# CARBON STOCK IN
# AN APENNINE BEECH FOREST

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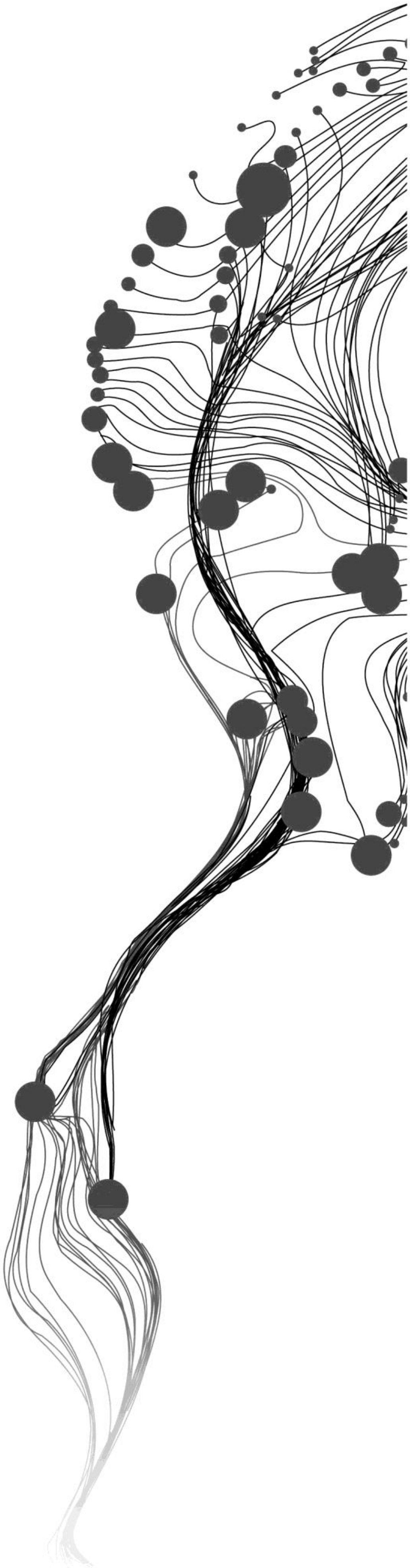

# CARBON STOCK IN AN APENNINE BEECH FOREST

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*To my lovely parents…*

# ABSTRACT

Italy has undertaken to reduce emissions of greenhouse gases by 6.5% over the periods of 2008-2012 and 20 % by 2020 below the 1990 level. In this context, modelling and estimating Above Ground Biomass (AGB) and carbon stock (CS-AGB) of a beech forests in the Pizzalto Mountain in the Majella National Park was performed using the GIS and remote sensing techniques in combination with field data. Slope angle, slope gradient, altitude, seasonal incoming solar radiation, length of growing season (LGS), MODIS NDVI and EVI values, soil type and forest management types were used in the modelling. Two styles of management, old-growth forest and young forest, were defined based on field observations. The average AGB and CS-AGB were 247 and 123 tons.ha$^{-1}$ respectively comparable to values found in beech forests in the Apennines and Europe. Results showed that in the linear regression model, LGS and management are the significant variables providing most of the variation in carbon stock in the AGB. Results indicate that modelling CS-AGB is an executable idea and can help the park authority by presenting environmental information to manage the forest areas as sinks of carbon in respect to international conventions such as United Nations Framework Convention on Climate Change (UFCCC) and related commitments (Kyoto protocol).


Keywords: beech forest, carbon stock, aboveground biomass (AGB), length of growing season (LGS), MODIS NDVI &EVI.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AGB | Above Ground Biomass |
| AP | Aerial Photograph |
| CS-AGB | Carbon Stock in Above Ground Biomass |
| DBH | Diameter at Breast Height |
| DEM | Digital Elevation Model |
| EVI | Enhanced Vegetation Index |
| GHG | Green House Gases |
| KP | Kyoto Protocol |
| LGS | Length of Growing Season |
| LULUCF | Land Use, Land Use Change and Forestry sector |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MODIS VI | Moderate Resolution Imaging Spectroradiometer Vegetation Index |
| NDVI | Normalized Difference Vegetation Index |
| RMSE | Root Mean Square Error |
| RS | Remote Sensing |
| UNFCCC | United Nations Framework Convention for Climate Change |
| USGS | United States Geological Survey |
| VIF | Variance Inflation Factor |

# 1. INTRODUCTION

## 1.1. Carbon stock,climate change and related international conventions and commitments

Forests act as an important part of the global carbon cycle (Dixon et al., 1994) as they store a large part of the total terrestrial organic carbon in both trees and soils (Brown et al., 1999). During photosynthesis forest absorbs carbon dioxide ($CO_2$) and stores it as plant biomass, which provides a natural stock of carbon. Forests also exchange $CO_2$ with the atmosphere. Although forest ecosystems cover only 30% of the land area they contain 81% of the Earth's terrestrial carbon biomass (Dupouey et al., 1999 cited in Lecointe et al., 2005). The World's forests store 289 gigatonnes (Gt) of carbon in their biomass (FAO, 2010). However, carbon stock in forests biomass have decreased by 0.5 (Gt) per year over the period of 2005 – 2010.

The carbon stocks held in the Earth's forests are an important part of the widespread discussion and debate about climate change. Climate change is caused by higher concentration of greenhouse gases in the atmosphere. The four principal greenhouse gases are water vapour, carbon dioxide, methane and ozone. These gases absorb heat, leading to increase in average temperature and acts as a partial blanket for the long wave radiation coming from the earth surface. This blanketing is known as the natural greenhouse effect (Houghton, 2005). As one of the significant greenhouse gases, carbon dioxide is a major component of the carbon cycle.

Currently forest carbon sinks are an important aspect of international greenhouse gas (GHG) policy under the United Nations Framework Convention for Climate Change (UNFCCC, 1992) and its Kyoto Protocol. These two international agreements deal with the issue of reducing anthropogenic greenhouse gas (GHG) emissions into the atmosphere. Based on these two agreements, countries are required to estimate and report the carbon emissions and removals by their forests. The aim of these conventions is 'to stabilize atmospheric greenhouse gases concentration at the level that would prevent dangerous anthropogenic interference with the climate system' (UNFCCC, 1998). This climate convention establishes a general framework for intergovernmental efforts to tackle the challenges caused by climate change (UNFCCC, 1998). Based on UNFCCC - which entered into force from 1994 - the governments gather and share information about national policies and best practices related to greenhouse gas emissions. The governments set specific obligations to reduce emissions based on this convention (UNFCCC, 1998). Therefore, UNFCCC attempt to invite countries to develop actions and strategies to conserve and improve natural ecosystems with the aim of promote carbon sequestration.

The Kyoto Protocol, as a part of the UNFCCC was adopted on 11 December 1997 and entered into force on 16 February 2005. The Kyoto Protocol proposes to deal with global warming by setting target levels for nations to reduce greenhouse gas emissions worldwide. According to this protocol, emissions can be reduced either by reducing fossil fuel consumption or by increasing net carbon sequestration. In the First Commitment Period (2008-2012) countries that ratified this Protocol undertook to reduce the level of emissions of greenhouse gases by 5.2% below the 1990 emission level. The European Union as a whole is committed to reduce emissions by 8% during the period of 2008-2012 below the 1990 emission levels. For the European Union to reach to these targets in 1998 a political agreement (Burden Sharing Agreement) was obtained to divide the burden of reaching 8% reduction emissions unequally amongst Union members. According to this agreement Italy has a commitment to reduce emissions by 6.5% over the period of 2008-2012. However, since there has been an increase in total emissions to about 13% during 1990 to 2003 the goal will be more challenging (Ciccarese et al., 2006). Furthermore, recently in United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) 15

(Copenhagen) in 2009, European Union members (including Italy) have committed to reduce greenhouse gases emission by 20 percent below 1990 emission level by 2020.
Forests can reduce climate change and its consequences by storing carbon in different section of them including above ground biomass, underground biomass, forest understory and soil. For this reason, one of the noticeable aspects of the Kyoto Protocol is the possibility of compensating part of the emission reduction in the "Land Use, Land Use Change and Forestry" sector (LULUCF) (Article 3 Kyoto Protocol). Two articles of the Kyoto Protocol in particular refer to the forest sector to calculate the effects of land management on the national carbon balance since 1990. Article 3.3 of the Kyoto Protocol refers to afforestation, reforestation and deforestation and about how countries (including Italy) must report emissions from these activates. In addition article 3.4 refers to additional activities in LULUCF sector that are forest management, cropland management, restoration of vegetation, and grazing land management. In this context, Italy has chosen forest management as an additional plan to develop through the forestry absorption of 16.2 Mt $CO_2$ per year corresponding to 15% of the total reduction (Valle et al, 2009). Changes in forests management practices can improve the capability of forests for carbon sequestration (Jandl et al., 2007).

## 1.2. Inventories of forest carbon

Due to forest variation, mainly in terms of their structure and type, the rate of carbon sequestration varies per hectare. Physical size, species, growth rate and age of trees are data used to assess the quantity of carbon storage in forest areas. Different factors may affect carbon stock in forest ecosystems of which some factors such as climatic factors, pest or disease out-breaks change over time. Therefore sustainable management, planting and rehabilitation of forests can conserve and increase forest carbon stocks (FAO, 2010).
Different approaches have been applied for providing estimations and inventories of forest carbon. Remote sensing is one of the useful and applicable methods for better estimation of trends and changes in forest carbon over time (Andersson et al., 2009). Potential capability for systematic observation at scale ranging from local to global and the provision of data archives extending back over several decades have made remote sensing as an accepted tool for estimation of forest carbon stock (Rosenqvist et al., 2003). In addition compared to the methods relying entirely on field observations, which are costly for assessing large spatial extents, remote sensing is often represented as a considerable cost savings method (Brown 1999; Foody, 2003). Therefore remote sensing can play major role in establishment of the national carbon stock baseline datasets and assessment of change in stocks. Such datasets are implicit requirements for establishing a reliable estimation of carbon stock which is required in order to meet the commitments of Kyoto Protocol (Rosenqvist et al., 2003). Methodologies for estimating carbon storage will increasingly incorporate remote sensing (RS) technologies to provide global, regional and national coverage and to update them rapidly after occurrences of disturbance (Brown et al., 2008). However using remote sensing techniques in forest ecosystems does not replace the need for precise field data. Modelling is a method usually used to make projections of future carbon stocks by using the data acquired in a defined period of time. Models could be used to project changes in carbon stocks in forests and plantations biomass (Ravindranath & Ostwald, 2008). Allometric equations or regression models are one of the models for estimating the biomass or volume of above-ground tree components (kg/tree) based on DBH and height data. The amount and spatial distribution of aboveground forest biomass (AGB) are required inputs for forest carbon budgets and ecosystem productivity models (Soenen et al., 2010). Allometric equations are developed by establishing statistical correlation coefficients between the measured forests attributes (DBH and height) and the measurements from the sample of individual tree species, and sometimes for representative samples of trees found in certain forest types (Keller et al., 2001; Gibbs et al., 2007). The suitability of a regression model is explained by the standard error of the regression coefficients and the

coefficient of determination ($R^2$), normally given along with the equation. Using allometric equations is a common and cost-effective method to estimate tree species biomass present in a forest or plantation (Ravindranath & Ostwald, 2008). Therefore combining remote sensing with field data collection and allometric modelling is the most useful method for estimating carbon stock (Andersson et al., 2009).

### 1.3. Beech forest distribution in Europe and Italy

The European beech (*Fagus sylvatica* L.*)* is a deciduous tree belonging to the *Fagaceae* family and is the main tree species in central European forest (Dittmar et al., 2003). Beech shows the largest geographical distribution and widest niche breadth among the European forests canopy trees (Leuschner et al., 2006) Beech is the most abundant broad-leaved forest tree and due to height, physiological tolerance range and competitiveness it is the main tree species in most of central Europe (Dittmar et al., 2003). Beech forest covers 19.5 million hectares of Europe's area (Huet et al., 2004). Its natural ranges extends in Europe is from southern Sweden (with a few isolated locations in southern Norway) to central Italy, France, northern Portugal and central Spain to central Greece, where it intergrades with *Fagus orientalis* (figure 1-1).

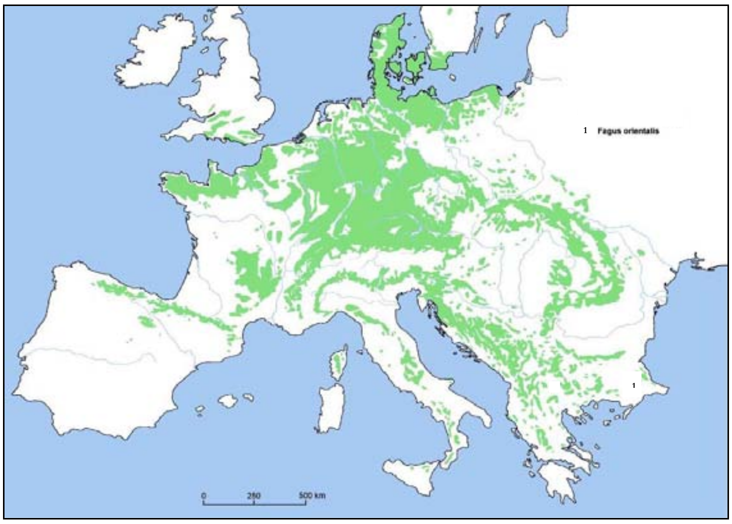



Figure 1-1: Natural distribution of beech forest in Europe
(Source: Meier, 2007)

In the southern part of its range around the Mediterranean, beech mainly grows in mountain forests, at the elevation of 600-1800 m (Aude, 1998). In Europe beech usually forms pure forests with little or no underground species and they remind one of the Gothic Cathedrals' period (Sass, 1995). It is a straight large broad-leaved deciduous tree that can reach heights of 35 to 42 meters (Peters, 1997). Beech forests are accessible to the population for recreation, and they provide near-natural habitats for many plants and animals. Although humidity should be constant for beech, appropriate temperature and climate conditions vary. Beech prefers well drained and not too acidic soils. It tolerates rigorous winter cold, but is sensitive to late spring frost which causes seed production to fail and seedlings to perish (Watt, 1925).This species grows slowly and it is hard to transplant. Although is somewhat tolerant of heat and dry soil, it prefers sunny locations, moist and light soils. The beech forests as one of broad-leaved deciduous plant species in Italy (at $41^0 52'$ latitude) generally indicate high carbon sequestration rate (6.0 tC. $ha^{-1}.yr^{-1}$) the same as tropical forest (Valentini et al., 2000).

In Italy, beech forests are distributed over several phytoclimatic regions from the Alps down to the southern regions of Campania, Basilicata, Calabria and Sicily in Italy (figure 1-2).

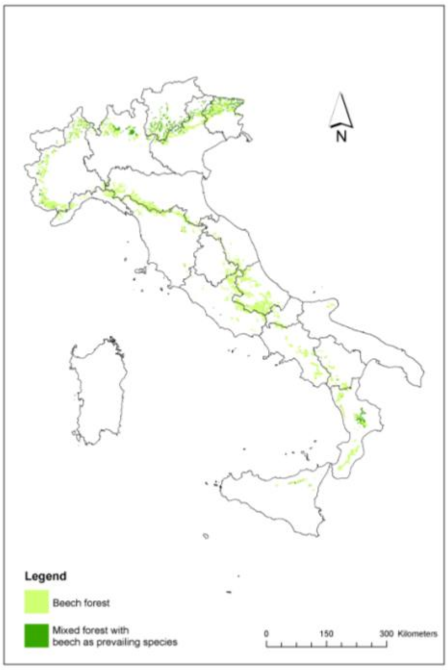



Figure 1-2: Distribution of beech forest in Italy
(Source: Nocentini, 2009)

In the Apennines beech extends over a 1400- 1500 m altitudinal interval, from hilly lowlands (300-400 m) to high elevation forests (1800-2000). According to the National Forest Inventory (cited in Nocentini 2009) the total area covered with beech in Italy is around 1 m ha which represent 9.4 % of the country's total forest area. The Abruzzo region in which the Majella National Park is located, accounts for about 12% of the total beech forest area in Italy (Nocentini, 2009).

## 1.4. Factors influencing the biomass of trees in forest ecosystems

Topography is one of the most important environmental gradients that affect biomass, stem size, stand density and spatial heterogeneity of stems (Clark et al., 2000; Katagiri & Tsutsumi, 1975; Tanner, 1980a, 1980b). It was found that due to interaction between solar radiation and soil properties (e.g. soil moisture, soil nutrient), slope and aspect has significant relationship with biomass in forest areas (Hicks et al, 1984; Tajchman et al, 1983). South-facing slopes which receive the most insolation (compare to north-facing slopes, which receive the least amount of insolation) typically have hot and dry soil surface (Sariyildiz et al, 2005).
Forest management activities can improve carbon sequestration and increase carbon stock (Bravo et al., 2008). Janssens et al. (1999) emphasised the role of forest management techniques on forest growth and biomass. Soil provides a variety of essential prerequisites for trees such as moisture supply and nutrient supply (Kimmins, 1987). Diverse soil resources in Europe reflect a combination of geology, climate, topography and land uses developed over thousands of years (EEA, 2010).

## 1.5. Lengths of growing season and it influence on carbon sequestration

Vegetation phenology refers to seasonal cycle stages of plant (Menzel & Fabian, 1999). A shift in the seasonal phenological cycle of vegetation is owing to the effect of global warming (Karlsen et al., 2007). Changes in vegetation phenology affect the carbon cycle through photosynthesis. The length of growing season (LGS) is a period between the green-up and the end of the growing season. The LGS strongly controls the functions of an ecosystem (White et al., 1999). Carbon dioxide increases in winter and decreases in summer mostly due to the seasonal growth of vegetation in the Northern Hemisphere (Keeling et al., 1996). Goulden et al. (1996) found that small changes in the timing of spring growth are related to annual carbon exchange. One of the effects of climate change is alteration in the LGS which influence the primary productivity of plants (MacCarty, 2001). Myneni et al. (1997) proved that enhanced photosynthetic activity of terrestrial vegetation observed from satellite data during 1981 and 1991, suggested a raise in plant growth related to lengthening of the growing season. Therefore, continual increase in the length of growing season may cause long term increase in carbon storage (White et al., 1999). In recent studies LGS has become a major concern for climate change and carbon-balance estimation in ecosystems (Chen et al., 2000).

## 1.6. Estimating lengths of growing season using remote sensing

Several studies found that vegetation indices are useful for estimating and modelling forest biomass (Gholz et al., 1997; Dong et al., 2003). Satellite remote-sensing methods have provided the capability for estimating LGS on different scales (MacCabe et al., 2006; Baghzouz et al., 2010). Duration of vegetation activity is mainly based on image time series of vegetation indices from optical data sensors. Data from the AVHRR, SPOT Vegetation and MODIS sensors are mainly used to assess and monitor the duration of growing season. NDVI and EVI are two vegetation indices that can be derived from aforementioned sensors to measure LGS. Vegetation indices from satellite sensors are desirable to compare with data observed at ground level (de Beurs & Henebry, 2010). The Normalized Difference Vegetation Index (NDVI) is one of the most well known vegetation index used for estimating green vegetation biomass by enhancing chlorophyll reflectance differences in red and near-infrared reflectance ratio. It provides an estimation of vegetation greenness and present meaningful comparisons of seasonal and inter-annual changes in vegetation growth and activity. NDVI has shown consistent correlation with vegetation biomass and dynamics in different ecosystem. In addition NDVI strongly declines the influence of varying illumination conditions and shadowing effects caused by variations in solar and viewing angle (Kimes et al., 1984). However, there are several limitations such as sensitivity to atmospheric conditions and soil background and a tendency to be saturated at high biomass levels. The enhanced vegetation index (EVI) was designed as a modified NDVI to enhance the green vegetation signal in areas with high biomass and minimize the atmosphere influences and soil background effects (Huete et al., 2002). However, it does not take the topographic effect into consideration. NDVI is chlorophyll sensitive which responds mostly to red reflectance, while the EVI is more near-infrared sensitive and responsive to canopy structure (e.g., LAI, canopy type and architecture).The topographic effect could be reduce or remove when vegetation indices such as NDVI are stated as band ratios. However, EVI includes a constant term, the soil adjustment factor L, in its equation to calculate vegetation greenness which make EVI cannot be ignored topographic effect easily as on NDVI (Matsushita et al., 2007).

## 1.7. Problem statement and Justification

The European beech represents one of the monospecific stands and dominant forest communities in the Italian Apennines including the Majella National Park (Piovesan et al., 2005). Beech is a broad-leaved deciduous tree having the ability to shed off in leaves to avoid adverse climate conditions and create its own ecosystem. The European beech was found to be very sensitive indicator, reflecting clearly the signals of environmental influences (Dittmar et al., 2003). It is considered as the most promising species for biological monitoring in European temperate forests (Piovesan et al., 2005). According to van Gils et al. (2008) beech forest in the Majella National Park in the period of 1975 - 2003 expanded 1.2 % per year and spatially the rate of expansion differed substantially from 1987 to 2003 which is almost doubled. The expansion and the change in spatial extent of beech forest over time have got several social and environmental significances. For instance it has positive impacts on carbon sequestration rate and consequently further carbon stock which is one of the potential strategies and services to mitigate the climate change, will be acquired. Therefore, it is useful to estimate the amount of carbon stock for the Majella National Park in order to have comprehensive database for more effective management of the areas in respect of climate change.

