THESIS

ESTIMATION OF CARBON STOCK CHANGES IN ABOVE GROUND WOODY BIOMASS DUE TO VOLCANO PYROCLASTIC FLOW AND PYROCLASTIC SURGE THE CASE OF MERAPI VOLCANO NATIONAL PARK

Thesis submitted to the Double Degree M.Sc. Programme, Gadjah Mada University and
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This document describes work undertaken as part of a programme of study at the Double Degree International Program of Geo-information for Spatial Planning and Risk Management, a Joint Education Program of Institute for Geo-information Science and Earth Observation, the Netherlands and Gadjah Mada University, Indonesia. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute

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ABSTRACT

Merapi volcano is active volcano which is well known for its pyroclastic flow. Merapi Volcano National Park (MVNP) is susceptible to volcanic hazard since it is located around Merapi volcano. Carbon sequestration in the national park is becoming a priority of forest development as stipulated in Government Regulation Number 28 Year 2011 and Number 49 Year 2011. Therefore, this study aims to know the effect of pyroclastic event to carbon stock in MVNP. In this study the natural carbon rate recovery in MVNP was estimated to determine the growth rate of natural carbon recovery in MVNP. Carbon stock in rehabilitation area was also estimated since there is rehabilitation activity in MVNP.

To estimate carbon stock change in MVNP, 2006 QuickBird and 2011 GeoEye satellite imageries were used. Object based image segmentation of high resolution satellites imagery could recognize physical dimensions of individual trees such as crown projection area (CPA). In this study, carbon stock was derived using allometric equation based on measured diameter at breast height (DBH) in the field. A model was developed to estimate carbon stock based on DBH estimation in the field and segmented CPA from the image. Earlier studies had shown that a relation exists between CPA and DBH. Carbon in affected area was estimated based on field measurement because no tree crowns were visible here.

Based on the segmentation process, the model of CPA and Carbon in MVNP was developed. The F score which indicate the accuracy of segmentation of needle leaf and broadleaved of 2011 GeoEye were 0.68 and 0.54 respectively. Logarithmic model which has 6.37 % error was used to estimate broadleaved carbon stock while quadratic model which has 10.31 % error was used to estimate Pine tree carbon stock in MVNP. Merapi volcano erupts 4-6 years periodically since 19^{th} century with Volcanic Explosivity Index (VEI) ≤ 2. The VEI 2 pyroclastic flow could reach distance to 7 km from the crater with different direction. Since MVNP is located in range of 7 km from the crater, it always prone to pyroclastic flow. In the affected area, carbon stock is high in the area farthest from the crater.

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LIST OF ABBREVIATIONS

CPA	Crown Projection Area
DBH	Diameter at Breast Height
ETM	Enhanced Thematic Mapper
FN	False Negative
FP	False Positive
GHG	Green House Gasses
IPB	Institut Pertanian Bogor Bogor Agricultural University
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
ITC	International Institute for Geo-information Science and Earth Observation
LiDAR	Light Detection and Ranging
MVNP	Merapi Volcano National Park
RMSE	Root Mean Square Error
SNI	Standar Nasional Indonesia Indonesia National Standard
SPOT	System for Earth Observation
SPSS	Statistical Package for the Social Sciences
TM	Thematic Mapper
TP	True Positive
UGM	Universitas Gadjah Mada Gadjah Mada University
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VEI	Volcanic Explosivity Index

CHAPTER I
INTRODUCTION

1.1. Background

Climate change is defined as changes in climate that are caused by nature dynamics or human activity. It means that the global climate system is warmed. This phenomenon is strengthened by the Intergovernmental Panel on Climate Change (IPCC) study (2007) that shows the increase in average temperature of air and ocean, the melting of snow and ice and the rise of global average sea level. The main cause of climate change is the increase of green house gasses (GHG) in the atmosphere. Solar radiation can pass through the GHGs and heat up the earth but accumulated thermal radiation from the earth cannot easily pass through. Consequently the atmosphere warms up. GHGs are CO_2, CH_4, N_2O. CO_2 is the main GHG which is sourced from the burning of fossil fuel, agriculture, and land use changes and deforestation (IPCC, 2012). The increasing population has caused the landuse changes; one of it is changing forestland into agricultural use. In addition, a large demand for fuel wood, fodder, and timber will reduce forest area. Deforestation will generate land and environmental degradation and also cause the increasing of greenhouse gasses (Chatterjee, 2003)

One way to control climate change and to reduce green house gas increase is to maintain the integrity of natural forests and increase the density of trees outside the forest. Vegetation is a carbon sink which stores more carbon than it emits. Forest is the best carbon sink since it stores carbon in large amounts (IPCC, 2006). So it has important role in controlling climate change. Reducing forests will reduce the amount of carbon that is stored and sequestrated by forest. Natural hazards such as volcanic hazard are natural phenomena which can reduce the amount of carbon stored in vegetation because it can cause the death and disintegration of vegetation/biomass.

