division I used for the differentiation of the forest types is weak especially because the plots are not located near the lower boundary of primary montane forest (the used boundary of the secondary forest and primary forest is 1500 meters).

This is probably the main reason, but the situation could be more complicated. Obviously the number of plots set out (6) remains low to measure structural characteristics of a forest well. Also the plot size for small trees with dbh 5-20 cm as advised by Pearson *et al.* (2005) is with a quadrant of 7 by 7 meters rather low. This results in small total numbers of measured small trees compared to medium sized an large trees. Consequently the results and statistical analysis of the results is also less secure. Another remarkable aspect is that the same dbh-class has an unnatural high number of trees in the secondary forest but not in the upper montane forest. A tree genus which has a large share in the dbh-class 15-20 cm in the secondary and primary lower montane forest (respectively ½ and 1/3 of all trees in this dbh-class) is *Myrcianthes spp.* This genus of trees has no occurrence in the upper montane forest and belongs to the family of *Myrtaceae* which is parasitic according to Carlos the local guide.

4.1.3 The outlaying amounts of carbon for plot 4 and 5 of the secondary forest

Plot 4 and 5 have an outstandingly high carbon quantity compared to the four plots in the secondary forest. The average of plot 4 and 5 (138.5±1.6 tC/ha) is more than twice the average of the other four plots (63.9±12.3 tC/ha). There is so much difference between these two plots and the other four that they almost could be regarded as different forest types. The CV of the secondary forest is 45%. Regarded as different zones, plot 4 and 5 have a CV of only 1% and the zone of the other four plots in the secondary forest have a CV of 19%. These differences are explainable by the history of the secondary forest. According to Carlos, the guide, plot 4 and 5 are located in a part of the forest (in a humid river valley) which is not being used for over 50 years, while much of the rest of the forest is only abandoned by about 25 years. The same history of land use in the area is documented by Rhoades and Coleman (1999).

4.2 About the plot quantity equations

Pearson *et al.* (2005) gives plot quantity formulas to calculate the number of plots necessary to make a solid estimation of the carbon stocks present in a certain area. Two kinds of formulas are given: a single-stratum equation and a multi-strata equation. When an area can be divided in different vegetation zones or forest types a multi-strata equation can be used. After using the multi-strata equation only the total number of plots is determined, and therefore it is necessary to use another equation to determine the number of plots per stratum. First lets compare the single-stratum equation with the multi-strata equation. The single stratum equation is n: $= (N * s)^2 / (N^2 * E^2 / t^2 + N * s^2)$.
The multi-strata equation is: $n = (\Sigma N_h * s_h)^2 / (N^2 * E^2 / t^2 + (\Sigma N_h * s_h^2))$.
The equation to calculate the number of plots per stratum: $n_h = n * ((N_h * s_h) / (\Sigma N_h * s_h))$.
For the translation of the different symbols see under paragraph 3.2.3.
One of the most remarkable effects of this methodology is that the amount of plots that are necessary is smaller when more strata are used. In the sourcebook an example area is used only slightly smaller than Maquipucuna in both size (5000 ha) as in average carbon amount per ha (101.6 tC/ha). Following the single-stratum equation (and thus assuming that the whole area consists out of one single forest type or other vegetation zone) 29 plots would be required. To show the use of the multi-strata equation, the same example area is used, but now assuming that the area can be divided in different zones (otherwise the multi-strata equation would not be applicable). Stratum 1 (zone 1) is 3,400 ha, stratum 2 is 900 ha and stratum 3 covers 700 ha. Three different strata are assumed, just like at Maquipucuna, but with different surface areas and carbon stocks. 18 plots are necessary for this area using the multi-strata equation. Using the equation for the number of plots per stratum, the number of plots for stratum 1 is 15 plots, for stratum 2 n = 2 and for stratum 3 n = 1. This approach is awkward as more different forest types would logically mean more variation within the area and therefore more plots should be required. The only two inputs contributing to a difference between the single-stratum equation and the multi-strata equation are the size of the area divided by the plot size (N) and the standard deviation of the expected carbon amounts for that type of forest (s). Because the plot size is the same for both examples (using single stratum and multi-strata), the input N can simply be regarded as surface area. The size of the area is obviously important as the larger an area the more likely there is variation in the area and thus the more plots are needed. The standard deviation is also important as it indicates the expected variation in the carbon amounts typical for that type of forest.
Though there is a problem in the way they use the standard deviation for all equations. To start they seem to forget that standard deviation in itself does not say anything about the