This study will present the possibility of using the remote sensing techniques in combination with field data collection to estimate carbon stock in AGB. Italy has undertaken to reduce emissions of greenhouse gases equivalent to several tonnes of carbon dioxide by 6.5% over the periods of 2008-2012 and 20 % by 2020 below 1990 level in respect of two agreements derived from United Nations Framework Convention on Climate Change and Kyoto protocol. In addition to this point, Italy has selected forest management as an extra activity and plans to develop it through the absorption of 16.2 Mt $Co_2$ per year or equal to 15% of the total committed reduction (Lumicisi et al., 2007). Modelling the carbon stock or in other words, understanding the performance of carbon sequestration in aboveground biomass of beech forests, as a new study in this area can be supposed as a progressive action to be bound by the international commitments to reduce the emission of greenhouse gases. Results of this study can provide some important criteria and indicators for designing forest management plan and monitoring schemes for the Majella National Park authority.

## 1.8. General research objective

The overall aim of this research is to assess the potential of beech forests at the Pizzalto Mountain in the Apennines beech belt for carbon sequestration.

### 1.8.1. Specific research objectives

1. To estimate above ground biomass and its relevant carbon stock using field measurement and an allometric equation.
2. To model and predict the carbon stock in above ground biomass of beech forest using related explanatory variables including slope angle, altitude, slope aspect, seasonal solar radiation, the length of the growing season (LGS), NDVI values, EVI values , soil type and management system.

## 1.9. Research Questions

1. What is the amount of the above ground biomass and carbon stock in beech forest estimated by allometric equation and field measurement?

2. Which explanatory variables significantly predict the variation of above ground biomass and consequently carbon stock in beech forest?

### 1.10. Research Hypotheses

1. Altitude has significant positive effect on the carbon storage in beech forest.
2. Length of growing season has significant positive effect on the carbon storage in beech forest.
3. Solar radiation has positive significant impact on carbon storage in beech forest.
4. Slope aspect has significant impact on carbon storage in beech forest
5. Slope angle has significant impact on carbon storage in beech forest.
6. The carbon stock of beech forest can show better relationship with the EVI values than NDVI values.
7. Different styles of forest management lead to different amount of carbon storage in beech forest.
8. Different soil types leads to different amount of carbon storage in beech forest.

# 2. MATERIAL AND METHODS

## 2.1. Study area

This study was undertaken in the Pizzalto Mountain which is located between two mountains Rotella (on the west) and Porrara (on the east) in the Majella National Park which covers 740 km² of Central-Apennines, Italy (in Latitude 41⁰ 52' N and Longitude 13⁰ 14' E) shown in figure 2-1. Majella National Park is one of the largest protected areas in Europe. It hosts 45% of wildlife and 36% of plant species in Italy. *Fagaceae* family has the highest frequency (17%) among tree species in this park (Majella National Park, 2010). Pizzalto Mountain's area is about 41 km² and it is one of the sixty mountains in the southern part of the park with the summit of 1966 m (Majella National Park, 2010). This area was chosen because of its large extensions of beech forest.

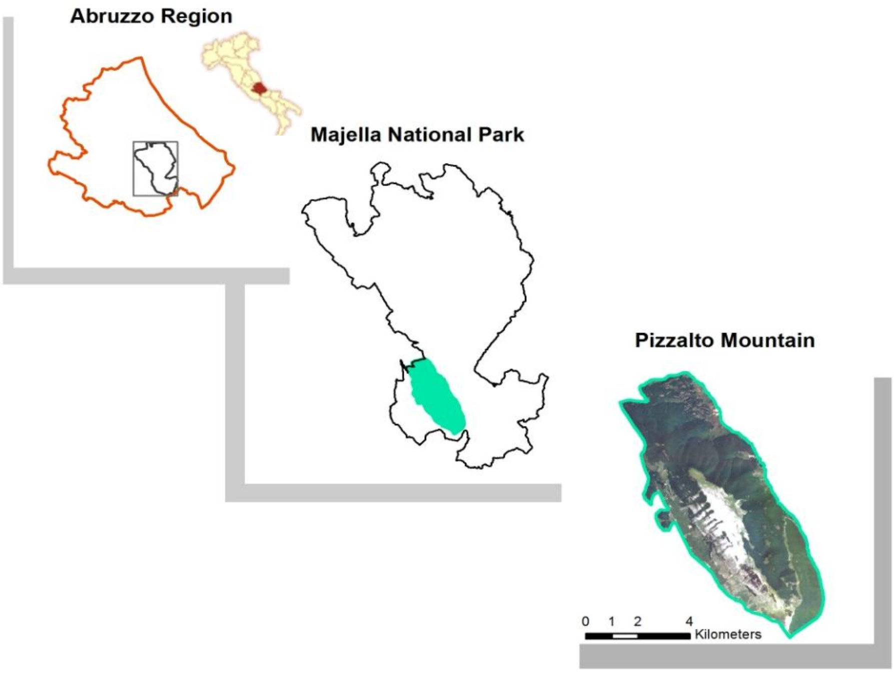



Figure 2-1: Location of the study area

### 2.1.1. Terrain

In this study, three maps of topographic factors including elevation map, slope gradient map and aspect map were produced by the Aster Digital Elevation Model (2008) with 30 meters resolution of the Pizzalto Mountain. These data obtained from United States Geographical Survey (USGS) geo data source through ITC. From these maps we can obtain the following details of the topography of the terrain:

- The elevation range of the Pizzalto Mountain is from 1000 to 2000 meter and most of the area is at elevation range between 1200 -1400 meters which is shown in figure 2-2.

- According to figure 2-3, it is clear that more than half of the study area is occupied by the slope gradient ranges of 20 to 50 degree and the flat landscape form only 7% of the area.

- The aspect of Pizzalto Mountain is visualized in the figure 2-4.

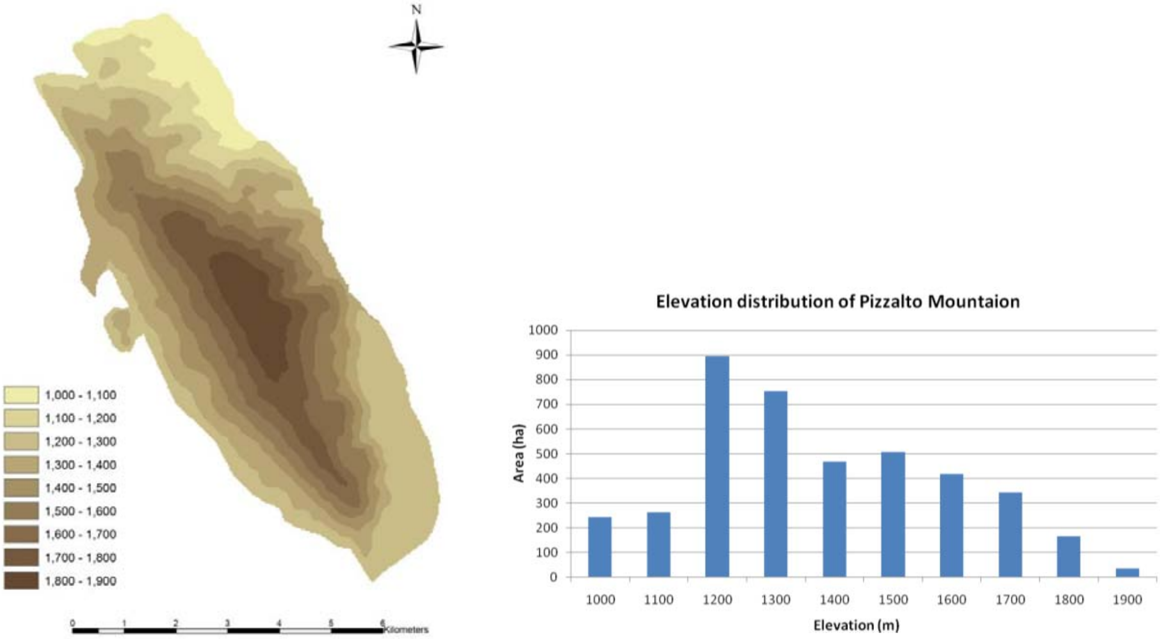



Figure 2-2: Elevation (m) map of the Pizzalto Mountain

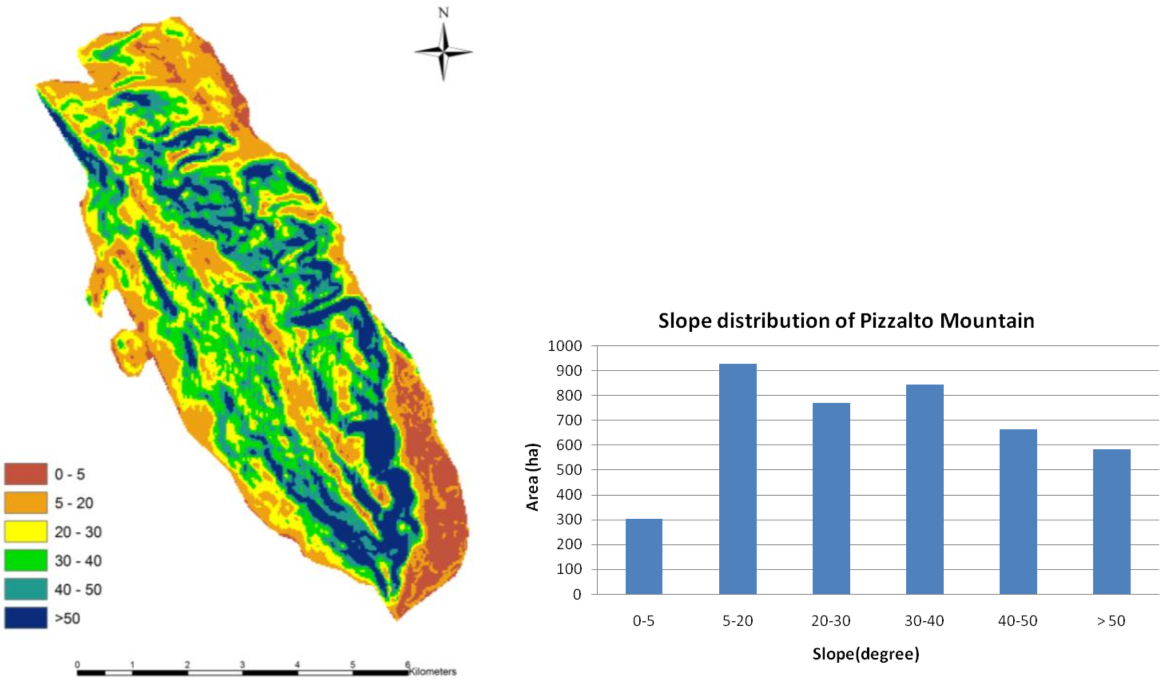



Figure 2-3: Slope (degree) map of the Pizzalto Mountain

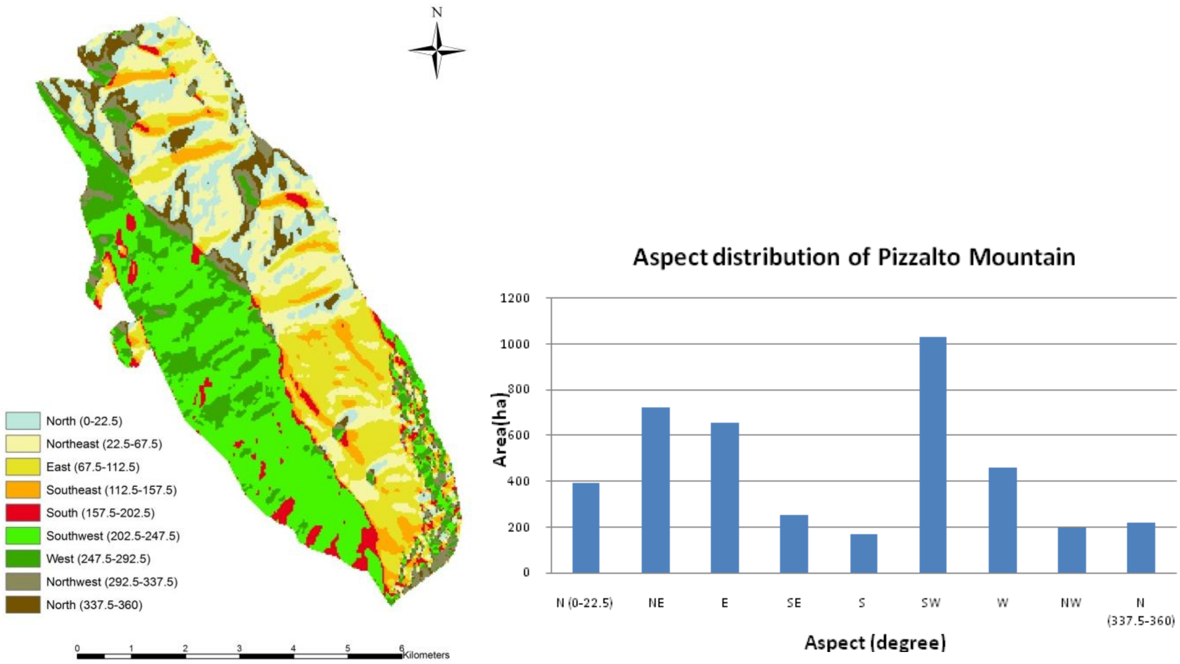



Figure 2-4: Aspect (degree) map of the Pizzalto Mountain

### 2.1.2. Climate

The climate data from 1960 to 1994 were collected from Pescocostanzo meteo-station (41° 53' 0'' N, 14° 4' 0'' E, elevation 1395 meters) which is the nearest station to Pizzalto Mountain in Majella National Park. Figure 2-5 shows climate diagram compiled by Walter and Lieth (1957-1966) which has been used by geographers, phytosociologists, agronomists, and foresters. Climate diagram displays the monthly averages of the temperature and the precipitation starting from January to December for the northern hemisphere. According to figure 2-5, it clear that the Pizzalto Mountain has moderate and dry summers, but cool and moist winters. The average annual rainfall and temperature for the period of 1960 to 1994 were 920 mm and 8.11 °C respectively.

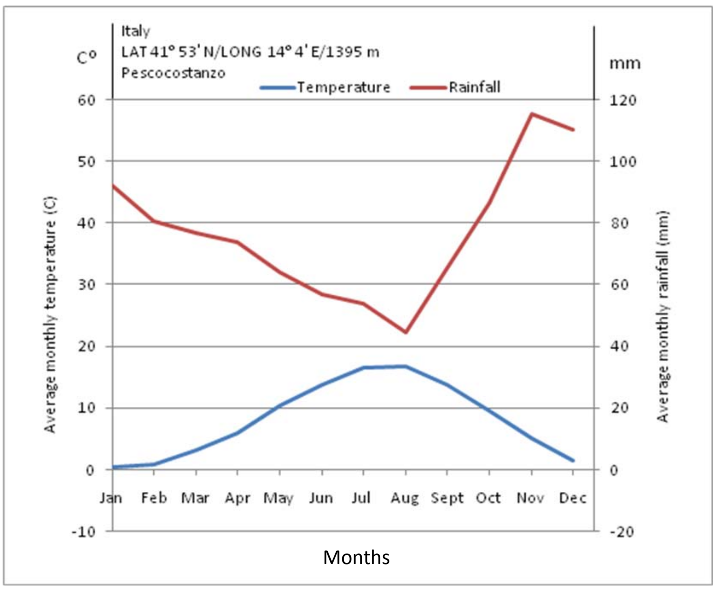



Figure 2-5: Climate diagram of the Pizzalto Mountain

### 2.1.3. Vegetation

Figure 2-6 shows that the European beech is the dominant species in the Pizzalto Mountain. In this area is beech distribution begins from elevation 1000 m where abandoned cropland, pastures and hay meadows are located to 1900 meters. From the elevation of 1700 to 2000 m covered with subalpine dwarf juniper of open grassland. In addition in the south-western part of the Pizzalto Mountain there is the black pine *(Pinus nigra* J.*)* plantation at the elevation range of 1600 to 1700 m. Beech forest represent approximately 60 percent of the total area of the Pizzalto Mountain.

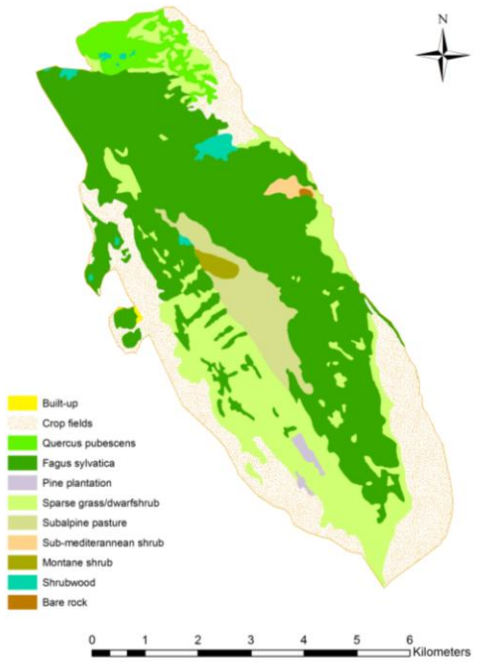



Figure 2-6: Vegetation map of the Pizzalto Mountain
(Source: Majella National Park)

### 2.1.4. Management zoning

According to the management system of Majella National Park, the beech forest of the Pizzalto Mountain is located in zone A and surrounding area is located in zone B and C (figure 2-6).

In zone A, the primary objective is to ensure the highest possible rates of reproduction and survival of animal species of special interest. Therefore, protection of fauna will be implemented in full form by certain restrictive measures comprising;

a) Occasional grazing allowed to residents;
b) Prohibition of forestry operations or forestry exploitation;
c) Prohibition of construction;
d) Denial of dogs presence;

For zone B the purpose is to increase the capacity of wildlife through active measures for environmental improvement. Restrictive measures also will be provided in this zone comprising :

a) Prohibition of construction;
b) Requirements for forestry activities;
c) Requirements for agricultural activities;

In zone C, the overall objective is to stimulate the development in socioeconomic status consistent with the presence of priority species. Some restrictive and essential measures will be applied comprising;

a) Prohibition of materials to create fences that prevent the free movement of fauna;
b) Prohibition of dogs without a leash, with the exception of the dogs used by shepherds;
c) Prohibition of the use of herbicides and desiccant and the gradual conversion to sustainable farming techniques.
It should be mentioned that in the study area located in zone A, some cutting and logging operation was observed during the field work (see Appendix 1).


Figure 2-7: Management zones at the Pizzalto Mountain based on Majella National Park stratification

## 2.2. Research Materials

### 2.2.1. Aerial photographs and satellite imagery

Table 2-1 provides the materials used for this study. The colour aerial photographs (AP) of the study area in 2007 (Majella National Park, 2007) were used to determine the area of beech forest and to locate the sample plots in them with the help of Arc GIS 9.3.
In order to understand the relation of vegetation indices with aboveground biomass MODIS vegetation indices (VI) product were used. These multi-temporal images were obtained from the NASA Terra satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor (table 2-1). It has global coverage and each tile is a 1200 km² scene with a spatial resolution of 250 meters as gridded level3 product in the Sinusoidal projection. This product consists of 12 layers including NDVI, EVI, a pixel reliability layer and input reflectance data (USGS, 2008). Two vegetation indices - NDVI and EVI - are routinely produced from MODIS VI sensor at 16 days intervals of 250-m, 500-m and 1-km resolutions. In this study, the NDVI and EVI values from 250-m MODIS VI (MOD13Q1) for the time interval of January to December for five years (2005 to 2009) have been used. To represent each pixel over the 16-day composite period only the higher quality, cloud free filtered data from all the retained filtered data select as best observation on a per pixel basis are used (Huete et al., 2002). The NDVI and EVI products are computed from atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols, and cloud shadows. The pixel reliability layer was used to check for pixel quality.

In order to determine the length of growing season of the beech forest in the study area, the multi-temporal images were used. Several studies in Europe indicate changes in growing season duration particularly in the last few decades (Linderholm, 2006). Zhou et al. (2001) found that growing season had increased between 40 0 N and 70 0 N by 18 days caused by earlier spring and late autumn. Due to lack of time and to be more consistent for better understanding the pattern of the changes in NDVI and EVI, the data of five recent years have been investigated.

### 2.2.2. Digital Elevation Model

An Aster Digital Elevation Model (DEM) with 30 m resolution of the Pizzalto Mountain was introduced to this study. The DEM was applied for:

- Derive the surface maps of topographical predictors elevation, slope aspect and slope angle.
- Acquire the potential direct solar radiation map of the growing season which was calculated using the method of Kumar et al. (1997).