Merapi volcano is one of the most active volcanoes in Indonesia, well known for its pyroclastic flow. This term also known as pumice flow, ash flow, block-and-ash flow, and glowing avalanche. SEAN (1989) and Simkin and Siebert (1994) as cited in Voight et al. (2000) reported that almost 50 % of 80 reported Merapi historical eruptions occurred with pyroclastic flow. According to Crandell et al. (1984), pyroclastic materials flow along and connect with the ground surface. It occurs in 3 (three) forms which are together with pyroclastic surge, clouds of ash and basal flows; compact, it is combining with blocks, bombs, lapilli, ash, and gases.

The other type of potentially hazardous volcanic events is pyroclastic surge. It was defined by Spark (1976) as cited in Crandell et al. (1984) as cloud of gases and rock debris with low of density which flows above the ground and may occur with water or stream or both. The effects of pyroclastic surge include the destruction of structure, vegetation, severe abrasion and impact by rock fragments.

The impact of 2010 Merapi eruption on the ecosystem is huge. The Bureau of Merapi Volcano National Park (2011) reported that over 2000-2500 Ha (31-39%) of Merapi Volcano National Park (MVNP) ecosystem which is located on Merapi volcano was destroyed. Merapi eruption 2010 has affected the storage of carbon in MVNP forest. As a national park, MVNP has an important role as nature conservation area and provider of environmental services, as stipulated in Government Regulation Number 28 Year 2011 and Number 49 Year 2011. In addition, carbon sequestration in the national park is becoming a priority of forest development in the future. So it is important that carbon stock in MVNP to be estimated.

1.2. Problem Statement

MVNP is prone to volcanic hazard because it is located on Merapi Volcano. The last Merapi eruption in 2010 destroyed 31-39 % of MVNP area which was mostly forested. Since forest store carbon, the destruction of vegetation in MVNP due to pyroclastic flow and pyroclastic surge affects biomass and carbon stock in MVNP.

In general, the estimation of carbon stock changes in forests focuses on above ground woody biomass since this stores carbon in large amount (IPCC, 2006). The 2006 eruption which was occurred before 2010 eruption produced pyroclastic flow. The estimation of carbon stock changes in woody biomass in MVNP between the last eruptions events is important to know the effect of pyroclastic flow to carbon stock in above ground woody biomass in MVNP.

Pyroclastic surge is less destructing than pyroclastic flow because pyroclastic surge has lower momentum and density than pyroclastic flow (Thouret, 2010) so the effect of pyroclastic flow on the vegetation is greater than pyroclastic surge. Changes of carbon stock in MVNP in area affected by pyroclastic flow will be different with the area affected by pyroclastic surge. Areas closer to crater will be more affected by pyroclastic flow and there will be more dead woods. This is based on the assumption that pyroclastic flow destroys all vegetation and only dead wood remains in this area while dead trees are dominant in area affected by pyroclastic surge. The assumption is that vegetation is damaged by pyroclastic surge, but not all of vegetation is collapsed, there are still standing dead trees because pyroclastic surge is less destructive than pyroclastic flow. The actual conditions of carbon stock characteristics in those areas are not known yet. So carbon estimation in those areas is essential to differentiate the effect of pyroclastic flow and pyroclastic surge to remained carbon stock.

The historical data of Merapi eruption shows various directions and the distance of pyroclastic flow and pyroclastic surge that is produced from

Merapi eruptions over the past 95 years (Geology Agency). As consequently vegetation regrowth in MVNP is different as well as carbon rate recovery. Knowing the carbon recovery in MVNP will give the information about the natural carbon recovery in MVNP.

1.3. Research Questions

1. How much is carbon stock change in the unaffected area?
   a. What is the relation between carbon and Crown Projection Area (CPA)
   b. How much is the remaining above ground biomass/carbon that is stored in MVNP in 2011 in unaffected areas which are divided into Pine and broadleaf trees?
   c. How much above ground biomass/carbon which was stored in MVNP in 2006, based on the CPA-carbon model of 2011?
2. How much carbon was stored in the affected areas before eruption
   a. What was the tree density and Crown Projection Area/CPA in affected areas, before eruption
   b. What was the above ground woody carbon stock in affected areas before the eruption, based on the 2011 CPA – carbon model
3. What is remaining carbon stock in areas affected by pyroclastic flow and pyroclastic surge?
   a. How much the proportion of carbon stock in dead woods?
   b. How much the proportion of carbon stock in dead trees?
   c. What is the effect of distance from the crater on the remaining carbon?
   d. What is the difference of remaining carbon stock in pyroclastic flow and pyroclastic surge area?
   e. What is the total carbon loss
4. What is the rate of carbon recovery in MVNP?