variation within an area. Standard deviation is a figure related to the mean. If the mean is high than the standard deviation is also likely to be high, but this high standard deviation doesn't mean to say that there is a lot of variation within the area. To make this more clear lets use an example. A dune environment typically has a much landscape variation with grassy areas and bushes. When compared to a forest environment the dunes tend to have not much carbon per ha but much spatial variation. The dune area for instance has $\mu = 40$ tC/ha and $\sigma = 15$, while the forest has $\mu = 80$ tC/ha and $\sigma = 15$. When using only the standard deviation one would assume that if both areas are of comparable size that the same number of plots are necessary for both areas.

Instead of using the standard deviation the CV (σ/μ) gives more logical results. In the example above using the CV would give for the three strata respectively the ratio 10:2:1 instead of 15:2:1.

4.3 About measuring carbon quantities

4.3.1 A closer look at the used biomass/carbon equations

Two equations were used to estimate the amounts of carbon: a formula of Brown for tropical moist environments and a formula of Winrock which was used only for small or medium sized (up to 40 cm dbh) Cecropia trees. When plotted as a graph the intersection point of the two formulas is 10.3309, 43.9145. So for a tree with a dbh of about 10 cm the biomass is approximately 43 kg. The Cecropia formula gives lower (biomass) results after the intersection point than Brown's formula. For a dbh value of 0, this formula gives a result of 12.764 kg and so the formula is not very appropriate for very small trees. This is not the only problem with this formula, also that it is quite complicated: $y = 12.764 + 0.2588 * x^{2.0515}$. Slightly alterated and much more simplistic it gives rounded of in whole kilograms the same results for trees with 10-40 cm dbh: $y = 12.8 + 0.26 * x^{2.05}$.

4.3.2The use of wood density and dbh to estimate biomass quantities vs. the use of dbh only

The amount of carbon present was compared in the results of the case to an expected amount of 110 t/ha. The measured carbon stocks in maquipucuna turned out to be way higher than expected. This might partly be due to formula constraints, and especially to the fact that wood density is not included in the used carbon stock formulas of Brown and Winrock but only dbh. The following formula by Chave *et al.* (2008) uses species specific wood density and dbh to calculate biomass (and therefore carbon quantities): $\text{Biomass} = \text{wood density} * \exp(-1.499+2.148*\ln(dbh) + 0.207*(\ln(dbh))^2-0.0281*(\ln(dbh))^3)$. This is probably a better formula as it includes species specific variety.

There are two reasons why it was impossible to use this formula of Chave for the carbon stocks of Maquipucuna: not all the measured trees could be identified on species or even genera and of the identified trees only about a limited number was there sufficient information available concerning wood density. Information on wood density was available for nine genera that were measured in maquipucuna (Chave *et al.* 2009). Four of those genera had a large number of trees within the plots set out in maquipucuna and consequently there was the possibility of comparing the outcomes of the two used (dbh/biomass-)equations with Chave's formula. Comparing Brown's equation for moist tropical forest with Chave's it is noticeable that for all the four genera the carbon stocks were estimated lower by Chave's than by Brown's. The genera used were *Nectandra, Ficus, Otoba* and *Cecropia.* The results of the calculated carbon stocks by Chave's formula were respectively 98.43%, 72.66%, 75.11% and 62.22% of the results of Brown's formula. The other used dbh-formula by Winrock is only applicable for small Cecropia trees. Chave's results are 125.04% of Winrock's and are therefore higher. But because of the scarcity of small Cecropia trees in the overall measured tree database, one can conclude that if wood density would be included that the carbon stock estimates are likely to drop significantly. In other words, the current carbon stock estimates using only dbh-related biomass equations are probably too high.

4.3.3 Determining the allometric coefficient; biomass quantities by the volume function

The methods to calculate carbon quantities are all based on calculations of biomass. The equations used in the results by Brown and Winrock have dbh as only input. The equation of Chave described in the previous paragraph uses dbh and wood density. These equations however are not very exact as height is not included. The very basic way of calculating biomass quantities is also the most complete and therefore the most exact: biomass = volume * wood density. In this formula height is included as the volume of a tree = BA (pi * (½ dbh)^2) * height * a. In this equation the symbol a stands for allometric coefficient. The allometric coefficient is included as a tree has roughly the shape of a cone. Without this input the results assume a tree in the form of a cylinder.