Table 2-1: List of the materials used for the study

| Material | Resolution (scale) | Source | Format | Data type |
|---|---|---|---|---|
| DEM (2008) | 30 m | ASTER | Raster | Continuous |
| Soil map | 1:25,000 | Majella NP | Vector | Categorical |
| Colour AP (2007) | 0.5 m | Majella NP | Raster | Image |
| MODIS VI (MOD13Q1) | 250 m | USGS | Raster | Continuous |

## 2.3. Research Methods

The research workflow and steps is shown in the figure 2-8 below:

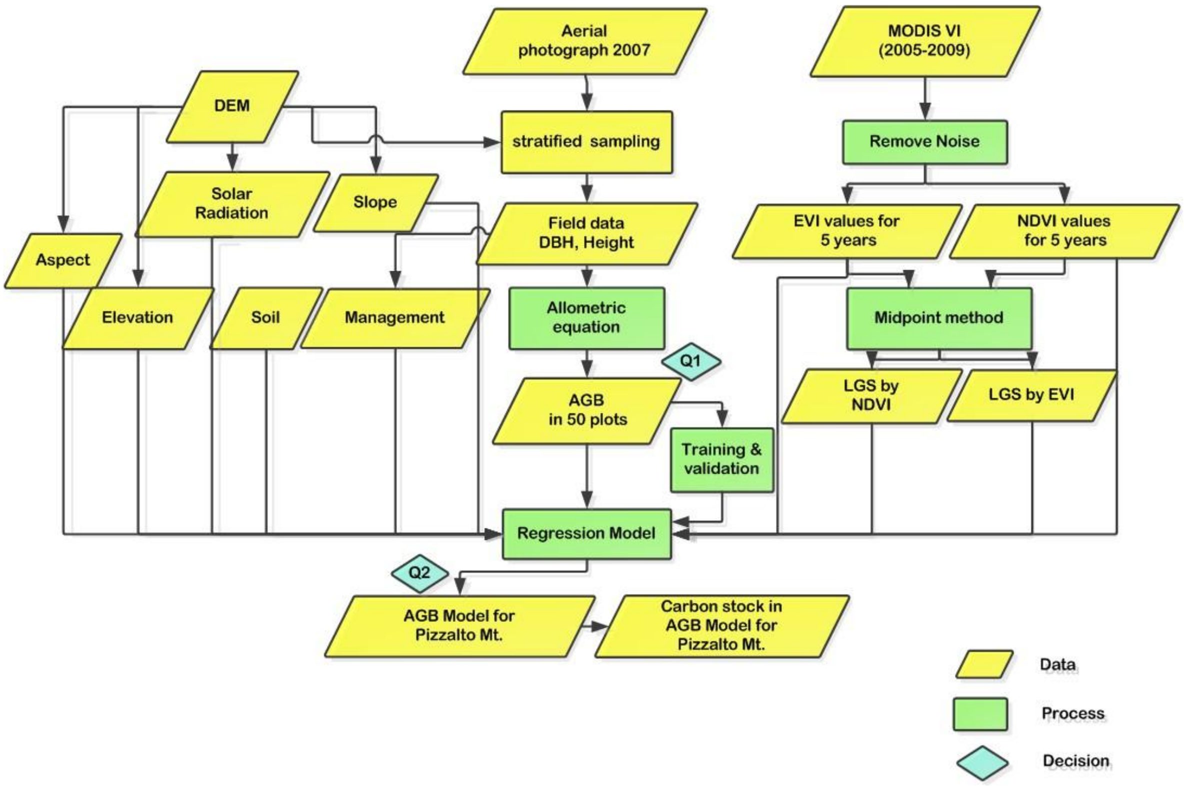



Figure 2-8: Research workflow and steps

### 2.3.1. Field survey

In the mountainous landscapes it is time consuming to access the certain random or systematic points. Therefore, the systematic sampling strategy which was designed before the start of the field work could not be implemented. In order to obtain maximum data from fieldwork, the stratified sampling method by elevation segments was applied. The strata in this study define as every 100 m elevation, starting from 1100 to 1900 m elevation. Due to the time limit in field work and few available tracks for walking inside beech forest 12 transects were selected. To establish the sample plots, different locations (north, east and west) in the Pizzalto Mountain were considered. Generally, in the south-west part of Pizzalto Mountain, which is almost rocky area, there are small patches of the beech along with sparse grass and black pine plantation. Therefore compare to other parts of Pizzalto Mountain there are few plots in south-west part. By utilizing the GPS and also using different tracks for walking inside and locate each transect (which is shown in figure 2-9) along tracks and select plots in each strata along and by buffering 100 m both sides of transect. Fifty plots were investigated in the beech forest during the period 7th September to 1st October, 2010. The coordinates of the field sampling plots are shown in Appendix 2. To eliminate any influences of edge effects on the forest biomass, all the plots were located in the beech forest at least 200 m away from the nearest road.

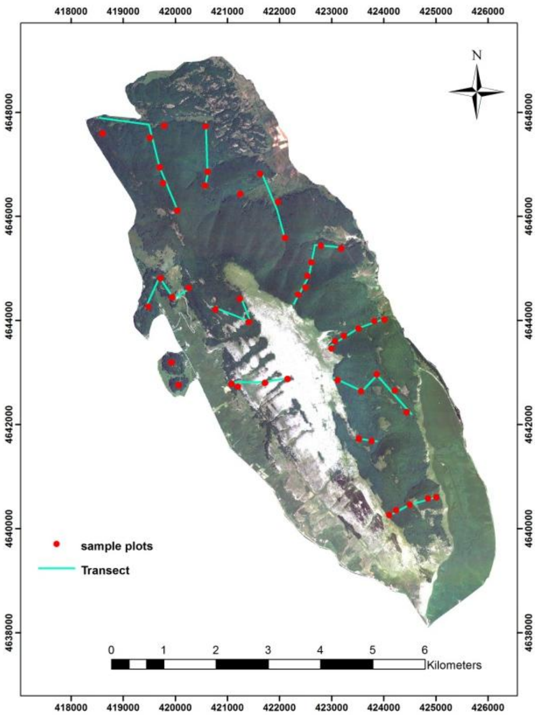



Figure 2-9: Distribution of sample plots (50 records) and transects

A circular plot on a slope always makes a problem due to ellipse shape of the (horizontally projected) circle on the slope which is smaller than the area of a circle. To set down the circle shape plots on slope it is necessary to find a new circle diameter on the slope which corresponds to the area of the ellipse on the slope (Husch et al., 2003). Thus, a slope correction table should be used (de Gier, 1989). This correction table will give the correct radius that should be used regarding the slope. After measuring the slope by using clinometers, the corresponding radius can be derived from the slope correction table (Appendix 3).
Two management systems were distinguished in the area based on two main forest types. In the first type which is called "old-growth forest" in this research, the mature beech trees were protected from logging

which is currently used for recreation purpose (see Appendix 1). This type of management is provided in the "Bosco di Sant Antonio" reserve. This reserve was 550 ha established in 1985. The elevation of this area extends from 1290 to 1420 m surrounded by Pizzalto Mountain and Rotella Mountain. The reserve is managed by the Municipality of Pescocostanzo and now is included in the Majella National Park. The criteria used for considering plots as this kind of management is 50% or more of stem-diameter at breast height of trees in plots were above 40 cm (Peters, 1997).
The second management type, called "young forest", has current or historical signs of logging or coppicing (see Appendix 1). The criteria used for taking into consideration plots as this kind of management is that over 50% stem-diameter of beech trees less than 40 cm (Peters, 1997).
For each sampling plot, the following procedure are considered and marked in data sheet collection (Appendix 4):

- Global Positioning System was applied to acquire the spatial location in the standard project system: WGS_1984_UTM_Zone_33N.
- Clinometer was used to measure slope degrees.
- The slope correction table which is used for finding the correct radius (or diameter), therefore, it can derive the boundary of plots function of the slope.
- At 1.3 meter above ground, for each standing beech tree, the DBH in the case of more than 5 cm were recorded by using Calliper.
- The beech height was measured using a Haga Clinometer.
- The management system was classified *a posteriori* into either old-growth forest or young forest.

#### 2.3.2. Selection of allometric equations for estimation of aboveground biomass

The allometric equation can explain the relationship between stem volume as well as biomass of several tree components and the diameter at breast height (DBH) and/or the tree height. In Europe, DBH is measured at 1.3 m above-ground. Allometric equations to estimate the AGB of European tree species have been developed by the countries participating in the EU Action "Contribution of forests and forestry to mitigate greenhouse effects" (Zianis et al. 2005). The relevant allometric equations for beech (*Fagus sylvatica*) are presented in table 2-2.

Table 2-2: Allometric equations for AGB of beech

| Country | Allometric equation | parameters | | | $R^2$ | n |
|---|---|---|---|---|---|---|
| | | a | b | c | | |
| Austria | $a+b\cdot\ln(D^*)+c\cdot\ln(H^*)$ | –2.872 | 2.095 | 0.678 | 0.99 | 42 |
| Italy | $a+b\cdot D^2\cdot H+c\cdot D^2$ | –1.0798 | 0.018017 | 0.25888 | 0.95 | 30 |
| Czech Republic | $a\cdot D^b$ | 0.453 | 2.139 | - | 0.97 | 20 |
| Spain | $a\cdot D^b$ | 0.1315 | 2.4321 | - | 0.98 | 7 |

(*D=DBH, H*=Height)

The published equation for Italy is the most obvious choice to apply to this study. However, before applying any allometric equation, it needs to be assessed for its quality. It is possible that a geographically appropriate equation is of doubtful quality and that another equation of good and known quality is available from a comparable geographical region. Therefore, the equation been developed for Italy was compared with equations in beech have been developed for Austria, the Czech Republic and Spain. The first two countries are close to Italy, but lie to the north. However, in terms of latitude, Spain is more similar to Italy than Austria and the Czech Republic. The results of this comparison are shown in figure 2-10 and table 2-2.

From figure (2-10), it can inferred that the allometric equation which has been developed for Italy is similar to those of Austria and Spain. Therefore**,** based on this confirmation, the Italian allometric equation for AGB of beech was used in this study. This equation was developed to cover a range of DBH from 9.5 cm to 54 cm and a height range from 9 m to 23 m.

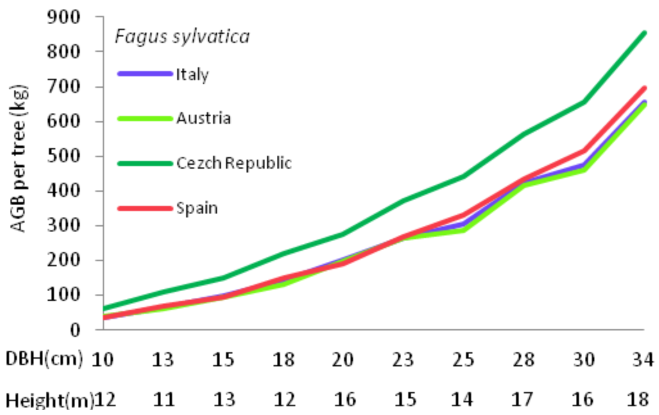



Figure 2-10: Compare allometric equations based on this study's dataset

#### 2.3.3. Predictor variables for modelling aboveground biomass and carbon stock

The environmental variables used for the modelling are: altitude, slope aspect, slope angle, solar radiation and soil type. In addition, two vegetation indices, NDVI and EVI were used. These two indices also used for determining the LGS in the study area. The elevation, the slope gradient and the slope aspect maps were extracted from DEM (table 2-3). The soil type map of Majella National Park was converted to raster based on 30 m resolution and after that the raster format subset to the study area by using of ArcGIS9.3. The potential direct solar radiation of the different seasons was calculated from the DEM, using the method developed by Kumar et al. (1997), which integrates topographic shading effects. The values which was being estimated every 30 minutes were added together to find the value for each season in ArcGIS 9.3. In addition, aforementioned forest management types were considered.

Table 2-3: List of predictor variables

| No | Variables | Data type | Spatial resolution | Range | Source of data |
|---|---|---|---|---|---|
| 1 | Elevation | continuous | 30 m | 1100 – 1900 m | DEM |
| 2 | Slope | continuous | 30 m | 0 – 90 degree | DEM |
| 3 | Aspect | continuous | 30 m | 0 - 360 degree | DEM |
| 4 | Solar radiation | continuous | 30 m | 34 – 80 $Kwh.m^2$ | DEM |
| 5 | MODIS average NDVI (per 16-day period) | continuous | 250 m | 0 -1 | USGS |
| 6 | MODIS average EVI (per 16-day period) | continuous | 250 m | 0 – 1 | USGS |
| 7 | LGS | continuous | 250 m | 140 – 280 days | NDVI/EVI |
| 8 | Forest Management | categorical | n.a | old-growth vs. young | Field work |

#### 2.3.4. The NDVI and EVI noise reduction process

The NDVI and EVI MODIS products have been produced with corrections for the effect of atmospheric gases absorption and aerosol scattering (Vermote et al., 2002). However, still some noises are remained in the datasets that need to be smoothed before being used mostly due to cloud cover and snow (Pettorelli et al., 2005). Therefore, TIMESAT version 2.3 (Jonsson and Eklundh , 2004) which is a software program for analysing time-series of satellite sensor data was employed to correct that effect and reconstruct a clean time series data. TIMESAT package iteratively fits mathematical functions to smooth noisy time-series satellite data. TIMESAT uses an adaptive filtering method, Savitzky-Golay, for this procedure. An adaptive Savitzky-Golay filter uses local polynomial functions for smoothing data and removing the effect of noises. We followed Chen et al. (2004) to set the important input parameters of this tool (i.e. cut-off for spikes and the size of the window). The cut-off for spikes was set to 1.5 and the window size was set to 1,2,3,4 and 5 for five fitted steps respectively.

#### 2.3.5. Calculating the spectral vegetation indices values

The images from MOD13Q1 data collection 5, tile h25v6, covering the study area during period 2005 to 2010 were used. In the first step the images were reprojected to UTM geographic coordinates WGS84 and resampled by nearest neighbour method using the MODIS Reproject Tool version 4 (USGS, 2008).The outputs of this process are NDVI and EVI images that reprojected and resampled in geotiff format.
Using the pixels quality layer of MODIS data for each year it could be understood if sample plots were covered by snow or clouds and therefore, EVI and NDVI values for those pixels need to be filtered and corrected. In order to smooth and filter NDVI and EVI values TIMESAT 2.3 software were used.
The output of this process is entered in TIMESAT 2.3 to smooth the curve and to filter time series of NDVI and EVI values. To obtain values of NDVI and EVI in original range (0 to +1) MODIS stretch function was used to change values from bytes to float values. Then sample plots were overlaid on NDVI and EVI that was processed to extract values at the location of each plot. Finally all NDVI and EVI 16-day composites during 5 years in fifty plots were smoothed and filtered.

#### 2.3.6. Determination of the growing season

NDVI and EVI 16-day composite images were used to estimate the length of growing season (LGS).The LGS or duration of greenness is number of days derived by subtracting the time of start of green-up from the time of the end of growing season from temporal NDVI or EVI profile (figure 2-11).

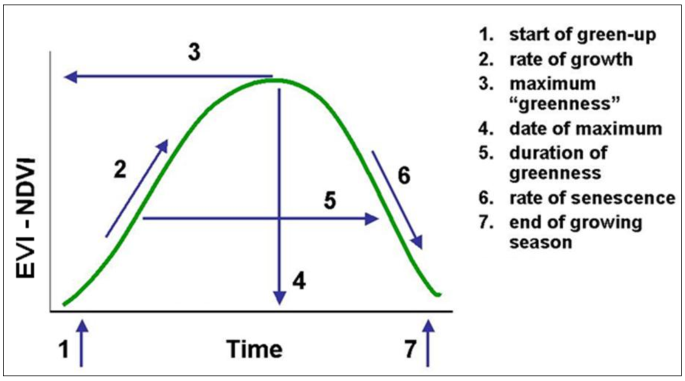



Figure 2-11: The length of growing season profile by NDVI and EVI
(Source: Reed et al., 1994)

The growing season was determined for the fifty beech forest plots from MODIS NDVI and EVI using the method from White et al. (2002). This method has been shown to relate well to deciduous broadleaves forests in New England (USA) and France (White et al., 2002). According to this method, first for each pixel the annual cloud-free minimum and maximum NDVI were selected and the midpoint between them was calculated. This is repeated for every year from 2005 to 2009. Subsequently, the average of the midpoint values per year was calculated. The average midpoint ($NDVI_{halfmax}$) is used as a threshold to identify the beginning of growing season and end of that for each pixel. The midpoint threshold represents the most rapid increase in greenness and shows that a certain pixel has attained 50% of its maximum greenness (de Beurs et al., 2010). The same method was applied to determine the length of growing season by using EVI values (Schwartz et al., 2002). The advantage of this method is that average minimum and maximum NDVI and EVI values in long term usually are not affected by outliers (de Beurs et al., 2010).

#### 2.3.7. Effects of topography on MODIS NDVI and EVI

MODIS EVI is more sensitive to topographic conditions due to the soil adjustment factor "L" compared to MODIS NDVI (Matsushita et al., 2007). The homogeneous land surface of the study area provides an ideal opportunity to distinguish variations in the length of growing season based on the EVI due to the topography factors. In order to evaluate this, in each elevation strata (every 100 meter) 10 points were randomly selected by using colour aerial photographs (2007) in beech forest (Majella National Park, 2007). Then following the method of White et al. (2002) growing season duration were calculated for each point by using NDVI and EVI indices. In addition, to evaluate the effect of slope on the length of growing season based on both NDVI and EVI, 10 points were randomly selected in each slope class, and then, growing season duration were computed using the same method as elevation.

#### 2.3.8. Multicollinearity analysis between explanatory variables

In regression applications when variables are highly correlated, it causes a problem for parameter estimation and therefore the contribution of each variable is not reliable. In this situation the highly correlated variables explain the same variance in the dependent variable. To deal with this problem, it is checked if the predictors are collinear. The Variance Inflation Factor (VIF) is one of indicators that measures how much the variance of an estimated regression coefficient is increased because of collinearity. At VIF variables which greater than 10 are excluded from further analysis (Marquardt, 1970).

#### 2.3.9. Modelling aboveground biomass and carbon stock

In order to find out which variables can predict the aboveground biomass in the beech forest, an appropriate statistical technique should be used. Regression analysis is one of common ways to acquire AGB estimation model (Lu, 2006). Regression analysis develops mathematical relationships among variables so that enable to predict the value of one variable (response) using one or more independent explanatory variables (predictors). In this study the simple linear regression and multiple linear regression models were applied. A simple linear regression model is the basis of all regression analyses. Simple linear regression is statistical method that uses straight line relationship between a response variable Y and a single explanatory variable X.
The multiple linear regression studies relationship between the response variable Y depends on a set of explanatory variables and is defined as:

$$Y= b_0 + b_1x_1 + b_2x_2 + b_3x_3 +...+ b_kx_k \quad (2\text{-}1)$$

Where $b_0$ is intercept and $b_1$, $b_2$, and $b_3$ are regression coefficients for $x_1$, $x_2$, and $x_3$ respectively.
Stepwise procedure was used to select the more relevant predictors and the final model selection. Stepwise multiple linear regression uses different approaches (e.g. Forward selection, Backward selection) to carry out an automatic procedure of variable selection. Backward procedure was use in this study that began with the full model of all introduced variables as well as its possible interactions. This technique uses Akaike Information Criterion (AIC) test to measure the goodness of fit of the statistical model at each step. The R software version 2.1.11 (R Development Core Team, 2010) was used in this study to develop the regression models. The importance of a variable was evaluated by the size of the p-value for dropping the variable from the model. After the variable with the smallest absolute highest p-value was dropped, the model was refitted. Again, the variable with the highest p-value was dropped. The process ended when getting highest R square by removing variables (Devore & Peck, 1993).

Carbon storage is estimated as 50% of dry weight biomass in trees (Brown, 1997). Thus, carbon stock can be calculated according to aboveground biomass value using conversion factor (0.5) in the developed model (IPCC, 2003).

### 2.3.10. Model Validation

To assess the accuracy of the prediction two statistical methods were applied. The first one was Pearson r, was used to check the correlation between the observed AGB and the predicted values. The Root Mean Squared Error (RMSE) was used, as the second method, to examine the deviation between observed data and predicted data and it was used as a measure of model performance. Equation 2-2 shows the formula of RMSE.

$$RMSE = \sqrt{\sum(Xn - xn)^2 / n} \tag{2-2}$$

Where n is the number of observations, Xn and xn shows the real value and prediction respectively. RMSE express square average model –prediction error in the units of variable of interests (Willmott et al., 2005). The Root Mean Square Error (RMSE) is called “apparent error” due to using the same data to assess the model as were used to fit. In other words the test sample is the same as the training sample (Efron & Tibshirani, 1994).To measure the RMSE and the prediction power of the model, a test data that are not used in the model is needed. In the case that an independent test data is not available, there is a common procedure in which the collected data is partitioned to train and test data. The train data can be used to develop the statistical model that will be evaluated using test data. There are some procedures to partition the collected data into train and test (e.g. one time partitioning, cross-validation, bootstrapping). Cross-validation procedure was used in this study.

Cross-validation is a statistical method to evaluate and assess accuracy of predictive model by dividing data in to two segments: one used to train a model and the other one used to validate the model. Cross-validation was originally employed to evaluate the predictive validity of linear regression equations. The advantage of cross-validation method is its capability for providing nearly unbiased estimations of the prediction error (Efron & Gong, 1983). Cross validation k-fold was used to validate multiple linear regression for all 50 plots in this study. In k-fold cross validation, the data are first partitioned into k equally sized segments or folds. Thus, we divide our fifty plots to k-folds (k=5 in this study) and in each k iteration a different fold of the data is held-out for validation while the remaining k-1 folds are used for training. After that the range of RMSE among all 5 folds is reported for the final model.

# 3. RESULTS

## 3.1. DBH and height distribution of trees

The largest number of beech trees in all 50 plots belonged to the DBH class 5 - 10 cm and the height range of 5 - 10 m. More than 75% of the trees fell in class < 20 cm DBH and <20 m height (figure 3-1). The average DBH and height values in beech forest were 15 cm and 10 m respectively. Therefore, it can be concluded that most of the trees were young trees (Peters, 1997).The average density of beech trees (DBH 5-86 (cm), height 5-36 (m)) in all 50 plots is 1194 trees.ha$^{-1}$.