1.4. Objectives

1. To estimate carbon stock in unaffected area
    a. To develop a model between CPA and carbon based on 2011 data
    b. To assess remaining above ground biomass and carbon in Pine and broadleaf trees that is stored in MVNP in 2011
    c. To estimate above ground biomass/carbon which was stored in MVNP in 2006
2. To estimate carbon stock before eruption in affected area
    a. To assess tree density and CPA before eruption in affected area based on 2006 image
    b. To estimate carbon stock before eruption (based on the model developed for the unaffected areas and the tree density/CPA)
3. To estimate remaining carbon stock in areas that are affected by pyroclastic flow and pyroclastic surge
    a. To estimate carbon stock in dead woods
    b. To calculate carbon stock in dead trees
    c. To identify the effect of distance from the crater on the remaining carbon stock
    d. To know the differences of remaining carbon stock in pyroclastic flow and pyroclastic surge area
    e. To estimate total carbon loss in MVNP
4. To calculate the rate of carbon recovery in MVNP

1.5. Outputs

1. Carbon stock in unaffected area
    a. Above ground biomass of Pine and broadleaf trees which was stored in MVNP in 2006
    b. Remaining above ground biomass that is stored in MVNP in 2011 in unaffected areas
2. Carbon stock that is likely to have been in the affected areas, before eruption

3. Carbon stock in areas that are affected by pyroclastic flow and pyroclastic surge
    a. Carbon stock in dead woods
    b. Carbon stock in dead trees
    c. The effect of distance from the crater to the carbon stock
        - The classification of carbon stock
        - The classification of dead woods decomposition
    d. Carbon stock in pyroclastic flow and pyroclastic surge area
    e. Total carbon loss
4. The equation of the rate of carbon recovery in MVNP

CHAPTER II
LITERATURE REVIEW

2.1. Pyroclastic Flow and Pyroclastic Surge

Pyroclastic flow and pyroclastic surge are the examples of direct volcano hazard (Tilling, 2005). Crandell et al. (1985) and Tilling (2005) differentiate pyroclastic flow and pyroclastic surge based on its material. The solid material in pyroclastic surge is less than pyroclastic flow and it has low density. The pyroclastic flow is the hot volcanic material which may occur together with pyroclastic surge, in form of clouds of ash and basal flows; compact, and combining with blocks, bombs, lapilli, ash, and gases (Crandell et al., 1985). Pyroclastic flow and pyroclastic surge originated from explosive eruption and dome collapse (Crandell, 1985 and Newhall, 2000). Pyroclastic flow streams and touches the ground surface and follows the topographic depression such as valley. The maximum temperature when it deposited could be reached 350 °C to more than 550 °C. Since the pyroclastic surge less dense than pyroclastic flow, pyroclastic surge could arise to the top of valley. The size of pyroclastic flow and pyroclastic surge affected area is depending on the energy eruption and the flow velocity of pyroclastic flow and pyroclastic surge. The effect of pyroclastic flow and pyroclastic surge to environment depend on its falling materials, the temperature and the distance of area to the volcano (Crandell et al., 1985 and Tilling, 2005).

Merapi volcano is active volcano since it was erupted more than 60 times with small to moderate eruption. Merapi volcano erupts 4-6 years periodically since 19th century with Volcanic Explosivity Index (VEI) ≤ 2. VEI is index that explains the scale of explosive eruption. Table 1 shows the description of VEI 0 – 4 (Newhall and Self, 1982).

Table 1.Volcanic Explosivity Index 0 – 4 Descriptions (Newhall and Self, 1982)

Criteria	VEI				
	0	1	2	3	4
Description	Non Explosive	Small	Moderate	Moderate-Large	Large
Ejected Volume (m3)	$<10^4$	10^4 - 10^6	10^6 - 10^7	10^7 - 10^8	10^8 - 10^9
Qualitative Description	Gentle, Effusive	Gentle, Effusive	Explosive	Explosive	Cataclysmic, Paroxysmal, Colossal

Costa et al. (2012) recorded that the Merapi eruptions in 1832, 1849, 1930, and 1961 are moderate eruption with VEI 3, Merapi eruptions in 1822, 1872 are large eruption with VEI 4. The 2010 eruption is the most explosive in the last century with VEI 4 (Lavigne et al., 2000; Costa et al., 2012 and Suronoet al., 2012). Almost half of history of Merapi volcano eruption recorded that Merapi erupted associated with pyroclastic event (Voight, 2000).