This allometric coefficient differs per tree and the average differs per species and genus. Because of the enormous diversity of tree species and rarity of these species (many are local endemics) in Maquipucuna it is hard to make find allometric coefficients from literature sources and thus to implement the volume formula. Though what is interesting to investigate is to determine the allometric coefficient of the trees in Maquipucuna by using the biomass results of Chave's equation. In this way Chave's equation is tested by the volume function which is more exact. The following mathematics are involved:

V = BA * H * a

V = volume (dm^3)

*BA = basal area (dm^2): pi * (dbh/20)^2; dbh (cm) is divided by 20 to make r (dm)*

H = height (dm)

a = allometric coefficient; usually a number between 0.5 and 1

Biomass results using Chave *et al.* (2008) and wood density from the global wood density data base (Chave *et al.* 2009).

ρ_s/ρ_g *= wood density (species specific or genus specific) in g/cm^3 is kg/dm^3*

B_s/B_g *= biomass (species specific or genus specific) in kg*

Now the volume of the trees according to Chave *et al.* (2008) and Chave *et al.* (2009) can be determined by the following equation:

V = B / ρ because dm^3 = kg / (kg/dm^3)

The allometric coefficient using Chave and Chave can be determined by the following equation:

a = V / (BA * H) where the inputs BA and H are from the measurements of this research.

The method described above of calculating the allometric coefficient per tree is only applicable for trees with the following characteristics: a) dbh and height is measured in this research and b) species or genus specific wood density is available at Chave *et al.* (2009). Of not all trees the height was measured and of only a couple genera and one species (of which the height is measured) the wood density is available. Consequently this method is appropriate for 38 trees from 5 different genera and for 3 trees from the only species where the wood density is known (*Psidium guajava*). Of one genus, *Inga densiflora*, there is only one tree available and this is therefore considered too few for statistical analysis.

The four genera of which the allometric coefficient is determined are *Nectandra (n=9), Ficus (n=4), Otoba (n=14) and Cecropia (n=10).* The average allometric coefficient of these genera is respectively 0.81(±0.21), 1.09(±0.2), 1.01(±0.12) and 0.93(±0.23). These results would assume that the trees from the latter three genera have a more or less cylindrical shape, which was not the case in reality. The most logical explanation is that Chave's formula is designed primarily for straight ("normally shaped") trees with large heights like for instance canopy trees in lowland rainforest, fast growing pioneers or plantation trees. This is confirmed by the results of the *Nectandra* trees in the lowland montane forest. Of the 9 *Nectandra* trees, 6 come from the secondary forest where they are the dominant canopy tree (all belonging to the species *Nectandra acutifolia*). The average allometric coefficient for these 6 trees is 0.68(±0.08). The other 3 *Nectandra* trees (all three *Nectandra membranaceae*) come from the primary lower montane forest and their average allometric coefficient is 1.07(±0.12).

The three *Psidium guajava* trees have an average allometric coefficient of 1.49(±0.11). This extraordinary high allometric coefficient can be explained by the shape of these trees. These trees are parasitic according to Carlos, the guide, and overgrow other trees as could be seen at Maquipucuna. Because of this characteristic of the tree they have often very weird shapes with very thick trunks near the ground and a quite sinuous shape more to the top. They are also never very high.

Two main conclusions can be drawn. The first conclusion is that the applicability of the biomass equations that don't use height and thus volume like those of Chave *et al.* (2008) is limited for natural forests where there are trees with sinuous shapes or other not straight cone-like shapes.

The second conclusion is that the estimated carbon quantities in this research are probably much too high. Some biomass equations like the one of Chave use dbh and wood density as inputs and can therefore be considered more advanced and thus better than the dbh only equations of Brown (1997), Winrock in Pearson *et al.* (2005) and numerous others. As indicated in the previous paragraph the carbon amounts using Chave are already significantly lower than the results from this research (using Brown and Winrock). The high allometric coefficients of the trees investigated above indicate an even lower amount of carbon when using the volume/biomass method than when using the biomass equation of Chave.