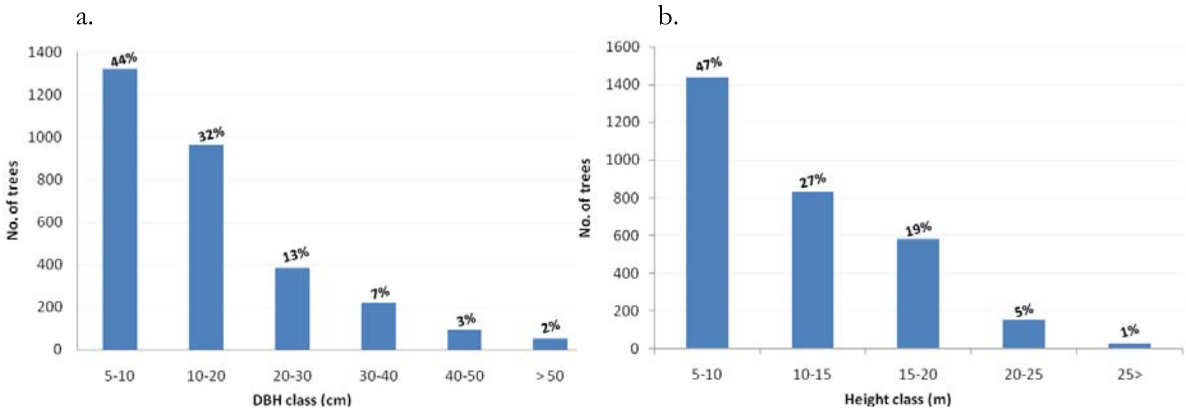



Figure 3-1: Distribution of beech trees (n=3033) by DBH class (a) and height class (b)

## 3.2. The AGB and carbon stock estimation

Area covered by beech forest at the Pizzalto is nearly 2300 ha. The AGB and carbon stock in AGB of all 50 plots in the Pizzalto beech forest were respectively 618 and 309 tons. The average aboveground biomass and carbon stock in AGB are 247 and 123 tons.ha$^{-1}$. The standard error of the average AGB and carbon stock are 18.6 and 9.3 tons.ha$^{-1}$. Figure 3-2 shows number of plots having certain amount of AGB and carbon stock ranges.

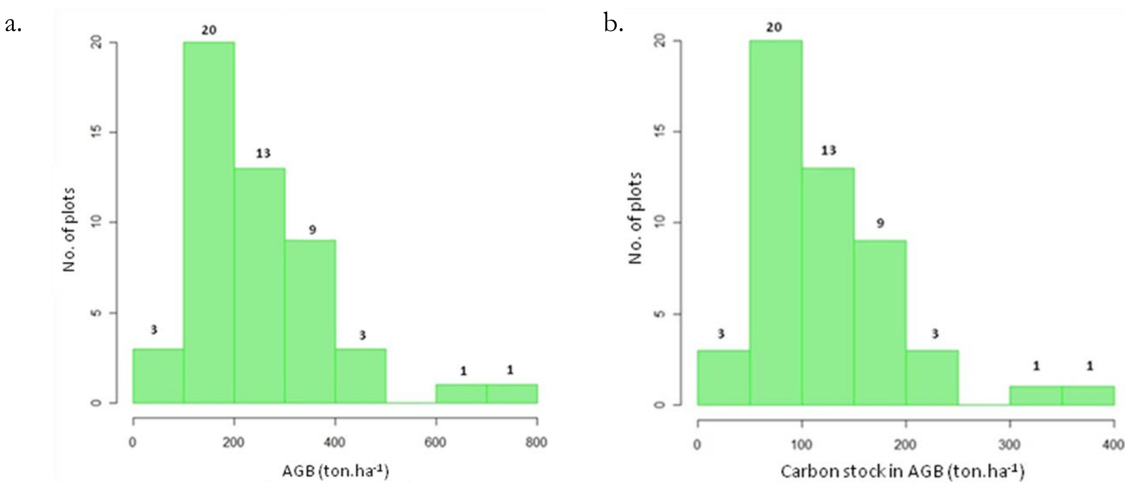



Figure 3-2: Distribution of AGB (a) and carbon stock (b) in plots (n=50)

## 3.3. Model building

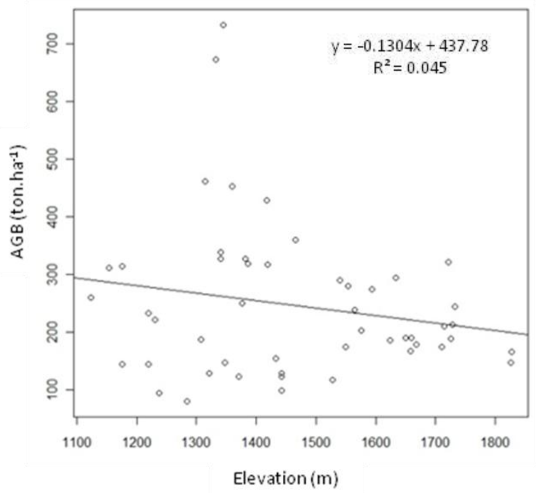
### 3.3.1. Regression modelling of DEM derived variables and AGB

The analysis is first done with all 50 plots and subsequently with 46 plots; i. e. by excluding the four plots with old-growth beech (section 2.3.1) with exceptional high DBH.

a) **Regression modelling with 50 plots**

There is a poor, negative relationship between AGB and elevation values when testing the correlation by simple linear regression (figure 3-3).

a.




b.

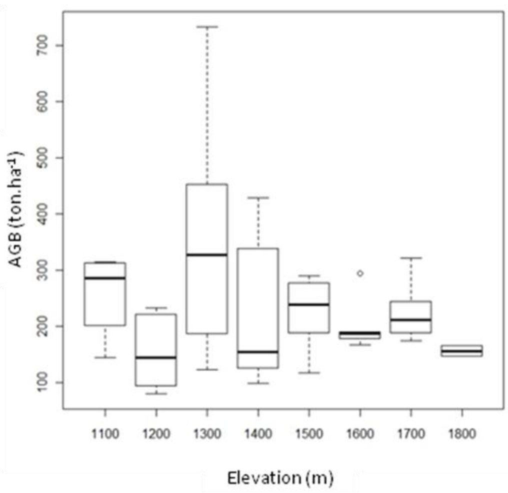



Figure 3-3: (a) Relationship between AGB and elevation (b) AGB at elevations every 100 m (n=50)

However, the AGB is related to various class of elevation (figure 3-3). In particular, the highest AGB appears in the elevation 1300 m. Figure 3-4 shows the AGB in various class of elevation every 200 m compared to various elevation classes every 100 m (figure 3-3) has no difference with elevation.

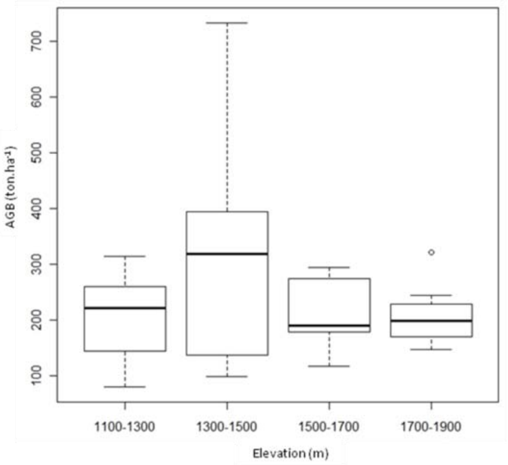



Figure 3-4: AGB in different elevation every 200 m (n=50)

The linear analysis shows (figure 3-5) that there is weak relationship between slope gradient and AGB.

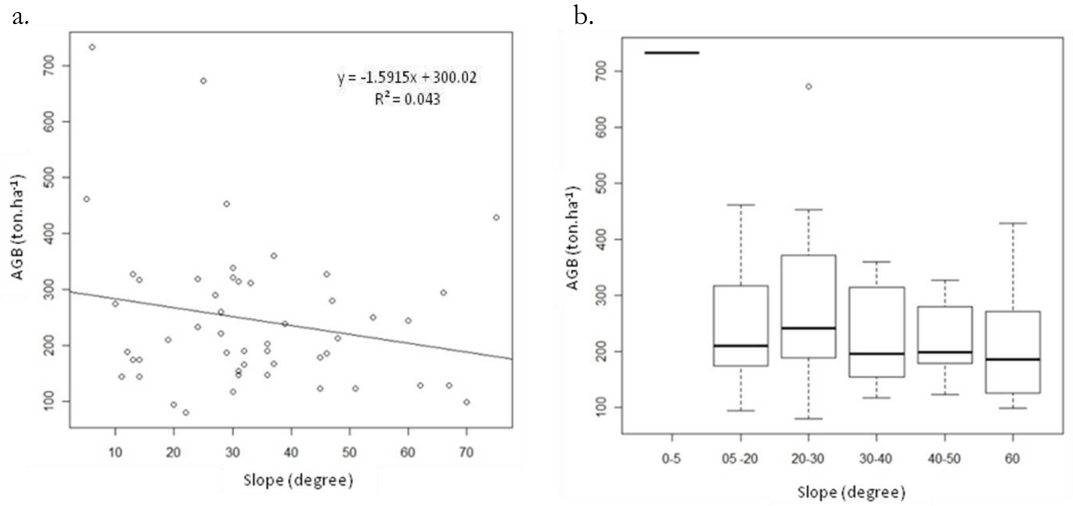


Figure 3-5: (a) Relationship between AGB and slope (b) AGB in different slope (n=50)

Figure 3-5 shows the variation of the AGB in different slope classes. According to the figure, in the slope class, there is only one plot in this dataset in flat area. It also shows that the AGB has no relation to the slope gradient. Aspect and AGB were correlated at 0.2 ($P < 0.05$). Figure 3-6 shows the variation of the AGB in different aspects. The highest value of the AGB appears in the west.

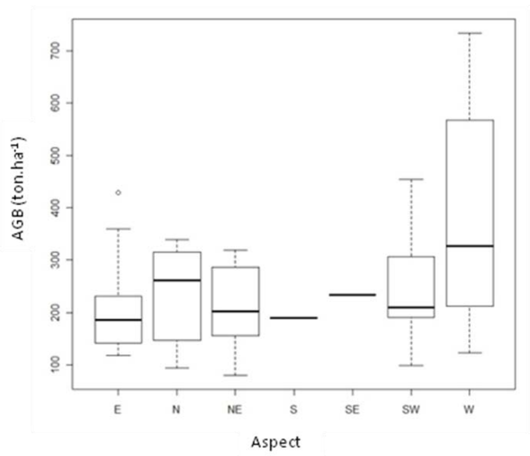


Figure 3-6: AGB in different aspect (n=50)

Seasonal solar radiation explained 10% of AGB in all 50 plots. Among seasonal solar radiation variables the winter has significant relation (P-value<0.05) with AGB. In addition, summer and fall showed negative relationships with AGB.

**b) Regression modelling with 46 plots**

Figure 3-7 shows similar trend between AGB and elevation with all plots that mentioned above. It shows a negative and weak relationship between AGB and elevation by using simple linear regression analysis. In addition as shown in the box plot the highest density of AGB appears in the elevation 1300 m.

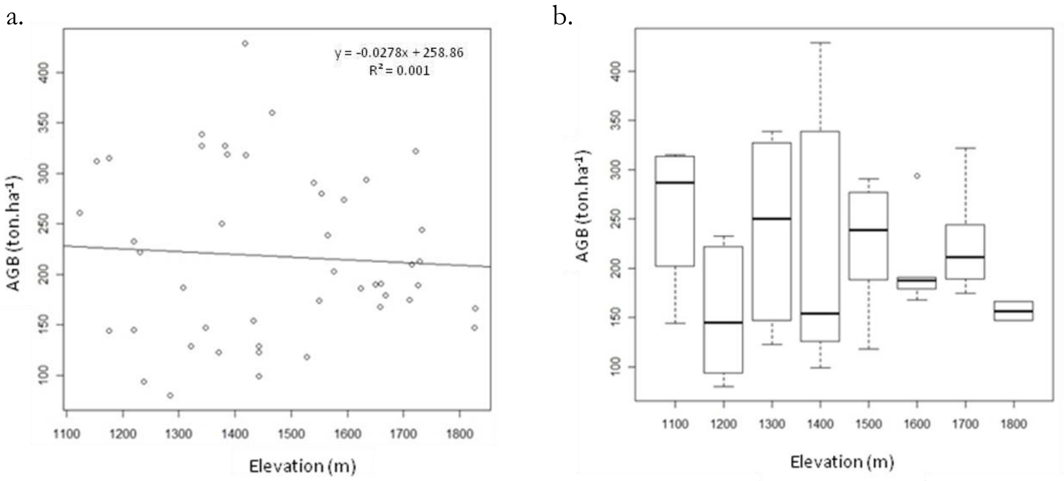



Figure 3-7: (a) Relationship between AGB and elevation (b) AGB at elevations every 100 m (n=46)

Figure 3-8 shows the AGB in various class of elevation every 200 m compare to various elevation classes every 100 m (figure 3-7) has no difference with elevation.

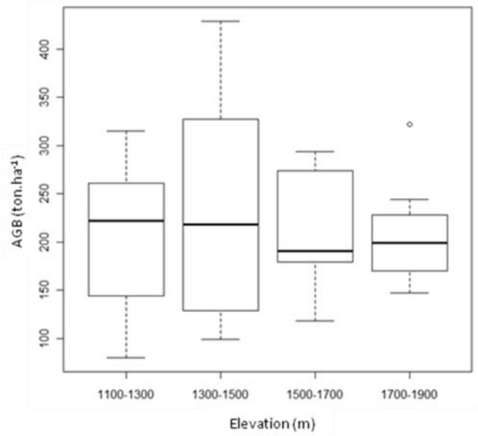



Figure 3-8: AGB in different elevation every 200 m (n=46)

Poor and negative relation between AGB and slope gradient is illustrated in figure 3-8. In addition the box plot (figure 3-9) shows that AGB is not related to slope classes as in figure 3-5.

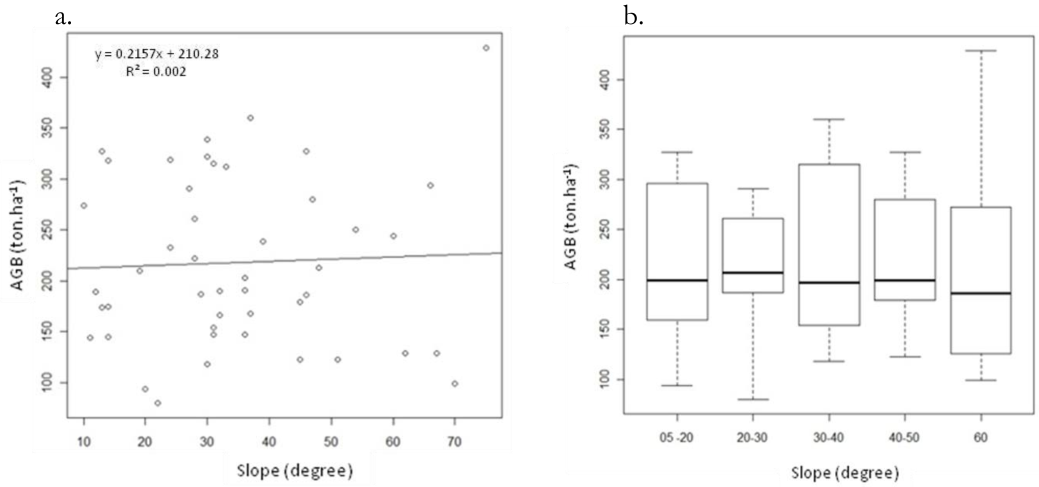



Figure 3-9: (a) Relationship between AGB and slope (b) AGB in different slope (n=46)

Aspect and AGB were weakly correlated and correlation coefficient is about 0.09. Figure 3-10 shows the variation of the AGB in different aspects.

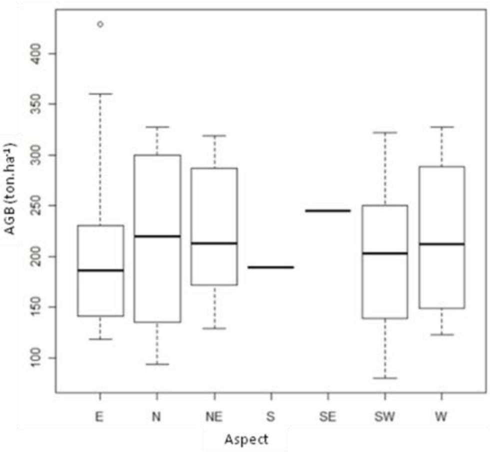



Figure 3-10: AGB in different aspect (n=46)

The relationships between AGB and seasonal solar radiation explained 13% (n=46). Among seasonal solar radiation variables, the winter season has a significant relation (P-value<0.05) with AGB. Summer and fall showed negative relationships with AGB.

The results of regression analysis without four plots in old-growth forest compare to all 50 plots were not significantly different therefore for rest of regression analysis all 50 plots were used.

#### 3.3.2. Regression modelling between MODIS NDVI and EVI with AGB

Figure 3-11 presents an example of the fitting curve NDVI and EVI obtained with the adaptive Savitzky Golay method. A few curves NDVI and EVI (total 100 graphs) acquired with the adaptive Savitzky Golay method for per pixel during five years are shown in Appendix 5.

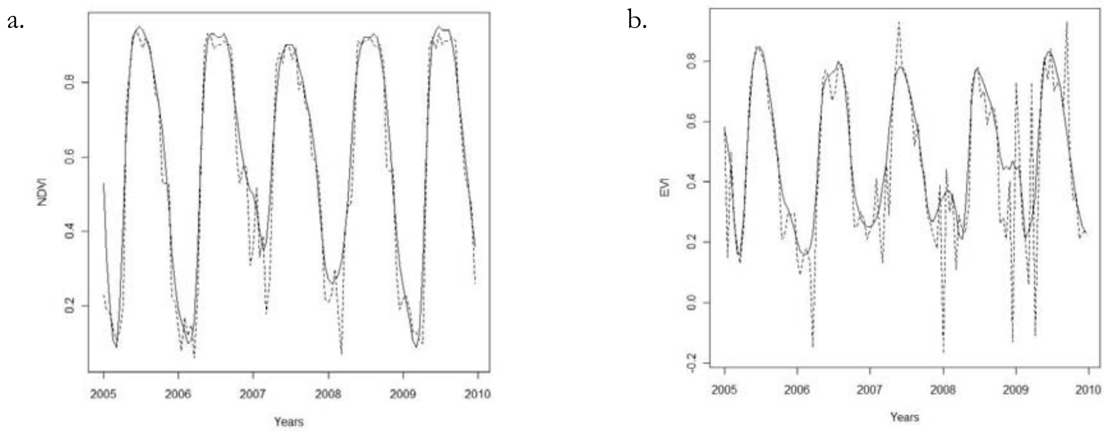



Figure 3-11: Example of Adaptive Savitzky-Golay filtering method for the plot (a) NDVI (b) EVI

Average NDVI values for every 16 days during five years and AGB were having low correlations. The coefficient of determination of simple linear regression model with all periods is very low (table 3-1). The significant but weak relation of MODIS NDVI with the AGB were found in the second half of March, first half of April and second half of November (table 3-1). The average of MODIS NDVI values per plot (16 days) period during 2005 to 2009 is shown in Appendix 6.

Average EVI values for every 16 days during 5 years and the AGB were having weak correlation. The significant but weak relations of MODIS EVI with the AGB were found during first half of April, October, November and December (table 3-1). The average of MODIS EVI values per plot per 16 days period during 2005 to 2009 is shown in Appendix 7.

Table 3-1: Result of simple linear regression MODIS NDVI (a) and MODIS EVI (b) with AGB

a.

| 16 days period of year (MODIS NDVI) | $R^2$ | P-value |
|---|---|---|
| January(1) | 0.05 | 0.59 |
| January (17) | 0.02 | 0.74 |
| February (33) | 0.05 | 0.61 |
| February (49) | 0.02 | 0.28 |
| March (65) | 0.06 | 0.08 |
| March (81) | 0.10 | 0.03 |
| April (97) | 0.07 | 0.04 |
| April (113) | 0.03 | 0.21 |
| May (129) | 0.003 | 0.68 |
| May (145) | 0.002 | 0.71 |
| June (161) | 0.01 | 0.47 |
| June (177) | 0.02 | 0.26 |
| July (193) | 0.03 | 0.20 |
| July (209) | 0.04 | 0.16 |
| August (225) | 0.03 | 0.19 |
| August (241) | 0.02 | 0.23 |
| September (257) | 0.01 | 0.50 |
| September (273) | 0.01 | 0.83 |
| October (289) | 0.01 | 0.45 |
| November (305) | 0.05 | 0.09 |
| November (321) | 0.08 | 0.03 |
| December (337) | 0.06 | 0.06 |
| December (353) | 0.04 | 0.15 |

b.

| 16 days period of year (MODIS EVI) | $R^2$ | P-value |
|---|---|---|
| January(1) | 0.03 | 0.18 |
| January (17) | 0.03 | 0.21 |
| February (33) | 0.05 | 0.09 |
| February (49) | 0.05 | 0.09 |
| March (65) | 0.05 | 0.09 |
| March (81) | 0.05 | 0.08 |
| April (97) | 0.07 | 0.03 |
| April (113) | 0.02 | 0.24 |
| May (129) | 0.04 | 0.65 |
| May (145) | 0.01 | 0.81 |
| June (161) | 0.04 | 0.62 |
| June (177) | 0.01 | 0.42 |
| July (193) | 0.02 | 0.31 |
| July (209) | 0.04 | 0.27 |
| August (225) | 0.02 | 0.29 |
| August (241) | 0.01 | 0.44 |
| September (257) | 0.01 | 0.94 |
| September (273) | 0.04 | 0.15 |
| October (289) | 0.16 | 0.003 |
| November (305) | 0.20 | 0.001 |
| November (321) | 0.18 | 0.002 |
| December (337) | 0.15 | 0.005 |
| December (353) | 0.10 | 0.02 |

### 3.3.3. Regression modelling between the LGS and AGB

Estimation of the LGS based on average of five years (2005-2009) is different between MODIS NDVI and EVI in each elevation (table 3-2). Onset, end and LGS measured from NDVI and EVI are shown in Appendix 8 and 9. The longest LGS is at elevation 1300 and 1400 m (table 3-2).