Darmawan (2012) modeled the next eruption using Titan2D Software. He predicted the next eruption based on 4 VEI scenarios (VEI 1 - 4) and validated the model using 11 November 2011 SPOT 5 satellite imagery, 2011 Geoeye satellite imagery and fieldwork. Based on the model the furthest distance of VEI 1, VEI 2, VEI 3 and VEI 4 pyroclastic flow are 3.2 km, 7 km, 12 km and 20 km from the crater respectively.

2.2. Carbon Pool

Carbon pool is the place where carbon is stored in nature (SNI 7724:2011, 2011). Atmospheric CO_2, biota, soil organic matter, and the ocean are the primary pools of actively cycling carbon. About 75 % of carbon stock in biota occurs in forests (Jansen, 2004).

According to IPCC Guidelines (2006), there are 5 (five) pools of carbon in forest, which are above ground biomass, below ground biomass, dead wood, litter and soil organic matter (Table 2).

Table 2. Carbon Pool (IPCC Guidelines, 2006)

Pool		Description
Living Biomass	Above-ground Biomass	All biomass of living vegetation, both woody and herbaceous, above the ground including stems, stumps, branches, bark, seeds and foliage
	Below-ground Biomass	All biomass of live roots. Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter
Dead Organic Matter	Deadwood	All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter
	Litter	All non-living biomass with a size greater than the limit for soil organic matter (the suggested minimum is 2 mm) and less than the minimum diameter chosen for deadwood (e.g. 10 cm) lying dead and in various states of decomposition above or within the mineral organic soil
Soil	Soil organic Matter	Organic carbon in mineral soils to a specified depth chosen and applied consistently through a time series. Live and dead fine roots within the soil (of less than the suggested minimum for below ground biomass) are included wherever they cannot be empirically distinguished from the soil organic matter

Carbon is stored by vegetation trough photosynthesis process. The results of photosynthesis process are carbohydrates ($C_6H_{12}O_6$) which are building blocks of vegetation. Mandal (2012) who studied the effect of deforestation and forest degradation on forest carbon stocks in collaborative forests in Nepal found that plant stages give different contribution in carbon stock. Pole and tree stages give high contribution to carbon stock while sapling and seedling stages give less contribution to carbon stock. Carbon is subsequently spread throughout the plant body and eventually stored in the plant body (carbon sequestration). It means that the carbon that is stored in life vegetation (biomass) is CO_2 from the atmosphere which is absorbed by vegetation. Carbon that is still stored in dead vegetation (necromass) represents the amount of CO_2 which is not released into the air (Hairiah et al., 2011)

2.3. Carbon Estimation Using Remote Sensing

Geomarasca (2004) as cited in Köhl et al. (2006) described that the role of remote sensing in forestry are forest monitoring and surveying of the land and the environment, including forest inventory, forest health and nutrition, forest sustainability and forest growth. Forest classification, land cover classification, structural and successional forest classes are the information which can be derived from the image. Detail information such as forest stand species composition, density, crown closure, height, and age can be extracted from the high resolution satellite imagery.

Satellite imagery for the estimation of carbon stock is widely used recently. The most accurate method to estimate carbon stock is destructive method by cutting and weighing the tree parts. Since it is time consuming and only restricted to small areas and small size of tree sample, the allometric equation which correlates tree diameter at breast height (DBH) or others tree variable with standing wood volume or total biomass can be applied. Allometric equation could be used as a link since carbon stock cannot directly generate from satellite imagery. Species-specific equation is preferable since different trees will have different architecture and wood density. But a general allometric equation can be applied and will not cause significant error as long as it is applied in the specified ecological region (Ketterings et al., 2001).