4.3.4 The future of carbon quantity measuring

The attention for the element with atomic number 6 has been on an impressive rise in the last couple of years. The relation with the global warming phenomenon is clear. But now also economically this element has been starting to become interesting. And when an economic interest is found, power comes around and the element gets a new life. It has become clear that recently quick measurements are more and more preferred over precise measurements.

The most simple method in terms of mathematics are the most precise but demand the most intensive labor when doing field measurements. Labor is becoming more and more expensive also in developing countries so it is understandable that these labor intensive methods are replaced by cheaper methods that demand more complex mathematics. For the volume based approach one needs to know the wood density and measure the height of the tree and the diameter at breast height, for the biomass equations one doesn't need to measure the height anymore and even the wood density is for some biomass equations (like those used in the case study) not required. Wood density databases are labor intensive to create but are very durable and thus on the long term not very labor intensive.
Recently a new technique in measuring carbon quantities is developing rapidly; remote sensing. The most common form of remote sensing is satellite imagery. The techniques of remote sensing by satellites are already very rapid and advancing steadily in accuracy. Asner (2009) developed a very accurate technique, an integrated satellite air-borne approach that supports high-resolution carbon stock assessment and monitoring in tropical forest regions. There are some large advantages of using remote sensing techniques. It is not restricted to forests, but virtually all biotopes can be monitored. It is obviously also not very labor intensive. From a REDD perspective, the development of rapid assessing techniques brings more forests and other natural areas to possible protection. In paragraph 2.3.1 it was mentioned that there is a potential supply of 7.2 billion AD credits. This is a potential supply and to make a readily available supply on the short term rapid assessing techniques like remote sensing could probably really make a difference. On the other hand the potential supply still outruns the demand of approximately 400 million as in 2008. A central question is will this rapid sensing also benefit local people with a limited financial capacity and not the "right" social network. In general knowledge about these rapid sensing techniques and especially those concerning remote sensing involves people with power (money, the "right" sort of social network). Rapid access to carbon quantity information gives rapid and easy access to a lot of (for now still potential) money. With this in mind, if REDD is launched on the market without any + mechanism involved the consequences are difficult to overseen and like Michael Richards (2008) formulized it, the poor are likely to lose out again.

<u>4.4 The potential monetary value of the carbon stocks of Maquipucuna</u>

The potential value of the carbon stocks depends much on the price per ton of carbon. This price fluctuates over time and also per source. According to the website of eco-bussiness the price of UN-certified credits fluctuates usually between 10 and 15 euro's per credit (ton of carbon) in October 2010. According to Barclays capital, an average of about 15 euro's per credit was quoted in August 2010. They forecast that by 2020 it will be between 40 and 70 euros per credit. Barclays estimates for European Union allowance prices in the second half of 2010 a rise of 3.3% to 15.50 euro's per credit. SPOT EUA, a leading European spot exchange, quotes the price of carbon also about 15 euro's per credit as in the beginning of June 2010.
It is very difficult to take a single price per carbon to estimate the potential value of the stocks of Maquipucuna because of the fluctuation of the carbon price and the fact that it is difficult to predict what the future development will be like. If we take 15 euro's per credit, an average amount given by different sources for 2010, the total value of the carbon stocks of

Maquipucuna can be estimated at 15,042,722 euros based on the aboveground and belowground tree carbon results from this research paper (1,002,848 tons of carbon). For the aboveground tree carbon amounts alone (852,812.3 tons) it concerns 12,792,185 euros. This amount is significant but one has to take at least three things in mind. Firstly, the carbon estimates are probably too high as is explained in paragraph 4.3.2 and 4.3.3. Secondly this is a potential supply of AD credits and as the potential supply of AD credits globally outruns by far the demand, a big challenge will be to sell those credits. Thirdly a lot of questions remain on how and when to launce a program like REDD or REDD+. It takes another study to figure out all the possible revenue options concerning REDD for Maquipucuna as it is beyond the scope of this study and my knowledge about economics.
However, the information in paragraph 2.3.4 might help together with the following source:

- A global guide concerning the economics of carbon is “Barclays capital global carbon index guide, May 2008” and can be found online at *www.ipathetn.com/pdf/grn-**index-guide**.pdf*

Picture 2: Inside the secondary forest

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