Table 3-2: Average LGS (days) at different elevation during (2005-2009)

| LGS (days) | Elevation (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 |
| NDVI | 211 | 208 | 227 | 220 | 215 | 209 | 207 | 195 |
| EVI | 170 | 165 | 175 | 170 | 167 | 163 | 168 | 155 |

The LGS in different elevation based on NDVI values are more normally distributed than the LGS based on EVI values (figure 3-12). This is supported by Shapiro-Wilk normality test which showed greater value for NDVI (W = 0.9) than EVI (W= 0.72). This result means that NDVI is more normally distributed than EVI.

a. b.

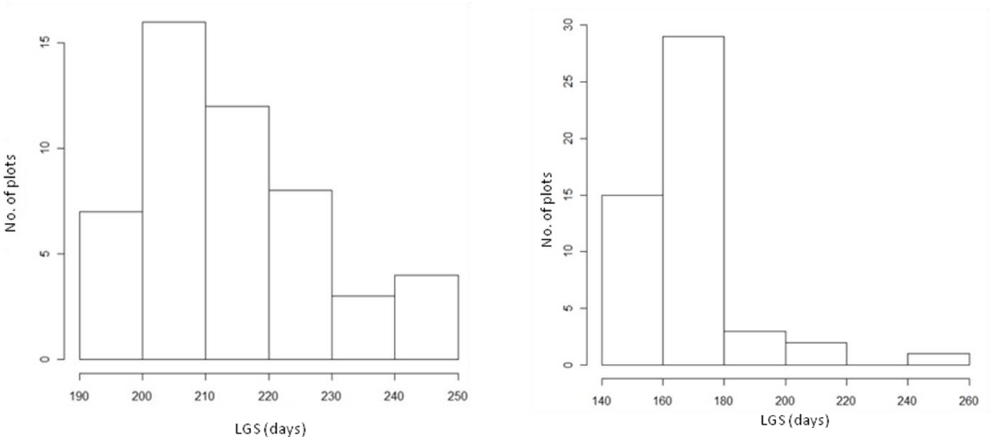



Figure 3-12: Distribution of LGS by using NDVI (a) and EVI (b)(n=50)

Figure 3-13 shows the average LGS per plot by using NDVI and EVI along elevation. It indicates the effect of elevation on LGS by using NDVI and EVI. In addition polynomial analyses between LGS by using NDVI and EVI with elevation are determined for all 50 plots (table 3-3). Significant relation was found between LGS as determined from NDVI and elevation.

a. b.

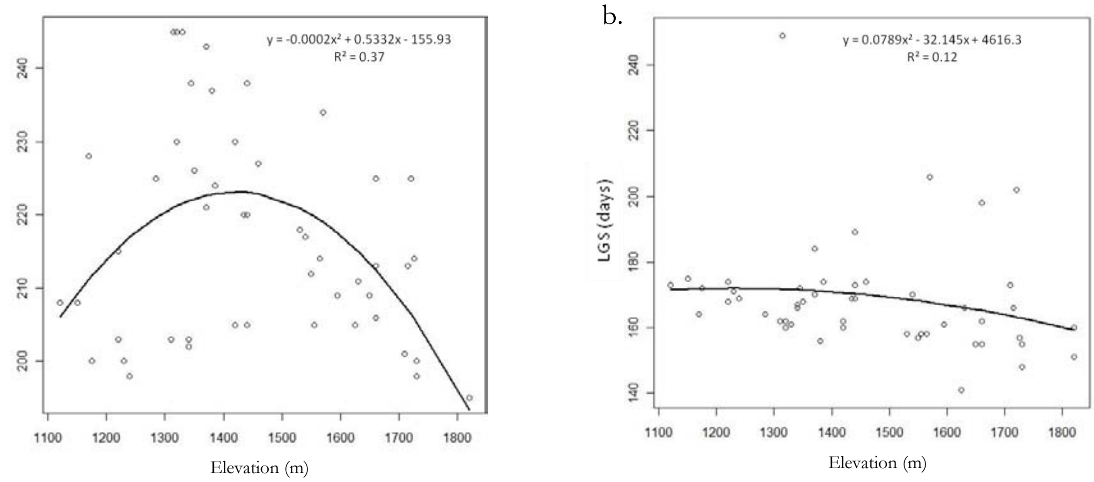



Figure 3-13: The change of LGS with elevation by NDVI (a) and EVI (b)

Table 3-3: Result of polynomial regression of LGS and elevation

| LGS (days) | Correlation coefficient ($R^2$) | P-value |
|---|---|---|
| NDVI | 0.37 | 0.0001** |
| EVI | 0.12 | 0.61 |

In addition simple linear regression analysis between the LGS determined from NDVI and EVI with the AGB are determined for all 50 plots (figure 3-14). No significant relation was found between LGS determined from EVI and AGB. However there is significant correlation between LGS measured by NDVI and AGB (table 3-4).

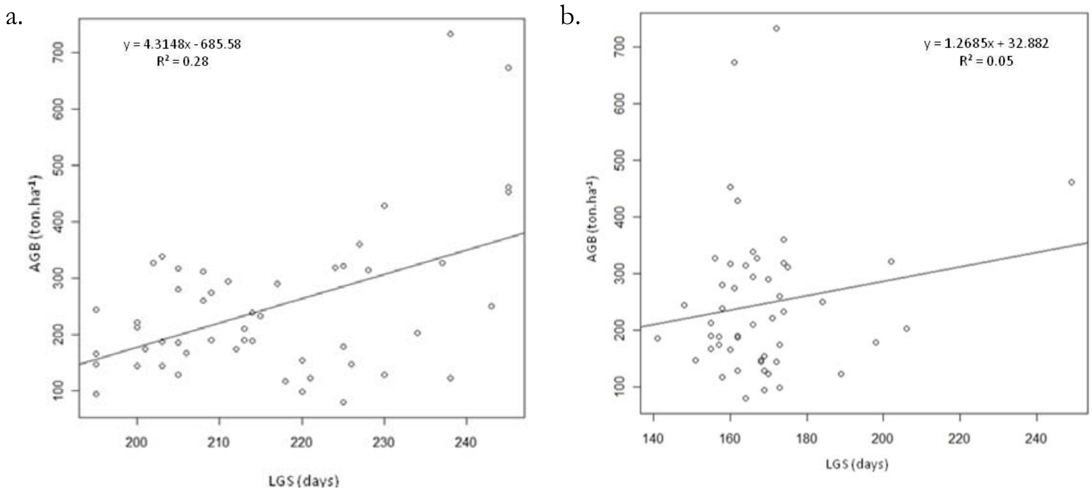



Figure 3-14: Relationship between AGB and LGS (a) NDVI (b) EVI

Table 3-4: Result of simple linear regression of LGS and AGB

| LGS (days) | Correlation coefficient ($R^2$) | P-value |
|---|---|---|
| NDVI | 0.28 | 0.0004*** |
| EVI | 0.05 | 0.21 |

### 3.3.4. Topographic effects on MODIS NDVI and EVI

The variance among the length of growing season by using NDVI and EVI by adding 10 pixels in beech forest in elevation between 1500 to 1800 m were estimated as shown in table 3-5. From elevation 1500 m to 1700 m the variance among LGS determined from EVI is very high compared to LGS determined from NDVI at all elevations.

Table 3-5: Variance of the LGS with elevation

| LGS (days) | Variance in each Elevation (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 |
| NDVI | 27 | 98 | 90 | 84 | 34 | 66 | 16 |
| EVI | 10 | 65 | 70 | 249 | 206 | 263 | 48 |

In addition variances among LGS using NDVI and EVI for 10 pixels in beech forest in slope classes were estimated as shown in table 3-6. In high slope classes LGS determined from EVI shows high variance compared to LGS determined from NDVI.

Table 3-6: Variance of the LGS with slope classes

| Slope class | Variance (LGS by NDVI) | Variance (LGS by EVI) |
|---|---|---|
| 0-20 | 79 | 70 |
| 20-30 | 48 | 83 |
| 30-40 | 21 | 290 |
| 40-50 | 99 | 270 |
| >50 | 75 | 147 |

### 3.3.5. Regression modelling between AGB and soil types

In Pizzalto Mountain the sample plots are located in four main types of soil (figure 3-15). Soil types and AGB were correlated and coefficient of determination is about 0.53 (P-value< 0.05). Soil types B and C have higher moisture-holding capacity than other types and locate on steep slopes. Soil type A is locate on moderate slopes and soil type D is locate on many rock outcrops and irregular slope shape with local cliffs and more dry than other types of soils (Appendix 10). Among all four soil types B and C have significant relationship with AGB (P-value<0.05). The proportion of average AGB per soil types is shown in figure 3-16 the highest percentage of average AGB was in soil type D. Thus, testing the hypothesis whether different soil types lead to different amount of carbon storage suggests that carbon storage in different soil types is varied.

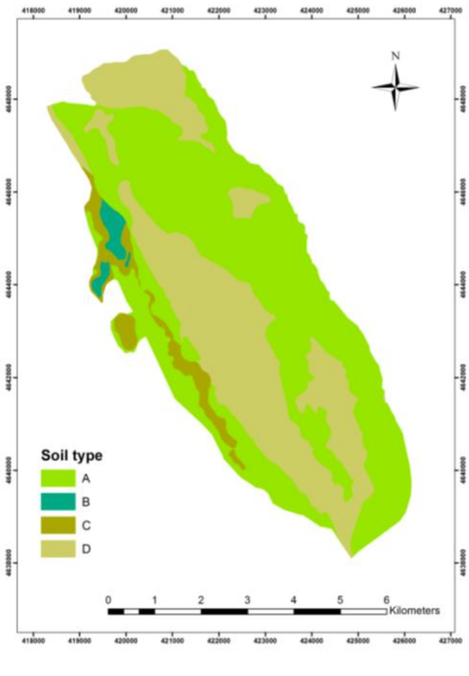



Figure 3-15: Soil type's map of the Pizzalto Mountain (Source: Majella National Park)

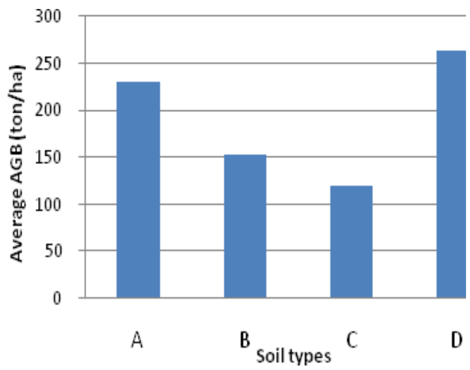



Figure 3-16: Average AGB per soil types

### 3.3.6. Regression modelling between AGB and management types

The type of management "old growth forest" is found in "Bosco di Sant'Antonio" reserve. The management type "young forest" therefore occurred in other part of Pizzalto Mountain (figure 3-17). Young forest management covers large areas and numbers of sample plots are larger compared to old-growth forest. However the highest AGB was in old growth forest (figure 3-18). The two management types were correlated (0.55) with AGB (P-value< 0.05). Additionally old growth forest management is highly significant in relation with AGB. Thus, testing the hypothesis whether different style of management leads to different amount of carbon storage suggests that the amount of carbon storage is differs between the two types of forest management.

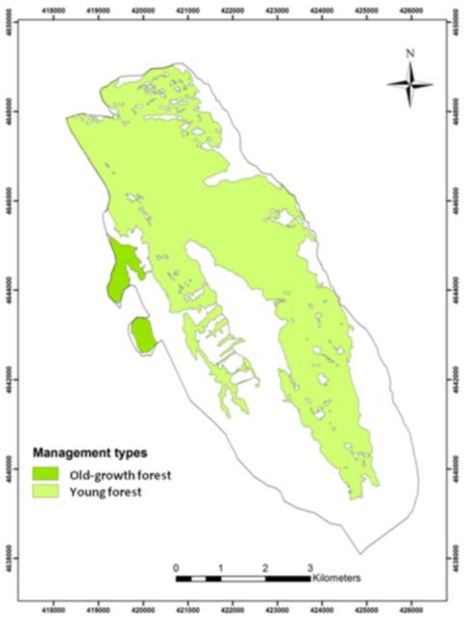



Figure 3-17: Management map of in the Pizzalto Mountain

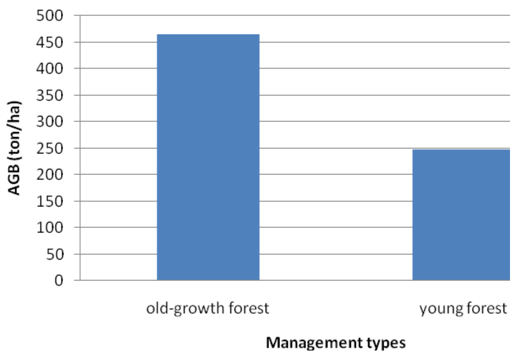



Figure 3-18: Average AGB in two management types

## 3.4. Multicollinearity analysis

Table 3-7 shows the remaining predictors with the corresponding VIF after multicollinearity analysis.

Table 3-7: Explanatory variables used for building model after multicollinearity analysis

| Explanatory variables | VIF |
|---|---|
| Elevation | 3.636 |
| Slope | 3.782 |
| Summer incoming solar radiation | 3.272 |
| Winter incoming solar radiation | 2.548 |
| LGS by NDVI | 5.950 |
| LGS by EVI | 2.525 |
| EVI*January (first half) | 2.520 |
| EVI*February (second half) | 1.117 |
| EVI*March (first half) | 2.097 |
| EVI*October(first half) | 3.037 |

* Average 2005-2009

### 3.5. Multiple linear regression model

The final result of multiple linear regressions was shown in table 3-8. Among all final variables old growth forest management is highly significant and the incoming summer solar radiation shows negative relation with relation with AGB.

Table 3-8: Final multiple linear regressions

| Model | Coefficients | P-value |
|---|---|---|
| Intercept | 406 | 0.01* |
| Summer solar radiation | -0.47 | 0.16 |
| Soil type B | 152 | 0.09 |
| Soil type C | 55 | 0.07 |
| Soil type D | 60 | 0.08 |
| Old growth forest management | 444 | 0.001** |

The Pearson r of the relationship between predicted values and real observation is 0.66 which shows that 66% of variations are explained by this model. Based on cross-validation (5-fold) the range of RMSE were 75 to 110 $ton.ha^{-1}$ which is 31 to 44 % of the average estimated AGB in all plots (247 $ton.ha^{-1}$).

# 4. DISCUSSION

This chapter discusses the results of the research described in the previous chapter. The chapter is divided into two sections. In section 4.1, the results of the AGB and carbon stock estimations are compared with results obtained in beech forests in southern and central Europe. Section 4.2 discusses the modelling explanatory variables for predicting AGB and carbon stock in AGB.

## 4.1. Estimation AGB and carbon stock in beech forest

The average carbon stock in above ground biomass (CS-AGB) of beech in fifty plots (123 tons.ha$^{-1}$) was comparable to those reported from similar types of forest in Spain (129 ton.ha$^{-1}$, Merino et al., 2007) and Germany (120-160 ton.ha$^{-1}$, Joosten et al., 2004) and higher than other beech forests in Spain (66 tons.ha$^{-1}$, Santa Regina & Tarazona, 1999). The CS-AGB of beech in the present study (123 tons.ha$^{-1}$) is very close to the CS-AGB of selectively logged beech stands in Spain (129 ton.ha$^{-1}$, Merino et al., 2007). In the managed beech stands in western Germany at elevations from 20 to 800 m (Joosten et al., 2004) the CS-AGB was 120-160 ton.ha$^{-1}$. In addition, the average CS-AGB in this study (123 tons .ha$^{-1}$) is higher than that of in coppice beech forest in Spain with less number of trees and locate at 1000 m elevation (66 tons.ha$^{-1}$, Santa Regina & Tarazona, 1999). These studies show that different management types can have different effects on the CS-AGB of beech forest.

The average CS-AGB of four plots with old growth trees (Bosco di Sant Antonio: 233 ton.ha$^{-1}$) was relatively similar to that of found in the unmanaged forests in Spain (205 ton.ha$^{-1}$). The categories for these forests in Spain are mentioned as large and old beech trees that mostly are located in areas of difficult access where there is no evidence of recent wood harvesting operation and have not been subjected to any other human disturbance. However, the four plots with the highest CS-AGB in the Pizzalto are located close to the main road and relatively on flat terrain where there is no evidence of recent wood harvesting and have been protected by local communities. In a similar study of an old growth beech forest in the Apennines the average CS-AGB (180 tons.ha$^{-1}$,Piovesan et al., 2010) was roughly close to the average CS-AGB in old growth forest in Bosco di Sant Antonio (233 tons.ha$^{-1}$).

## 4.2. Modelling explanatory variables for predicting AGB and CS-AGB

The research result revealed that topographic parameters (elevation, slope and aspect) all have poor relationships with AGB in the Pizzalto Mountain. Results of the present study are in line with Merino et al. (2007) who reported that there is no relationship between altitude and beech tree biomass. Merino et al. (2007) explained their result based on complexity of mountainous landscape with regard to slope, aspect, soil depth and microclimate condition. In the Pizzalto Mountain although in addition to complexity of mountainous landscape, the management style is another factor which can describe this result. Whittaker et al (1975) found that AGB decreases from high elevation (2700 m) to low elevation (980 m) in Santa Catalina Mountain natural forests in Arizona due to the drought condition. In present study, not only we did not find such a trend but also there was a negative relation between elevation and AGB. The relation was not find in this study compare to Whittaker et al. (1975) can be due to type of our forest that is managed or secondary also drought condition which is not happens in Pizzalto Mountain. De Castilho et al. (2006) showed a model with topographic factors (slope, altitude) explaining 20 percent of the variation in AGB in central Amazon Forest. They explained that due to the soil conditions which derived from topography, can indirectly affect AGB. Hicks et al. (1984) found a significant relationship between aspect and AGB in the West Virginia forest and reported that aspect can affect the chemical properties of soil and indirectly affect AGB, therefore, it can be supposed as a useful variable to predict AGB. Aspect can explain 20% of AGB especially in the west which is may be due to the high amount of AGB in plots including old growth trees in Bosco di Sant Antonio.

Solar radiation in summer and fall has negative relationship with AGB and carbon stock. This result is in agreement with the study of Dittmar et al. (2003) on relationship between beech growth and climate condition in Italy which showed that solar radiation effect until May is positive but after that becomes negative. They found that in the very beginning of greenness period water stored in soil is sufficient for growth. During the summer and fall, high solar radiation and unfavourable precipitation lead to water deficiency and dry conditions which are negatively affect tree growth. In the mountainous areas in the central- southern of Italy, summer drought is a key climatic factor which affects the beech growth with different intensity at different level of elevations depending on LGS (Piovesan et al., 2005). They explained that during May as a turning point between dormant-bud bursting and growing season, higher temperature regime can cause water stress for beech trees whereas at high elevation, mild temperature is required to protect them from the late spring frost. Generally, beech trees require relatively cool and moist climate condition. During the last century, the climate in Italy has become drier and the number of rainy days has decreased (Brunetti et al., 2004) which can have an effect on the growth and consequently biomass of the beech trees.

Vegetation indices such as NDVI and EVI are often used for AGB estimation. Medium spatial resolution sensors such as MODIS VI provide daily coverage of vegetation greenness of the earth and compared to high resolution sensors, weather events seldom remain as an obstacle to images and their acquisition are free and not time-consuming. Average values of EVI and NDVI during the five years have poor correlation with AGB of beech forest in the Pizzalto Mountain. However, EVI shows slightly higher correlation with AGB than NDVI. Both NDVI and EVI show significant relationship with AGB in the beginning of growing season in early April and in early November before it start snowing in the Pizzalto Mountain.

In areas with high tree biomass, NDVI values, due to the saturation problem, do not respond to the variations in green biomass. This result is in line with Steininger (2000) who found that saturation occurs in canopy reflectance when biomass is above 150 $ton.ha^{-1}$. Therefore, saturation of NDVI at current level of AGB in the Pizzalto Mountain (average 247 $ton.ha^{-1}$) is likely. Olofsson et al (2007) also reported that due to saturation, MODIS NDVI had non linear relationship with the ground measured parameters in northern Europe forests. In this study, three periods of NDVI values (second half of March, first half of April and second half of November) which are at the beginning and the end of growing season have significant relationship with AGB. However, the rest of periods have very poor linear relationship with AGB which can be due to the existence of saturation problem in these growing periods. Gholz (1997) also found very low correlation between the biomass of deciduous broadleaf forest and NDVI in temperate forest in Japan. According to Huete et al (2002), snow affects both MODIS Vegetation Indices. Snow significantly reduces the NDVI values because of its influences on canopy brightness which makes the EVI values show a false increase. Based on pixel reliability layer in MODIS data for the Pizzalto Mountain during the five years from 2005 to 2009, it snows from December to April which affects both MODIS NDVI and EVI. Therefore, this can be a reason for the significant relationship between EVI and AGB during December.