As most carbon is stored in woody above ground biomass, the estimation of above ground biomass is required for carbon stock inventory. Various applications of remote sensing have been developed to estimate carbon stock. Medium resolution satellite imagery measures carbon stock based on land cover classification. Mass of carbon per unit area (carbon density) is estimated based on field measurements by calculating carbon per type of land cover (Achard et al., 2004; Blackard et al., 2008; DeFries et al.,2007; Potter et al., 2008; and Saatchi et al., 2007 as cited in Gonzales et al., 2010). Medium resolution optical data is more appropriate to generate carbon stock in a simple homogeneous forest stand structure than in a complicated forest stand (Lu, 2005). Pandiwijaya (2011) estimated carbon stock in MVNP using Landsat 5 TM and Lansat 7 ETM based on MVNP land cover. Asner (2009) estimated carbon stock in eastern Brazilian Amazon forest based on the class of deforestation using LiDAR. Pareta and Pareta (2011) estimated carbon stock in Sagar District India based on its land use and land cover using Landsat ETM 7. On the other hand, physical dimensions of individual trees are recognized by high-resolution satellites which can be correlated to above ground biomass. High resolution satellite imagery such as QuickBird, IKONOS, WorldView, and GeoEye can distinguish individual tree crowns so correlation between physical dimensions of trees, such as tree crown projection area, and biomass can be acquired (Gonzales et al., 2010)

There are some researches that estimate carbon stock based on relation between DBH and Crown Projection Area (CPA). CPA is vertical projection of outward perimeter of the tree crown on the horizontal plane (Gschwantner et al., 2009) (Figure 1). The study by Avsar (2004) in Kahramanmaras, Turkey showed there was significant relationship between DBH and crown diameter. Shimano (1997) analyzed the relationship of DBH and CPA of broadleaved and coniferous in Nikko area,central Japan. The result showed that the CPA growth will slow as the growth of DBH. He also concluded that the CPA of conifer trees is lower than CPA of broadleaved trees, the growth rate of CPA of conifer trees decrease in smaller DBH than the broadleaved trees. Hemery et al. (2005) concluded that the comparison between crown diameters and stem diameters is high when the trees young but the comparison is decrease as the DBH rise.

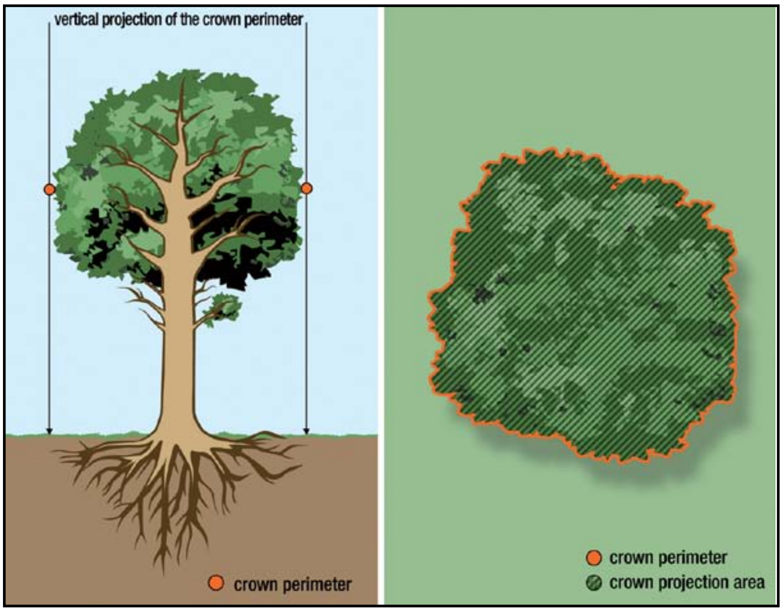


Figure 1. Crown Perimeter and Crown Projection Area (Gschwantneret al., 2009)

Shah (2011) who studied relationship between tree CPA and above ground carbon stock of standalone trees using GeoEye satellite images concluded that there is highly significant correlation (P<0.001) not only between CPA and DBH but also between CPA and biomass of standalone trees of the dominant species since biomass is derived from DBH through allometric equations.

Baral (2011) studied carbon stock mapping using GeoEye satellite images in subtropical forest of Nepal and she concluded that the relationship between CPA derived from Geo-Eye image and carbon stock obtained from DBH measured in the field is a non-linear relationship. The result of her study showed that the model validation of *Shorea robusta* and the mix of other species are 0.77 and 0.79 respectively means that the model explained 77 % and 79 % the measured carbon of *Shorea robusta* and the mix of other species respectively. The RMSE of predicted carbon stock obtained from these models is 39%; it means that the accuracy of model in carbon prediction is 61%. The accuracy of the model is acceptable since it is more than half error.

Shrestha (2011) who studied carbon stock of broadleaved and needle leaved trees in Dolakha, Nepal using GeoEye satellite imagery concluded that there were weak positive relationships between field measured DBH and CPA derived from image segmentation (CPA-segmented) of needle leaved and broadleaved trees.

Other studies are conducted by Gonzalez et al. (2010) and Bautista (2012) who compared high resolution satellite imagery; QuickBird and GeoEye respectively, combined with LiDAR data to estimate carbon stock. LiDAR provides height information for both tree canopy and the ground surface. Both concluded that forest carbon estimation using LiDAR is more accurate.