Results of this study show that LGS of beech varies per elevation zone from 1100 to 1800 m. The longest LGS belongs to the elevations from 1300 to 1400 m elevation and the shortest LGS belongs to the elevations 1800 to 1900 m and 1100 to 1200 m. Peters (1997) reported that the average length of growing season for beech along the elevation from 1400 to 1700 m was between 170 to 130 days in central Spain which is correspond to the result of present study.

As it is shown in figure 3-13, elevation plays an important role in LGS through its control on precipitation and temperature. High elevation areas have lower average temperature than low elevation areas due to decrease in temperature at a rate of about 0.4 $^0$C per 100 m of elevation. In addition, precipitation increases from low to high elevation. Therefore, at low elevation (1100 m) due to less precipitation and higher temperature also high evapotranspiration, beech cannot grow well whereas at higher elevation growth can also be poor due to lower temperature. In addition, snow melt can be another factor which affects LGS. During winter it stores in soils and the amount of snow declines from high to low elevation. Thus, combination of these factors can affect LGS at different elevation. Estimating LGS with both NDVI and EVI values increase with elevation and reaches to its maximum value at the elevation around 1300 to 1400 m, which is almost in middle of the Pizzalto Mountain and then decrease as elevation reach beyond 1400 m. Based on midpoint method by NDVI for average of five years, LGS is between 220 to 230 days when the elevation is between 1300 to 1400. On the other side, by using midpoint method by EVI for average of five years LGS is between 170 to 175 days where the elevation is between 1300 and 1400. LGS is short when elevation is lower than 1300 m and higher than 1400 m and whitin these elevation ranges, carbon sequestration is less than that of at the elevation between 1300 and 1400 m. The rate of change in LGS along elevation is different from midpoint method by NDVI and EVI values. The rate varies slightly at lower elevations from 1100 to1300 m but it varies significantly where the elevation is higher than 1400 m with both NDVI and EVI. However, fluctuation in LGS can be observed by using EVI at the elevations above 1400 m. In addition, using midpoint method with NDVI LGS shows significant relationship with AGB while EVI does not show any significant relationship. The topographic condition such as elevation and slope can explain the variation of the MODIS EVI values. LGS determined by EVI varies at each elevation zone and slope classes compare to the NDVI which shows smaller variation. The NDVI values can reduce the topographic effects due to its band ratio format in formula (Matsushita et al., 2007).

Results indicated that AGB of beech forest have positive relationship with soil types with high moisture holding capacity located mostly on steep slopes. High moisture holding capacity of soil types in this mountainous area can be due to storing melted snow. Water availability is an important factor for beech trees especially when summer precipitation is irregular or insufficient. In mountainous areas in central Europe, beech forests stand on steep slope with well-drained soil types. Meier et al. (2009) also found that in temperate beech forests decrease of moisture content of soil can have negative effect on carbon sequestration in forests.

The Bosco di Sant Antonio reserve, due to its ecological and historical values, has been protected since 1985. This area was decided to be reserved and protected by local communities who have lived near to this area and Municipality of Pescocostanzo.

There are two reasons which can explain why this area is protected for centuries. First not to let the animals (sheep, cattle...) go inside the forest (surrounded by stone walls) and second to protect forest against agriculture. There is no sign of logging or selection cutting in this area. However, in surrounding and at higher elevation areas elements of old or recent cutting or logging can be observed. Conservation for biological and ecological diversity and recreation purpose are strategies that cause Bosco di Sant Antonio to store the highest carbon stock, in its old growth trees.

Forests with old-growth trees are important carbon reservoirs and they represent a huge pool of carbon. Studies on the role of old growth trees in the global carbon cycle are increasing (Luyssaert et al., 2008; Wirth et al., 2009; Piovesan et al., 2010). Piovesan et al. (2000) found that old growth forests in temperate zones are much richer in carbon stock than what carbon cycle models assume. The old standing trees steadily accumulate vast quantities of carbon over centuries. These forests will emit much of carbon to the atmosphere if their sites be disturbed. Thereupon, based on carbon-accounting rules for forests leaving old-growth forest undamaged will bring credit to the Majella National Park Authority. Furthermore, changing the land use from logging to other alternatives such as recreation may help the beech forests in terms of carbon sequestration in long term.

Results of this study showed that old growth trees are considerable reservoir of carbon which is in agreement with Marchetti & Blasi, (2010) who reported that old-growth forests play an important role in biodiversity conservation and carbon storage. Nevertheless, it should be called to mind that carbon sequestration does not happen only in above ground biomass of forests. Besides forest biomass, forest soils also store a great deal of carbon in their different layer and horizons. Moreover, since forest soils are not as utilizable as forest woods, it can be supposed as a more sustainable sink of carbon. It is advised that consider and estimate the carbon stored in soils to have real understanding of forest potential for carbon storage.

# 5. CONCLUSIONS

-The average AGB and CS-AGB are about 247 and 123 tons.ha$^{-1}$ respectively in 2010 at the Pizzalto Mountain. This result is comparable to beech forests in the Apennines and elsewhere in Europe.

- This research indicate a substantial potential for carbon sequestration in the beech forests in Apennines to provide CS-AGB at the level of old-growth forest (233 tons.ha$^{-1}$) by using different forest management options to obtain credits for international conventions and to fulfil commitments made by Italy.

-This research indicates that among all parameters used for regression modelling of AGB and CS-AGB the NDVI-derived LGS and the management type are the most significant factors in the Pizzalto Mountain.

- Measurement of the NDVI-derived LGS shows a better correlation results with AGB and elevation than the EVI-derived LGS.

According to research hypotheses:

- Altitude has insignificant and negative effect on the carbon storage in beech forest.
- Length of growing season derived by NDVI has significant positive effect on the carbon storage in beech forest.
- Winter solar radiation has significant impact on the carbon storage in beech forest.
- Slope aspect has insignificant impact on the carbon storage in beech forest.
- Slope angle has insignificant impact on the carbon storage in beech forest.
- The carbon stock of beech forest shows a better relationship with the EVI than NDVI values.
- Different styles of forest management lead to different amount of carbon storage in beech forest.
- Different soil types leads to different amount of carbon storage in beech forest.

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# APPENDIXES

Appendix 1: Some photos of study area

**Old-growth beech forest**



**Young beech forest**


**Logging or cutting**

Appendix 2: Field sampling plots

Coordinate system: WGS_1984_UTM_Zone_33N

| plots No. | X | Y | plots No. | X | Y |
|---|---|---|---|---|---|
| 1 | 423561 | 4642637 | 26 | 419515 | 4647512 |
| 2 | 419715 | 4644805 | 27 | 419703 | 4646943 |
| 3 | 419942 | 4644450 | 28 | 420622 | 4646858 |
| 4 | 421720 | 4642801 | 29 | 420571 | 4646592 |
| 5 | 422152 | 4642872 | 30 | 425008 | 4640602 |
| 6 | 421076 | 4642783 | 31 | 424849 | 4640578 |
| 7 | 421201 | 4642723 | 32 | 424503 | 4640457 |
| 8 | 422993 | 4643458 | 33 | 424239 | 4640350 |
| 9 | 423867 | 4642966 | 34 | 424106 | 4640263 |
| 10 | 419485 | 4644261 | 35 | 423521 | 4641726 |
| 11 | 424212 | 4642647 | 36 | 423766 | 4641679 |
| 12 | 424443 | 4642237 | 37 | 420587 | 4647734 |
| 13 | 421246 | 4646431 | 38 | 418604 | 4647594 |
| 14 | 422107 | 4645587 | 39 | 420260 | 4644627 |
| 15 | 421629 | 4646819 | 40 | 420766 | 4644212 |
| 16 | 421970 | 4646275 | 41 | 421413 | 4643969 |
| 17 | 423119 | 4642852 | 42 | 421241 | 4644419 |
| 18 | 423066 | 4643601 | 43 | 423180 | 4645385 |
| 19 | 423235 | 4643706 | 44 | 422797 | 4645435 |
| 20 | 424010 | 4644017 | 45 | 422611 | 4645114 |
| 21 | 423518 | 4643845 | 46 | 422531 | 4644856 |
| 22 | 423820 | 4643985 | 47 | 422495 | 4644633 |
| 23 | 420036 | 4646113 | 48 | 422362 | 4644492 |
| 24 | 419768 | 4646642 | 49 | 419926 | 4643192 |
| 25 | 419791 | 4647742 | 50 | 420066 | 4642758 |

Appendix 3: Slope correction table

Plot size 500 $m^2$

| Slope% | Radius(m) | Slope% | Radius(m) | Slope% | Radius(m) |
|---|---|---|---|---|---|
| 0 | 12.62 | | | | |
| 1 | 12.62 | 36 | 13.01 | 71 | 13.97 |
| 2 | 12.62 | 37 | 13.03 | 72 | 14.00 |
| 3 | 12.62 | 38 | 13.05 | 73 | 14.04 |
| 4 | 12.62 | 39 | 13.07 | 74 | 14.07 |
| 5 | 12.62 | 40 | 13.09 | 75 | 14.10 |
| 6 | 12.63 | 41 | 13.12 | 76 | 14.14 |
| 7 | 12.63 | 42 | 13.14 | 77 | 14.17 |
| 8 | 12.64 | 43 | 13.16 | 78 | 14.21 |
| 9 | 12.64 | 44 | 13.19 | 79 | 14.24 |
| 10 | 12.65 | 45 | 13.21 | 80 | 14.28 |
| 11 | 12.65 | 46 | 13.24 | 81 | 14.31 |
| 12 | 12.66 | 47 | 13.26 | 82 | 14.35 |
| 13 | 12.67 | 48 | 13.29 | 83 | 14.38 |
| 14 | 12.68 | 49 | 13.31 | 84 | 14.42 |
| 15 | 12.69 | 50 | 13.34 | 85 | 14.45 |
| 16 | 12.70 | 51 | 13.37 | 86 | 14.49 |
| 17 | 12.71 | 52 | 13.39 | 87 | 14.52 |
| 18 | 12.72 | 53 | 13.42 | 88 | 14.56 |
| 19 | 12.73 | 54 | 13.45 | 89 | 14.60 |
| 20 | 12.74 | 55 | 13.48 | 90 | 14.63 |
| 21 | 12.75 | 56 | 13.51 | 91 | 14.67 |
| 22 | 12.77 | 57 | 13.53 | 92 | 14.71 |
| 23 | 12.78 | 58 | 13.56 | 93 | 14.74 |
| 24 | 12.79 | 59 | 13.59 | 94 | 14.78 |
| 25 | 12.81 | 60 | 13.62 | 95 | 14.82 |
| 26 | 12.82 | 61 | 13.65 | 96 | 14.85 |
| 27 | 12.84 | 62 | 13.68 | 97 | 14.89 |
| 28 | 12.86 | 63 | 13.72 | 98 | 14.93 |
| 29 | 12.87 | 64 | 13.75 | 99 | 14.97 |
| 30 | 12.89 | 65 | 13.78 | 100 | 15.00 |
| 31 | 12.91 | 66 | 13.81 | 101 | 15.04 |
| 32 | 12.93 | 67 | 13.84 | 102 | 15.08 |
| 33 | 12.95 | 68 | 13.87 | 103 | 15.12 |
| 34 | 12.97 | 69 | 13.91 | 104 | 15.15 |
| 35 | 12.99 | 70 | 13.94 | 105 | 15.19 |

(Source: de Gier, 2000)

Appendix 4: Data sheet

**Name of recorder:** ............................ **Date:** ............................ **Plot radius size:** ....................

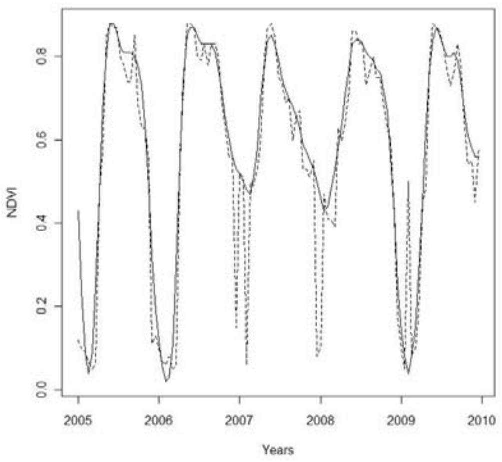
| Sampling plot No. | Elevation zone | Geographical coordinate X | Y | Slope (%) |
|---|---|---|---|---|
| | | | | |

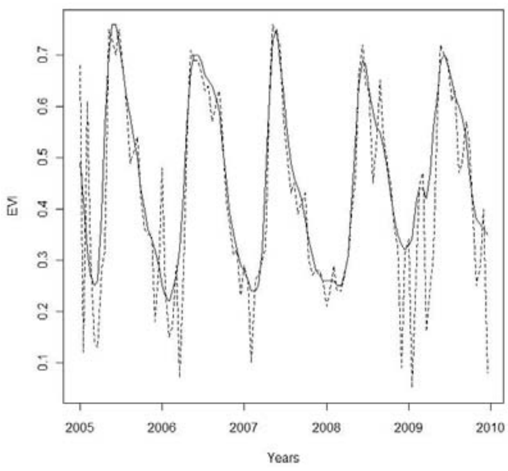
| Forest Management type | Observation |
|---|---|
| | |

| Tree No. | Species | DBH (cm) | Height (m) | Remarks |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |
| 21 | | | | |
| 22 | | | | |
| 23 | | | | |
| 24 | | | | |
| 25 | | | | |
| 26 | | | | |
| 27 | | | | |
| 28 | | | | |
| 29 | | | | |
| 30 | | | | |

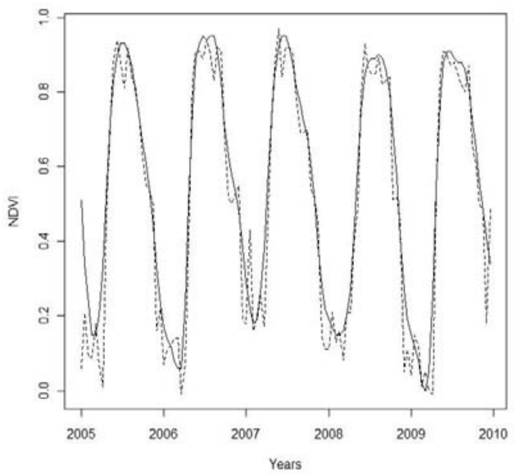
Appendix 5: Examples of NDVI and EVI with adaptive Savitzky-Golay method during (2005-2009)

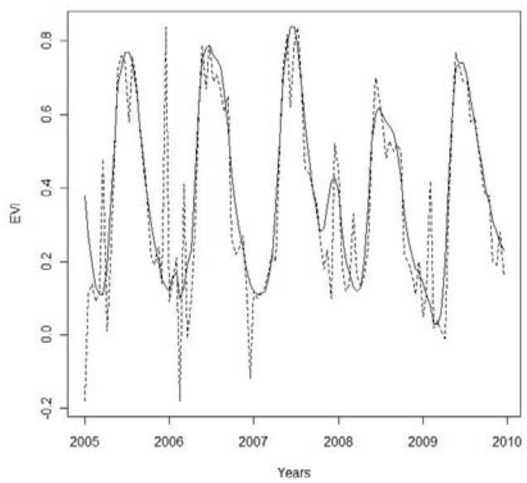
Plot 2:



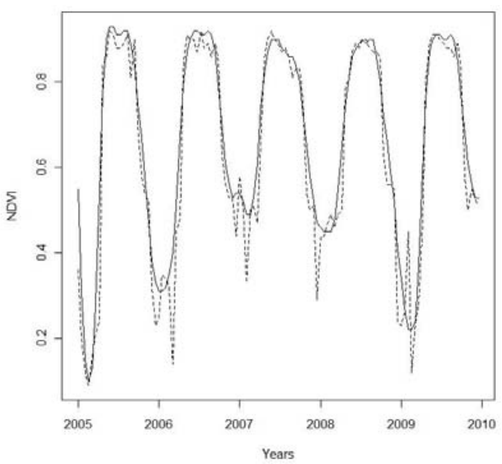



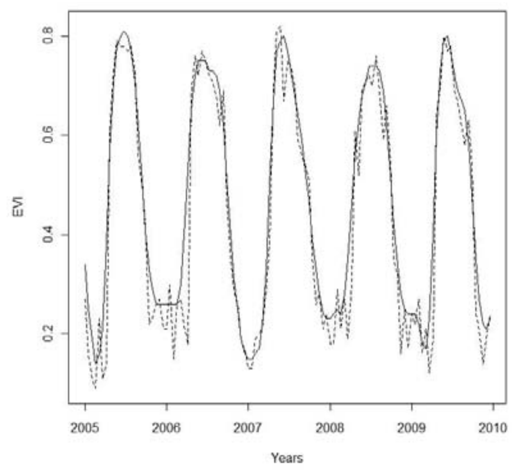

Plot 3:



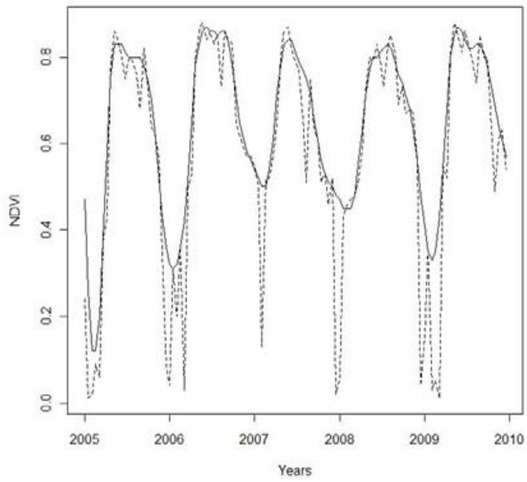



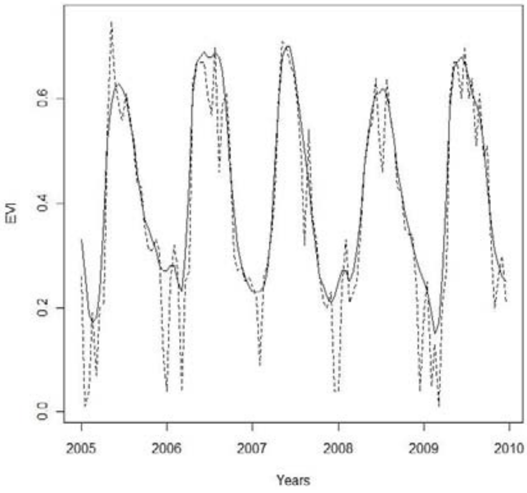

Plot 4:



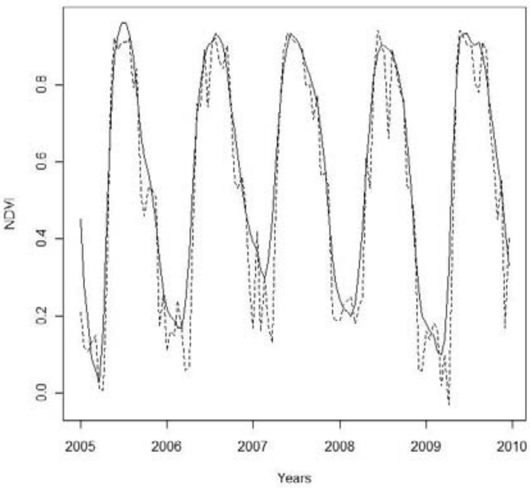



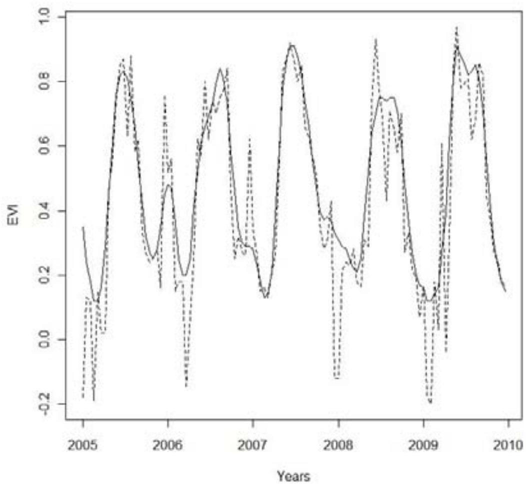
Plot 5:



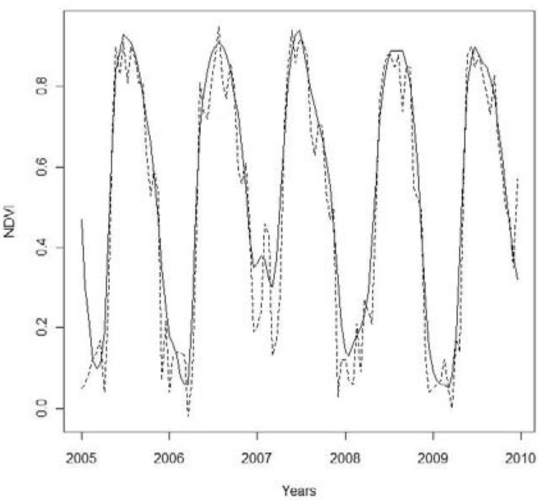



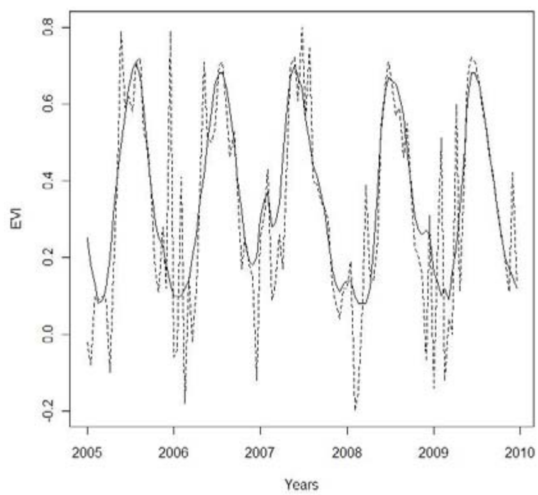

Plot 6:




Plot 7:



Appendix 6: Average of MODIS NDVI values per plot every 16 days (2005-2009)

| Plots No. | Jan (1) | Jan (2) | Feb (1) | Feb (2) | Mar (1) | Mar (2) | Apr (1) | Apr (2) | May (1) | May (2) | Jun (1) | Jun (2) | Jul (1) | Jul (2) | Aug (1) | Aug (2) | Sep (1) | Sep (2) | Oct | Nov (1) | Nov (2) | Dec (1) | Dec (2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.34 | 0.28 | 0.23 | 0.19 | 0.19 | 0.27 | 0.44 | 0.65 | 0.81 | 0.89 | 0.92 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 | 0.83 | 0.76 | 0.69 | 0.61 | 0.51 | 0.42 | 0.34 |
| 2 | 0.33 | 0.26 | 0.21 | 0.22 | 0.27 | 0.40 | 0.56 | 0.70 | 0.81 | 0.85 | 0.86 | 0.83 | 0.81 | 0.79 | 0.79 | 0.78 | 0.77 | 0.73 | 0.68 | 0.63 | 0.55 | 0.48 | 0.40 |
| 3 | 0.34 | 0.30 | 0.27 | 0.26 | 0.31 | 0.42 | 0.57 | 0.70 | 0.78 | 0.82 | 0.81 | 0.78 | 0.74 | 0.71 | 0.69 | 0.68 | 0.68 | 0.69 | 0.67 | 0.65 | 0.58 | 0.49 | 0.41 |
| 4 | 0.18 | 0.14 | 0.13 | 0.13 | 0.15 | 0.21 | 0.31 | 0.42 | 0.50 | 0.54 | 0.55 | 0.54 | 0.51 | 0.49 | 0.48 | 0.46 | 0.46 | 0.45 | 0.44 | 0.42 | 0.36 | 0.28 | 0.20 |
| 5 | 0.13 | 0.10 | 0.08 | 0.07 | 0.07 | 0.11 | 0.19 | 0.29 | 0.38 | 0.43 | 0.45 | 0.45 | 0.44 | 0.43 | 0.41 | 0.40 | 0.40 | 0.38 | 0.37 | 0.33 | 0.28 | 0.21 | 0.16 |
| 6 | 0.33 | 0.28 | 0.26 | 0.28 | 0.35 | 0.45 | 0.56 | 0.66 | 0.73 | 0.76 | 0.75 | 0.70 | 0.65 | 0.61 | 0.60 | 0.61 | 0.61 | 0.61 | 0.60 | 0.58 | 0.53 | 0.46 | 0.39 |
| 7 | 0.28 | 0.25 | 0.23 | 0.26 | 0.31 | 0.40 | 0.50 | 0.59 | 0.66 | 0.70 | 0.70 | 0.67 | 0.64 | 0.61 | 0.59 | 0.58 | 0.58 | 0.57 | 0.56 | 0.54 | 0.48 | 0.40 | 0.33 |
| 8 | 0.26 | 0.20 | 0.15 | 0.12 | 0.13 | 0.18 | 0.32 | 0.54 | 0.74 | 0.85 | 0.91 | 0.92 | 0.91 | 0.90 | 0.88 | 0.84 | 0.79 | 0.72 | 0.64 | 0.55 | 0.45 | 0.35 | 0.27 |
| 9 | 0.36 | 0.29 | 0.24 | 0.23 | 0.25 | 0.33 | 0.48 | 0.67 | 0.82 | 0.89 | 0.92 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 | 0.83 | 0.77 | 0.69 | 0.62 | 0.55 | 0.47 | 0.40 |
| 10 | 0.38 | 0.32 | 0.30 | 0.31 | 0.38 | 0.50 | 0.63 | 0.74 | 0.83 | 0.87 | 0.88 | 0.87 | 0.85 | 0.84 | 0.83 | 0.82 | 0.79 | 0.75 | 0.70 | 0.65 | 0.58 | 0.49 | 0.43 |
| 11 | 0.30 | 0.24 | 0.21 | 0.20 | 0.23 | 0.33 | 0.49 | 0.66 | 0.79 | 0.86 | 0.88 | 0.88 | 0.87 | 0.85 | 0.84 | 0.82 | 0.78 | 0.73 | 0.67 | 0.60 | 0.52 | 0.43 | 0.34 |
| 12 | 0.31 | 0.24 | 0.20 | 0.19 | 0.24 | 0.34 | 0.52 | 0.70 | 0.83 | 0.89 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.85 | 0.81 | 0.75 | 0.68 | 0.61 | 0.52 | 0.43 | 0.36 |
| 13 | 0.44 | 0.37 | 0.32 | 0.32 | 0.35 | 0.46 | 0.63 | 0.78 | 0.86 | 0.90 | 0.91 | 0.90 | 0.90 | 0.90 | 0.90 | 0.89 | 0.85 | 0.78 | 0.70 | 0.62 | 0.55 | 0.49 | 0.45 |
| 14 | 0.51 | 0.46 | 0.41 | 0.37 | 0.38 | 0.46 | 0.60 | 0.75 | 0.85 | 0.89 | 0.91 | 0.91 | 0.90 | 0.90 | 0.90 | 0.89 | 0.85 | 0.79 | 0.70 | 0.62 | 0.56 | 0.52 | 0.49 |
| 15 | 0.44 | 0.38 | 0.34 | 0.35 | 0.41 | 0.52 | 0.65 | 0.76 | 0.82 | 0.84 | 0.84 | 0.82 | 0.82 | 0.81 | 0.81 | 0.80 | 0.77 | 0.73 | 0.68 | 0.64 | 0.58 | 0.53 | 0.49 |
| 16 | 0.45 | 0.40 | 0.37 | 0.37 | 0.41 | 0.51 | 0.64 | 0.79 | 0.86 | 0.89 | 0.90 | 0.90 | 0.89 | 0.88 | 0.89 | 0.88 | 0.84 | 0.77 | 0.67 | 0.59 | 0.55 | 0.50 | 0.47 |
| 17 | 0.29 | 0.24 | 0.21 | 0.17 | 0.18 | 0.23 | 0.37 | 0.57 | 0.76 | 0.86 | 0.91 | 0.92 | 0.92 | 0.90 | 0.88 | 0.84 | 0.78 | 0.72 | 0.65 | 0.57 | 0.47 | 0.37 | 0.30 |
| 18 | 0.25 | 0.21 | 0.18 | 0.15 | 0.14 | 0.17 | 0.28 | 0.47 | 0.67 | 0.81 | 0.87 | 0.90 | 0.90 | 0.88 | 0.86 | 0.83 | 0.79 | 0.74 | 0.67 | 0.58 | 0.47 | 0.35 | 0.25 |
| 19 | 0.33 | 0.28 | 0.24 | 0.21 | 0.20 | 0.25 | 0.39 | 0.59 | 0.77 | 0.87 | 0.91 | 0.93 | 0.92 | 0.92 | 0.90 | 0.88 | 0.82 | 0.76 | 0.68 | 0.60 | 0.50 | 0.40 | 0.33 |
| 20 | 0.31 | 0.25 | 0.21 | 0.21 | 0.23 | 0.34 | 0.51 | 0.68 | 0.80 | 0.85 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.79 | 0.74 | 0.67 | 0.60 | 0.51 | 0.42 | 0.34 |
| 21 | 0.34 | 0.31 | 0.29 | 0.28 | 0.30 | 0.37 | 0.52 | 0.69 | 0.82 | 0.89 | 0.91 | 0.92 | 0.91 | 0.90 | 0.89 | 0.87 | 0.84 | 0.78 | 0.71 | 0.63 | 0.54 | 0.44 | 0.36 |
| 22 | 0.36 | 0.31 | 0.27 | 0.25 | 0.28 | 0.37 | 0.54 | 0.71 | 0.83 | 0.89 | 0.90 | 0.90 | 0.89 | 0.88 | 0.88 | 0.86 | 0.83 | 0.77 | 0.69 | 0.61 | 0.54 | 0.46 | 0.40 |
| 23 | 0.39 | 0.34 | 0.31 | 0.29 | 0.30 | 0.37 | 0.52 | 0.70 | 0.82 | 0.89 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.88 | 0.83 | 0.76 | 0.68 | 0.60 | 0.52 | 0.44 | 0.39 |
| 24 | 0.47 | 0.43 | 0.39 | 0.37 | 0.39 | 0.46 | 0.60 | 0.74 | 0.85 | 0.90 | 0.91 | 0.92 | 0.91 | 0.91 | 0.91 | 0.89 | 0.84 | 0.77 | 0.68 | 0.60 | 0.54 | 0.50 | 0.48 |
| 25 | 0.51 | 0.47 | 0.43 | 0.41 | 0.45 | 0.54 | 0.67 | 0.80 | 0.87 | 0.90 | 0.91 | 0.90 | 0.90 | 0.90 | 0.90 | 0.88 | 0.84 | 0.76 | 0.68 | 0.61 | 0.56 | 0.53 | 0.51 |
| 26 | 0.55 | 0.51 | 0.45 | 0.39 | 0.40 | 0.49 | 0.64 | 0.78 | 0.86 | 0.90 | 0.91 | 0.91 | 0.90 | 0.90 | 0.90 | 0.88 | 0.83 | 0.76 | 0.68 | 0.61 | 0.56 | 0.53 | 0.53 |
| 27 | 0.50 | 0.47 | 0.43 | 0.40 | 0.41 | 0.50 | 0.63 | 0.77 | 0.86 | 0.90 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.89 | 0.85 | 0.77 | 0.68 | 0.60 | 0.54 | 0.50 | 0.48 |
| 28 | 0.53 | 0.51 | 0.47 | 0.44 | 0.46 | 0.54 | 0.67 | 0.79 | 0.87 | 0.89 | 0.91 | 0.91 | 0.90 | 0.90 | 0.91 | 0.89 | 0.85 | 0.77 | 0.68 | 0.60 | 0.53 | 0.49 | 0.49 |
| 29 | 0.49 | 0.44 | 0.41 | 0.39 | 0.41 | 0.51 | 0.66 | 0.78 | 0.87 | 0.90 | 0.91 | 0.91 | 0.91 | 0.90 | 0.91 | 0.90 | 0.85 | 0.78 | 0.69 | 0.61 | 0.54 | 0.49 | 0.47 |
| 30 | 0.31 | 0.24 | 0.19 | 0.20 | 0.23 | 0.33 | 0.49 | 0.66 | 0.78 | 0.84 | 0.86 | 0.85 | 0.82 | 0.78 | 0.75 | 0.73 | 0.71 | 0.69 | 0.66 | 0.62 | 0.56 | 0.47 | 0.37 |
| 31 | 0.31 | 0.24 | 0.19 | 0.20 | 0.23 | 0.33 | 0.49 | 0.66 | 0.78 | 0.84 | 0.86 | 0.85 | 0.82 | 0.78 | 0.75 | 0.73 | 0.71 | 0.69 | 0.66 | 0.62 | 0.56 | 0.47 | 0.37 |
| 32 | 0.30 | 0.26 | 0.23 | 0.21 | 0.22 | 0.31 | 0.47 | 0.65 | 0.78 | 0.85 | 0.88 | 0.89 | 0.88 | 0.87 | 0.85 | 0.81 | 0.76 | 0.70 | 0.63 | 0.56 | 0.48 | 0.39 | 0.33 |
| 33 | 0.36 | 0.31 | 0.26 | 0.24 | 0.25 | 0.32 | 0.48 | 0.66 | 0.81 | 0.88 | 0.91 | 0.92 | 0.91 | 0.90 | 0.88 | 0.86 | 0.81 | 0.75 | 0.68 | 0.60 | 0.51 | 0.43 | 0.38 |
| 34 | 0.31 | 0.27 | 0.25 | 0.24 | 0.26 | 0.31 | 0.43 | 0.62 | 0.79 | 0.88 | 0.91 | 0.91 | 0.89 | 0.87 | 0.86 | 0.83 | 0.79 | 0.73 | 0.66 | 0.57 | 0.48 | 0.39 | 0.33 |
| 35 | 0.34 | 0.28 | 0.24 | 0.23 | 0.24 | 0.31 | 0.47 | 0.66 | 0.81 | 0.88 | 0.92 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 | 0.83 | 0.76 | 0.69 | 0.61 | 0.53 | 0.43 | 0.35 |
| 36 | 0.38 | 0.32 | 0.27 | 0.24 | 0.25 | 0.33 | 0.49 | 0.69 | 0.83 | 0.90 | 0.92 | 0.93 | 0.92 | 0.91 | 0.90 | 0.87 | 0.82 | 0.76 | 0.70 | 0.62 | 0.53 | 0.43 | 0.36 |
| 37 | 0.49 | 0.44 | 0.41 | 0.41 | 0.46 | 0.56 | 0.68 | 0.80 | 0.86 | 0.89 | 0.90 | 0.90 | 0.89 | 0.89 | 0.89 | 0.87 | 0.83 | 0.76 | 0.68 | 0.62 | 0.57 | 0.52 | 0.49 |
| 38 | 0.47 | 0.44 | 0.39 | 0.38 | 0.42 | 0.51 | 0.64 | 0.77 | 0.84 | 0.88 | 0.89 | 0.89 | 0.88 | 0.88 | 0.88 | 0.86 | 0.82 | 0.76 | 0.68 | 0.61 | 0.54 | 0.49 | 0.47 |
| 39 | 0.36 | 0.30 | 0.26 | 0.25 | 0.27 | 0.37 | 0.53 | 0.69 | 0.81 | 0.87 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.86 | 0.82 | 0.75 | 0.68 | 0.60 | 0.53 | 0.45 | 0.40 |
| 40 | 0.33 | 0.27 | 0.23 | 0.21 | 0.22 | 0.32 | 0.48 | 0.66 | 0.79 | 0.85 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.83 | 0.79 | 0.72 | 0.65 | 0.58 | 0.50 | 0.43 | 0.36 |
| 41 | 0.21 | 0.15 | 0.11 | 0.09 | 0.10 | 0.15 | 0.29 | 0.45 | 0.59 | 0.64 | 0.67 | 0.68 | 0.67 | 0.67 | 0.67 | 0.65 | 0.62 | 0.59 | 0.54 | 0.48 | 0.40 | 0.30 | 0.23 |
| 42 | 0.23 | 0.17 | 0.13 | 0.12 | 0.15 | 0.22 | 0.36 | 0.53 | 0.69 | 0.78 | 0.81 | 0.83 | 0.82 | 0.81 | 0.79 | 0.76 | 0.71 | 0.66 | 0.59 | 0.51 | 0.43 | 0.34 | 0.27 |
| 43 | 0.33 | 0.28 | 0.25 | 0.25 | 0.28 | 0.39 | 0.55 | 0.71 | 0.81 | 0.86 | 0.88 | 0.88 | 0.86 | 0.85 | 0.83 | 0.82 | 0.78 | 0.74 | 0.68 | 0.61 | 0.54 | 0.45 | 0.39 |
| 44 | 0.39 | 0.33 | 0.30 | 0.29 | 0.32 | 0.43 | 0.59 | 0.74 | 0.84 | 0.88 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.82 | 0.77 | 0.70 | 0.63 | 0.56 | 0.48 | 0.41 |
| 45 | 0.48 | 0.45 | 0.41 | 0.38 | 0.37 | 0.41 | 0.54 | 0.70 | 0.82 | 0.88 | 0.91 | 0.91 | 0.91 | 0.91 | 0.90 | 0.89 | 0.85 | 0.79 | 0.71 | 0.63 | 0.55 | 0.48 | 0.45 |
| 46 | 0.48 | 0.45 | 0.41 | 0.38 | 0.37 | 0.41 | 0.54 | 0.70 | 0.82 | 0.88 | 0.91 | 0.91 | 0.91 | 0.91 | 0.90 | 0.89 | 0.85 | 0.79 | 0.71 | 0.63 | 0.55 | 0.48 | 0.45 |
| 47 | 0.40 | 0.36 | 0.33 | 0.32 | 0.31 | 0.36 | 0.47 | 0.63 | 0.78 | 0.87 | 0.91 | 0.92 | 0.92 | 0.92 | 0.92 | 0.90 | 0.85 | 0.79 | 0.70 | 0.62 | 0.53 | 0.44 | 0.38 |
| 48 | 0.40 | 0.36 | 0.33 | 0.32 | 0.31 | 0.36 | 0.47 | 0.63 | 0.78 | 0.87 | 0.91 | 0.92 | 0.92 | 0.92 | 0.92 | 0.90 | 0.85 | 0.79 | 0.70 | 0.62 | 0.53 | 0.44 | 0.38 |
| 49 | 0.43 | 0.38 | 0.35 | 0.36 | 0.44 | 0.56 | 0.69 | 0.79 | 0.85 | 0.87 | 0.86 | 0.84 | 0.81 | 0.79 | 0.78 | 0.77 | 0.76 | 0.75 | 0.72 | 0.68 | 0.62 | 0.53 | 0.47 |
| 50 | 0.43 | 0.38 | 0.35 | 0.38 | 0.46 | 0.59 | 0.70 | 0.77 | 0.79 | 0.77 | 0.75 | 0.72 | 0.68 | 0.66 | 0.66 | 0.67 | 0.69 | 0.71 | 0.71 | 0.69 | 0.64 | 0.57 | 0.50 |

(1): First 16 days per month
(2): Second 16 days per month

Appendix 7: Average of MODIS EVI values per plot every 16 days (2005-2009)

| Plots No. | Jan (1) | Jan (2) | Feb (1) | Feb (2) | Mar (1) | Mar (2) | Apr (1) | Apr (2) | May (1) | May (2) | Jun (1) | Jun (2) | Jul (1) | Jul (2) | Aug (1) | Aug (2) | Sep (1) | Sep (2) | Oct | Nov (1) | Nov (2) | Dec (1) | Dec (2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.36 | 0.35 | 0.32 | 0.26 | 0.25 | 0.27 | 0.35 | 0.51 | 0.66 | 0.76 | 0.79 | 0.79 | 0.77 | 0.74 | 0.70 | 0.64 | 0.56 | 0.47 | 0.39 | 0.34 | 0.32 | 0.31 | 0.30 |
| 2 | 0.32 | 0.30 | 0.29 | 0.29 | 0.29 | 0.32 | 0.41 | 0.54 | 0.65 | 0.70 | 0.71 | 0.68 | 0.63 | 0.59 | 0.57 | 0.54 | 0.51 | 0.46 | 0.40 | 0.36 | 0.34 | 0.32 | 0.30 |
| 3 | 0.31 | 0.28 | 0.26 | 0.25 | 0.26 | 0.31 | 0.40 | 0.51 | 0.60 | 0.64 | 0.65 | 0.61 | 0.56 | 0.51 | 0.48 | 0.45 | 0.44 | 0.43 | 0.43 | 0.41 | 0.39 | 0.36 | 0.33 |
| 4 | 0.14 | 0.12 | 0.12 | 0.12 | 0.14 | 0.17 | 0.21 | 0.27 | 0.34 | 0.38 | 0.39 | 0.38 | 0.36 | 0.34 | 0.31 | 0.30 | 0.28 | 0.27 | 0.26 | 0.25 | 0.22 | 0.19 | 0.16 |
| 5 | 0.14 | 0.13 | 0.11 | 0.11 | 0.12 | 0.13 | 0.17 | 0.22 | 0.28 | 0.30 | 0.31 | 0.31 | 0.30 | 0.30 | 0.30 | 0.29 | 0.28 | 0.26 | 0.24 | 0.22 | 0.20 | 0.18 | 0.16 |
| 6 | 0.22 | 0.20 | 0.18 | 0.20 | 0.23 | 0.30 | 0.38 | 0.45 | 0.52 | 0.56 | 0.55 | 0.51 | 0.45 | 0.40 | 0.38 | 0.37 | 0.37 | 0.36 | 0.36 | 0.34 | 0.32 | 0.30 | 0.27 |
| 7 | 0.21 | 0.20 | 0.18 | 0.18 | 0.22 | 0.25 | 0.30 | 0.37 | 0.44 | 0.49 | 0.50 | 0.48 | 0.43 | 0.39 | 0.37 | 0.35 | 0.35 | 0.34 | 0.33 | 0.32 | 0.30 | 0.27 | 0.25 |
| 8 | 0.23 | 0.18 | 0.15 | 0.11 | 0.11 | 0.14 | 0.22 | 0.37 | 0.56 | 0.69 | 0.74 | 0.75 | 0.72 | 0.67 | 0.62 | 0.56 | 0.48 | 0.40 | 0.32 | 0.28 | 0.26 | 0.24 | 0.22 |
| 9 | 0.32 | 0.31 | 0.29 | 0.26 | 0.27 | 0.28 | 0.37 | 0.54 | 0.68 | 0.76 | 0.78 | 0.77 | 0.76 | 0.73 | 0.70 | 0.65 | 0.58 | 0.49 | 0.39 | 0.32 | 0.28 | 0.25 | 0.25 |
| 10 | 0.27 | 0.25 | 0.24 | 0.26 | 0.27 | 0.34 | 0.45 | 0.57 | 0.67 | 0.72 | 0.74 | 0.73 | 0.70 | 0.67 | 0.64 | 0.59 | 0.53 | 0.47 | 0.40 | 0.35 | 0.31 | 0.28 | 0.26 |
| 11 | 0.25 | 0.22 | 0.20 | 0.20 | 0.21 | 0.27 | 0.37 | 0.51 | 0.63 | 0.69 | 0.72 | 0.72 | 0.70 | 0.67 | 0.64 | 0.59 | 0.54 | 0.47 | 0.40 | 0.34 | 0.29 | 0.25 | 0.24 |
| 12 | 0.25 | 0.23 | 0.23 | 0.24 | 0.29 | 0.36 | 0.47 | 0.60 | 0.70 | 0.75 | 0.77 | 0.76 | 0.74 | 0.71 | 0.68 | 0.63 | 0.56 | 0.48 | 0.39 | 0.33 | 0.29 | 0.27 | 0.25 |
| 13 | 0.24 | 0.23 | 0.21 | 0.20 | 0.22 | 0.30 | 0.45 | 0.61 | 0.71 | 0.76 | 0.77 | 0.77 | 0.74 | 0.72 | 0.69 | 0.65 | 0.57 | 0.48 | 0.38 | 0.31 | 0.26 | 0.23 | 0.22 |
| 14 | 0.24 | 0.22 | 0.20 | 0.18 | 0.19 | 0.24 | 0.38 | 0.54 | 0.67 | 0.74 | 0.77 | 0.76 | 0.74 | 0.71 | 0.68 | 0.63 | 0.56 | 0.45 | 0.34 | 0.26 | 0.21 | 0.19 | 0.18 |
| 15 | 0.26 | 0.25 | 0.23 | 0.21 | 0.22 | 0.29 | 0.41 | 0.55 | 0.62 | 0.65 | 0.66 | 0.65 | 0.63 | 0.60 | 0.57 | 0.53 | 0.46 | 0.40 | 0.34 | 0.31 | 0.28 | 0.26 | 0.25 |
| 16 | 0.17 | 0.17 | 0.18 | 0.19 | 0.23 | 0.32 | 0.44 | 0.56 | 0.64 | 0.68 | 0.70 | 0.69 | 0.67 | 0.64 | 0.60 | 0.55 | 0.48 | 0.38 | 0.28 | 0.21 | 0.16 | 0.14 | 0.13 |
| 17 | 0.31 | 0.27 | 0.22 | 0.18 | 0.16 | 0.21 | 0.31 | 0.49 | 0.65 | 0.76 | 0.79 | 0.81 | 0.80 | 0.78 | 0.77 | 0.71 | 0.62 | 0.51 | 0.40 | 0.32 | 0.29 | 0.28 | 0.28 |
| 18 | 0.19 | 0.18 | 0.16 | 0.13 | 0.14 | 0.18 | 0.25 | 0.36 | 0.46 | 0.56 | 0.63 | 0.65 | 0.65 | 0.62 | 0.58 | 0.52 | 0.44 | 0.36 | 0.28 | 0.22 | 0.19 | 0.18 | 0.17 |
| 19 | 0.39 | 0.30 | 0.24 | 0.16 | 0.13 | 0.15 | 0.26 | 0.40 | 0.60 | 0.71 | 0.73 | 0.72 | 0.70 | 0.68 | 0.64 | 0.57 | 0.47 | 0.37 | 0.27 | 0.22 | 0.21 | 0.26 | 0.32 |
| 20 | 0.20 | 0.18 | 0.17 | 0.15 | 0.16 | 0.21 | 0.33 | 0.50 | 0.61 | 0.66 | 0.67 | 0.66 | 0.63 | 0.60 | 0.57 | 0.54 | 0.49 | 0.42 | 0.35 | 0.28 | 0.23 | 0.19 | 0.17 |
| 21 | 0.42 | 0.37 | 0.33 | 0.30 | 0.29 | 0.31 | 0.41 | 0.54 | 0.66 | 0.73 | 0.75 | 0.75 | 0.72 | 0.70 | 0.67 | 0.62 | 0.54 | 0.44 | 0.33 | 0.28 | 0.27 | 0.31 | 0.35 |
| 22 | 0.21 | 0.21 | 0.20 | 0.21 | 0.23 | 0.28 | 0.39 | 0.53 | 0.66 | 0.73 | 0.74 | 0.73 | 0.70 | 0.68 | 0.65 | 0.61 | 0.55 | 0.47 | 0.37 | 0.28 | 0.22 | 0.18 | 0.17 |
| 23 | 0.27 | 0.26 | 0.23 | 0.19 | 0.17 | 0.21 | 0.33 | 0.50 | 0.67 | 0.74 | 0.77 | 0.77 | 0.76 | 0.73 | 0.70 | 0.65 | 0.56 | 0.44 | 0.34 | 0.26 | 0.22 | 0.21 | 0.21 |
| 24 | 0.24 | 0.23 | 0.21 | 0.20 | 0.20 | 0.25 | 0.37 | 0.53 | 0.65 | 0.70 | 0.72 | 0.72 | 0.70 | 0.67 | 0.64 | 0.58 | 0.49 | 0.38 | 0.29 | 0.22 | 0.18 | 0.17 | 0.17 |
| 25 | 0.22 | 0.23 | 0.22 | 0.23 | 0.25 | 0.33 | 0.47 | 0.59 | 0.67 | 0.71 | 0.72 | 0.71 | 0.69 | 0.66 | 0.63 | 0.57 | 0.49 | 0.38 | 0.27 | 0.21 | 0.17 | 0.16 | 0.15 |
| 26 | 0.23 | 0.23 | 0.23 | 0.23 | 0.24 | 0.32 | 0.45 | 0.58 | 0.67 | 0.71 | 0.73 | 0.72 | 0.70 | 0.68 | 0.64 | 0.59 | 0.51 | 0.40 | 0.31 | 0.24 | 0.20 | 0.18 | 0.17 |
| 27 | 0.24 | 0.23 | 0.22 | 0.21 | 0.21 | 0.26 | 0.40 | 0.56 | 0.68 | 0.73 | 0.75 | 0.74 | 0.72 | 0.69 | 0.66 | 0.60 | 0.52 | 0.41 | 0.31 | 0.24 | 0.20 | 0.19 | 0.18 |
| 28 | 0.22 | 0.21 | 0.21 | 0.21 | 0.25 | 0.33 | 0.46 | 0.59 | 0.68 | 0.71 | 0.73 | 0.73 | 0.71 | 0.69 | 0.65 | 0.59 | 0.51 | 0.40 | 0.29 | 0.22 | 0.19 | 0.18 | 0.18 |
| 29 | 0.25 | 0.23 | 0.21 | 0.19 | 0.21 | 0.28 | 0.42 | 0.58 | 0.69 | 0.74 | 0.76 | 0.76 | 0.74 | 0.72 | 0.69 | 0.64 | 0.55 | 0.44 | 0.34 | 0.26 | 0.22 | 0.21 | 0.20 |
| 30 | 0.24 | 0.20 | 0.16 | 0.14 | 0.14 | 0.19 | 0.30 | 0.45 | 0.59 | 0.67 | 0.70 | 0.68 | 0.64 | 0.60 | 0.56 | 0.51 | 0.46 | 0.41 | 0.36 | 0.32 | 0.29 | 0.26 | 0.23 |
| 31 | 0.24 | 0.20 | 0.16 | 0.14 | 0.14 | 0.19 | 0.30 | 0.45 | 0.59 | 0.67 | 0.70 | 0.68 | 0.64 | 0.60 | 0.56 | 0.51 | 0.46 | 0.41 | 0.36 | 0.32 | 0.29 | 0.26 | 0.23 |
| 32 | 0.23 | 0.21 | 0.20 | 0.20 | 0.21 | 0.24 | 0.33 | 0.45 | 0.58 | 0.67 | 0.69 | 0.69 | 0.67 | 0.64 | 0.61 | 0.56 | 0.48 | 0.38 | 0.30 | 0.24 | 0.21 | 0.19 | 0.19 |
| 33 | 0.28 | 0.31 | 0.34 | 0.36 | 0.38 | 0.39 | 0.45 | 0.55 | 0.65 | 0.73 | 0.77 | 0.77 | 0.75 | 0.72 | 0.69 | 0.62 | 0.53 | 0.43 | 0.34 | 0.27 | 0.23 | 0.21 | 0.21 |
| 34 | 0.20 | 0.19 | 0.18 | 0.17 | 0.18 | 0.21 | 0.30 | 0.48 | 0.67 | 0.78 | 0.82 | 0.81 | 0.77 | 0.72 | 0.67 | 0.61 | 0.53 | 0.44 | 0.34 | 0.28 | 0.23 | 0.20 | 0.20 |
| 35 | 0.31 | 0.34 | 0.32 | 0.31 | 0.29 | 0.30 | 0.40 | 0.53 | 0.67 | 0.75 | 0.79 | 0.80 | 0.78 | 0.75 | 0.71 | 0.65 | 0.57 | 0.46 | 0.36 | 0.29 | 0.24 | 0.22 | 0.22 |
| 36 | 0.29 | 0.28 | 0.29 | 0.30 | 0.32 | 0.37 | 0.44 | 0.56 | 0.66 | 0.73 | 0.76 | 0.77 | 0.75 | 0.72 | 0.68 | 0.61 | 0.52 | 0.43 | 0.35 | 0.29 | 0.26 | 0.24 | 0.26 |
| 37 | 0.22 | 0.23 | 0.22 | 0.22 | 0.25 | 0.34 | 0.47 | 0.60 | 0.68 | 0.72 | 0.72 | 0.72 | 0.70 | 0.67 | 0.63 | 0.57 | 0.49 | 0.38 | 0.29 | 0.22 | 0.17 | 0.15 | 0.15 |
| 38 | 0.24 | 0.24 | 0.23 | 0.22 | 0.23 | 0.30 | 0.42 | 0.55 | 0.63 | 0.68 | 0.70 | 0.69 | 0.67 | 0.64 | 0.60 | 0.55 | 0.49 | 0.40 | 0.31 | 0.24 | 0.20 | 0.17 | 0.17 |
| 39 | 0.26 | 0.21 | 0.19 | 0.17 | 0.19 | 0.25 | 0.36 | 0.51 | 0.64 | 0.71 | 0.74 | 0.73 | 0.72 | 0.69 | 0.67 | 0.63 | 0.57 | 0.50 | 0.42 | 0.35 | 0.31 | 0.28 | 0.26 |
| 40 | 0.27 | 0.25 | 0.23 | 0.24 | 0.25 | 0.29 | 0.38 | 0.49 | 0.60 | 0.67 | 0.70 | 0.70 | 0.68 | 0.66 | 0.63 | 0.58 | 0.52 | 0.45 | 0.39 | 0.33 | 0.29 | 0.26 | 0.23 |
| 41 | 0.15 | 0.15 | 0.14 | 0.12 | 0.12 | 0.13 | 0.21 | 0.31 | 0.38 | 0.42 | 0.44 | 0.45 | 0.46 | 0.46 | 0.45 | 0.43 | 0.40 | 0.36 | 0.32 | 0.28 | 0.25 | 0.20 | 0.17 |
| 42 | 0.23 | 0.19 | 0.16 | 0.14 | 0.13 | 0.15 | 0.23 | 0.36 | 0.49 | 0.59 | 0.62 | 0.62 | 0.60 | 0.57 | 0.54 | 0.49 | 0.44 | 0.38 | 0.33 | 0.29 | 0.27 | 0.24 | 0.22 |
| 43 | 0.21 | 0.19 | 0.16 | 0.16 | 0.20 | 0.27 | 0.38 | 0.50 | 0.59 | 0.66 | 0.69 | 0.70 | 0.68 | 0.63 | 0.58 | 0.53 | 0.47 | 0.39 | 0.32 | 0.27 | 0.23 | 0.21 | 0.19 |
| 44 | 0.24 | 0.23 | 0.22 | 0.21 | 0.24 | 0.30 | 0.40 | 0.53 | 0.63 | 0.69 | 0.73 | 0.73 | 0.70 | 0.66 | 0.62 | 0.57 | 0.51 | 0.43 | 0.35 | 0.28 | 0.23 | 0.20 | 0.19 |
| 45 | 0.17 | 0.18 | 0.20 | 0.22 | 0.24 | 0.30 | 0.39 | 0.54 | 0.65 | 0.71 | 0.74 | 0.74 | 0.72 | 0.69 | 0.66 | 0.60 | 0.52 | 0.39 | 0.27 | 0.19 | 0.14 | 0.12 | 0.11 |
| 46 | 0.22 | 0.22 | 0.21 | 0.18 | 0.16 | 0.19 | 0.30 | 0.46 | 0.62 | 0.71 | 0.74 | 0.75 | 0.73 | 0.70 | 0.66 | 0.61 | 0.53 | 0.42 | 0.31 | 0.23 | 0.18 | 0.16 | 0.15 |
| 47 | 0.22 | 0.22 | 0.21 | 0.21 | 0.20 | 0.24 | 0.31 | 0.45 | 0.59 | 0.68 | 0.72 | 0.73 | 0.71 | 0.68 | 0.65 | 0.59 | 0.50 | 0.38 | 0.28 | 0.21 | 0.17 | 0.15 | 0.15 |
| 48 | 0.22 | 0.22 | 0.21 | 0.21 | 0.20 | 0.24 | 0.31 | 0.45 | 0.59 | 0.68 | 0.72 | 0.73 | 0.71 | 0.68 | 0.65 | 0.59 | 0.50 | 0.38 | 0.28 | 0.21 | 0.17 | 0.15 | 0.15 |
| 49 | 0.35 | 0.33 | 0.31 | 0.30 | 0.32 | 0.38 | 0.48 | 0.59 | 0.66 | 0.71 | 0.71 | 0.69 | 0.64 | 0.60 | 0.57 | 0.54 | 0.51 | 0.47 | 0.43 | 0.39 | 0.36 | 0.34 | 0.33 |
| 50 | 0.30 | 0.27 | 0.25 | 0.27 | 0.33 | 0.41 | 0.50 | 0.56 | 0.58 | 0.59 | 0.57 | 0.54 | 0.51 | 0.48 | 0.47 | 0.47 | 0.48 | 0.49 | 0.49 | 0.48 | 0.45 | 0.41 | 0.35 |

(1): First 16 days per month

(2): Second 16 days per month

Appendix 8: Onset, end and LGS (days of year) measured from NDVI

| Plots No. | Onset of LGS | End of LGS | LGS (days) | Plots No. | Onset of LGS | End of LGS | LGS (days) |
|---|---|---|---|---|---|---|---|
| 1 | 105 | 314 | 209 | 26 | 98 | 296 | 198 |
| 2 | 92 | 329 | 237 | 27 | 96 | 299 | 203 |
| 3 | 89 | 334 | 245 | 28 | 94 | 294 | 200 |
| 4 | 96 | 330 | 234 | 29 | 95 | 298 | 202 |
| 5 | 104 | 329 | 225 | 30 | 99 | 329 | 230 |
| 6 | 86 | 329 | 243 | 31 | 99 | 329 | 230 |
| 7 | 89 | 327 | 238 | 32 | 101 | 313 | 212 |
| 8 | 111 | 309 | 198 | 33 | 102 | 313 | 211 |
| 9 | 103 | 317 | 214 | 34 | 107 | 308 | 201 |
| 10 | 88 | 326 | 238 | 35 | 103 | 317 | 214 |
| 11 | 97 | 324 | 227 | 36 | 102 | 315 | 213 |
| 12 | 98 | 319 | 221 | 37 | 91 | 299 | 208 |
| 13 | 94 | 309 | 215 | 38 | 96 | 299 | 203 |
| 14 | 100 | 303 | 203 | 39 | 98 | 318 | 220 |
| 15 | 90 | 328 | 228 | 40 | 100 | 317 | 217 |
| 16 | 93 | 302 | 208 | 41 | 103 | 328 | 225 |
| 17 | 110 | 308 | 198 | 42 | 104 | 317 | 213 |
| 18 | 116 | 315 | 198 | 43 | 96 | 321 | 225 |
| 19 | 109 | 314 | 205 | 44 | 94 | 320 | 226 |
| 20 | 97 | 321 | 224 | 45 | 104 | 309 | 205 |
| 21 | 100 | 318 | 218 | 46 | 104 | 309 | 205 |
| 22 | 98 | 318 | 220 | 47 | 102 | 308 | 206 |
| 23 | 101 | 310 | 209 | 48 | 109 | 309 | 200 |
| 24 | 98 | 303 | 205 | 49 | 83 | 328 | 245 |
| 25 | 95 | 295 | 200 | 50 | 83 | 328 | 245 |

Appendix 9: Onset, end and LGS (days of year) measured from EVI

| Plots No. | Onset of LGS | End of LGS | LGS (days) | Plots No. | Onset of LGS | End of LGS | LGS (days) |
|---|---|---|---|---|---|---|---|
| 1 | 112 | 267 | 155 | 26 | 96 | 265 | 169 |
| 2 | 106 | 262 | 156 | 27 | 103 | 265 | 162 |
| 3 | 102 | 262 | 160 | 28 | 94 | 266 | 171 |
| 4 | 104 | 310 | 206 | 29 | 101 | 269 | 167 |
| 5 | 109 | 311 | 202 | 30 | 109 | 271 | 162 |
| 6 | 93 | 277 | 184 | 31 | 109 | 271 | 162 |
| 7 | 103 | 292 | 189 | 32 | 109 | 266 | 157 |
| 8 | 100 | 293 | 151 | 33 | 68 | 235 | 166 |
| 9 | 110 | 268 | 158 | 34 | 92 | 265 | 173 |
| 10 | 100 | 272 | 172 | 35 | 109 | 267 | 157 |
| 11 | 105 | 279 | 174 | 36 | 102 | 264 | 162 |
| 12 | 100 | 270 | 170 | 37 | 92 | 265 | 173 |
| 13 | 99 | 273 | 174 | 38 | 98 | 267 | 168 |
| 14 | 105 | 271 | 166 | 39 | 107 | 280 | 173 |
| 15 | 99 | 265 | 164 | 40 | 105 | 275 | 170 |
| 16 | 93 | 268 | 175 | 41 | 108 | 306 | 198 |
| 17 | 114 | 274 | 160 | 42 | 113 | 279 | 166 |
| 18 | 118 | 266 | 148 | 43 | 102 | 267 | 164 |
| 19 | 117 | 258 | 141 | 44 | 102 | 270 | 168 |
| 20 | 103 | 278 | 174 | 45 | 100 | 269 | 169 |
| 21 | 106 | 264 | 158 | 46 | 111 | 269 | 158 |
| 22 | 104 | 273 | 169 | 47 | 111 | 266 | 155 |
| 23 | 109 | 270 | 161 | 48 | 111 | 266 | 155 |
| 24 | 104 | 264 | 160 | 49 | 100 | 261 | 161 |
| 25 | 92 | 265 | 172 | 50 | 82 | 332 | 249 |

Appendix 10: Descriptive soil map legend for Pizzalto Mountain

Soil-landscape legend, Majella National Park

**1-Continental Plio-Quaternary Units**

Debris alluvial cone, fluvial and colluvial deposits, moraine deposits, paleosols on residual deposits (Terra Rossa) and fluvial deposits.

**Soil A** : Slope areas covered by recent or current debris and alluvial cone and/or moraine deposits. The morphology is regular (smooth) and the slope goes from moderately sloping to steep.(Typic Rendolls); 1100-2250 m; materials derived from these; less dry, deep, steep slopes, calcareous.
**Soil B**: Slope areas covered by colluvial deposits mixed with debris and/or moraine deposits over residuum. The surface morphology is irregular and the slopes are mostly steep. The dominant processes are superficial and deep gravitational phenomena (mass movements). (Typic and Aquic Eutrochrepts); 1000-1600 m; toe and footslopes below unit A; locates in a toe slope position and probably receives seepage from above may have more rock fragments; less dry, deep, steep, slopes calcareous : has a highest moisture-holding capacity.

**3 -Terrigenous Units**

Alternating beds of sandy pelites, multi-coloured claystones and calcareous arenites.

**Soil C**: Hilly relief mostly composed of clay-marl, with alternations of sandy levels. Morphology is gently undulating to undulating, with slopes from strongly sloping to steep subject. Superficial landslide processes. Local badland formation. (Typic Eutrochrepts, inclusions of Aquatic Eutrochrepts); 1000-1500 m; lowest unit on the landscape but soils are not debris, they are weathered in place; less dry, some seepage (wettest soil), deep, moderate slopes

**4-Limestone units of the continental platform and slope**

**Soil D**: Includes transitional units from limestone to marl. Slopes with irregular morphology with very steep slopes. Landslide and ice-induced (cryoclastic) phenomena prevail. Many rock outcrops, therefore irregular slope shape with local cliffs (Lithic Udorthents and Lithic Rendolls); elevation 1300-2500 m; dry, shallow, hill slope, calcareous.

(Source: Orgil, 2007)