2.4. Object Based Image Analysis

The conventional method of image classification is pixel-based and uses spectral differences which differentiate several features. This method is only based on spectral information and will lead to low classification accuracy if applied to high-spatial resolution imagery (Hay and Castilla, 2008).

Instead of analyzing the image based on the pixel, object based image analysis analyze the image based on its objects. An object is defined as a group of pixels with the similar spectral and spatial properties reference. Image segmentation is the technique to create numerous objects from an image. The image is segmented into objects based on several criteria such as scale, color, smoothness and compactness. It is possible to combine those criteria to get meaningful outputs/objects. These objects correspond with/reflect features in the real world. Various aspects of remote sensing such as spectral, spatial, contextual, textural and temporal properties can be utilized in object oriented image analysis because it groups pixels together based on homogeneity of spectral and spatial characteristics (Navulur, 2007).

Image segmentation which is the process to separate an image into objects (Navulur, 2007) and is followed by image classification which labels the objects is the main parts of object based image analysis (Johansen, Bartolo and Phinn, 2010 as cited in Blaschke et al., 2011). In general there are 2 basics fundamental in image segmentation approaches which are "cutting something big into smaller pieces" or top-down segmentation and merging small pieces to get something bigger or "bottom-up method" (Definiens, 2009).

2.5. Carbon Stock and Carbon Recovery of Merapi Volcano National Park

Pandiwijaya (2011) estimated carbon stock changes in MVNP which were caused by land cover change. The results showed a decrease of carbon stock in the period 1991–2001 and in the period 1991-2009 by 1,574,581 Mg and 145,391 Mg respectively. This was due to the reduction of secondary forest area. In period 2001-2009 carbon stock of MVNP is increased by 12,06 7 Mg. The increase occurred in mixed plantation area which was rehabilitation planted by MVNP Bureau together with the community in order to rehab the destructed secondary forest area due to the 2006 Merapi eruption.

There are 2 (two) processes of regeneration in MVNP after the eruption, artificial process from rehabilitation activity and natural process.

The prerequisites of rehabilitation tree in conservation areas according to Ministry of Forestry Decree No. P.26/Menhut-II/2010 are it has a long cycle, its evaporation is low, it has a deep root, its seedlings/seeds/cuttings are from native local species of concerned conservation area or from nursery of native local species of concerned conservation area. If seedlings/seeds/cuttings are not available in concerned conservation area, seedlings/seeds/cuttings can be taken from local habitat or from other locations.

Bureau of Merapi Volcano National Park (2011) reported that *Schima wallichii* is the potential plant for rehabilitation in mountainous area, but its dominance in MVNP is not too large. Rehabilitation of MVNP after eruption has started in 2011. So the natural process of carbon recovery in MVNP occurred in affected area which is not rehabilitated.

2.6. Conceptual Framework

Figure 2 illustrates the conceptual framework of the research. The pyroclastic flow and pyroclastic surge are the main hazard studied in this research. Since the material of pyroclastic flow and pyroclastic surge is different therefore their effects into the vegetation are different (Crandell et al., 1985 and Tilling, 2005). The effect of pyroclastic flow and pyroclastic surge to vegetation as the element at risk is become important to be analyzed since forest store 75 % of carbon stock in biota (Jansen, 2004).

The use of satellite imagery to estimate carbon stock is widely use recently (Pandiwijaya, 2011; Asner, 2009; Pareta and Pareta, 2011). The use of high resolution satellite imagery allows the analysis image based on objects. The image is segmented into objects based on several criteria such as scale, color, smoothness and compactness (Navulur, 2007). Using object oriented image analysis, objects, such as tree crowns, can be created. The amount of carbon stock cannot directly obtain from the satellite imagery. The allometric equation which correlates DBH with total biomass can link the carbon stock with segmented CPA since the DBH is related with the CPA (Avsar, 2004; Shimano, 1997; Hemery et al., 2005) and develop the model of CPA-carbon relation. To protect the role of MVNP in environmental service especially its role on carbon sequestration, the carbon management in MVNP is needed.

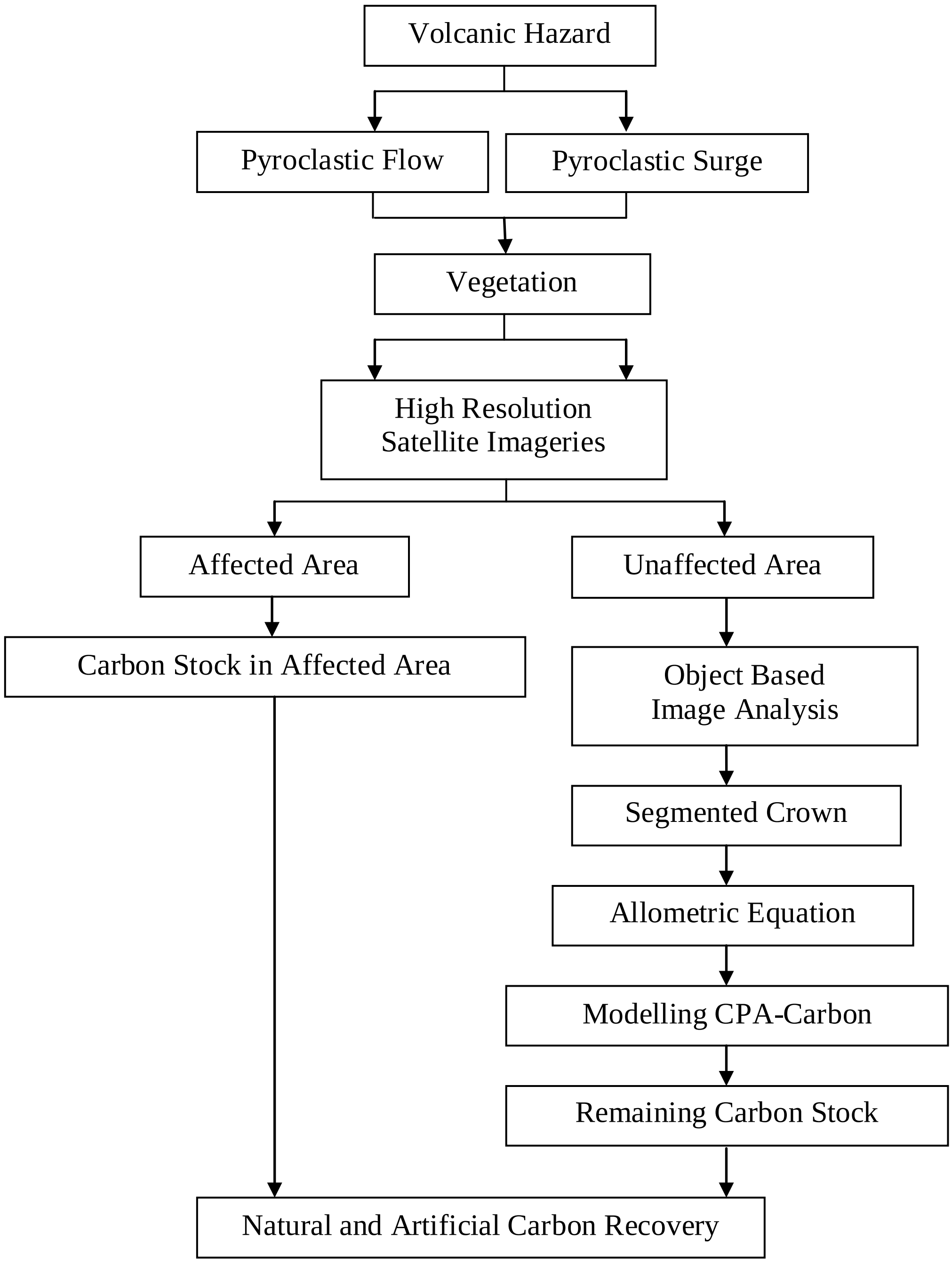


Figure 2. Conceptual Framework

CHAPTER III
RESEARCH METHOD

3.1. Study Area

Research was conducted in Merapi Volcano National Park (MVNP). It is located in Central Java and Yogyakarta Province. The 6410 hectare-MVNP was established by government based on The Forestry Ministerial Decree Number 134/MENHUT-II/2004 dated 4th of May 2004. Forest cover of MVNP before eruption based on 2009 Landsat 7 ETM are of mixed forest, secondary forest and Pine forest (Pandiwijaya, 2011). The sand which is depicted in the map represents sand areas from the eruption whereas the bare land is area is overgrown by weeds (Figure 3).

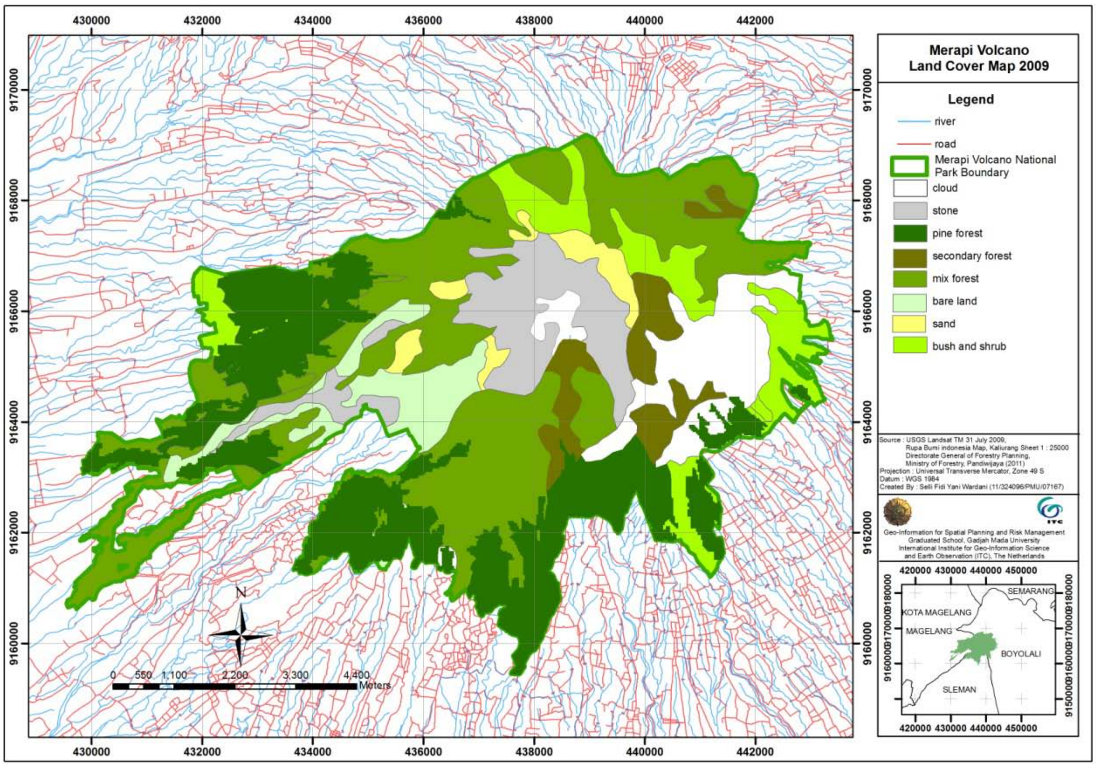


Figure 3. The 2009 Merapi Volcano National Park Land Cover Map (USGS Landsat TM 31 July 2009; Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry; Pandiwijaya, 2011)

3.2. Materials and Equipments

3.2.1. Satellite data

Two satellite data of MVNP that were used in the study were QuickBird and GeoEye.

Having 60–70 cm resolution for panchromatic imagery and 2.4 and 2.8 m resolutions for multispectral imagery, Quickbird provides high accuracy and high image resolution (Xie et al., 2008). It has a panchromatic sensor (450-900 nm) and a multispectral sensor with 4 (four) bands which are blue (450-520 nm), green (520-600 nm), red (630-690 nm) and near IR (760-900 nm). Sourced from National Land Agency of Central Java Province, QuickBird satellite imagery used for this study was recorded in 11 September 2006; before the last eruption.

GeoEye satellite imagery used for the study consist of 4 (four) scenes, it was recorded 11 June 2011 sourced from Gadjah Mada University. The image was pan-sharpened by 0.5 m and only has 3 (three) bands which are blue (450 - 510 nm), green (510 - 580 nm) and red (655 - 690 nm).

3.2.2. Map

There were some maps that were used in the study. The historic map of pyroclastic deposits of MVNP from 1911 to 2006 from Geology Agency is used to obtain the rate of natural carbon recovery in MVNP. The modeled VEI made by Darmawan (2012) was overlapped with the historic map of pyroclastic deposits of MVNP to identify the range of periodic eruption in MVNP. Based on the historic map of pyroclastic deposits we can see that the direction of pyroclastic flow of Merapi volcano is varies (Figure 4). Based on Figure 4, more than half of MVNP always prone to 4 – 6 period eruption since the period occurred with VEI≤ 2 produced maximal 7 km pyroclastic flow deposit from the crater. The distance of pyroclastic flow deposit from the crater was created based on the surface distance which was derived from the contour map from National Land Agency of Central Java Province. Based on the image, the pyroclastic flow deposit is not represented in the southwest and west part of MVNP because the contour map does not cover all areas of MVNP. The southwest and west part of MVNP and a small part of south Merapi volcano will affect by pyroclastic flow produced by VEI 3 and VEI 4 which can reach distance by 12 km and 20 km from the crater respectively.

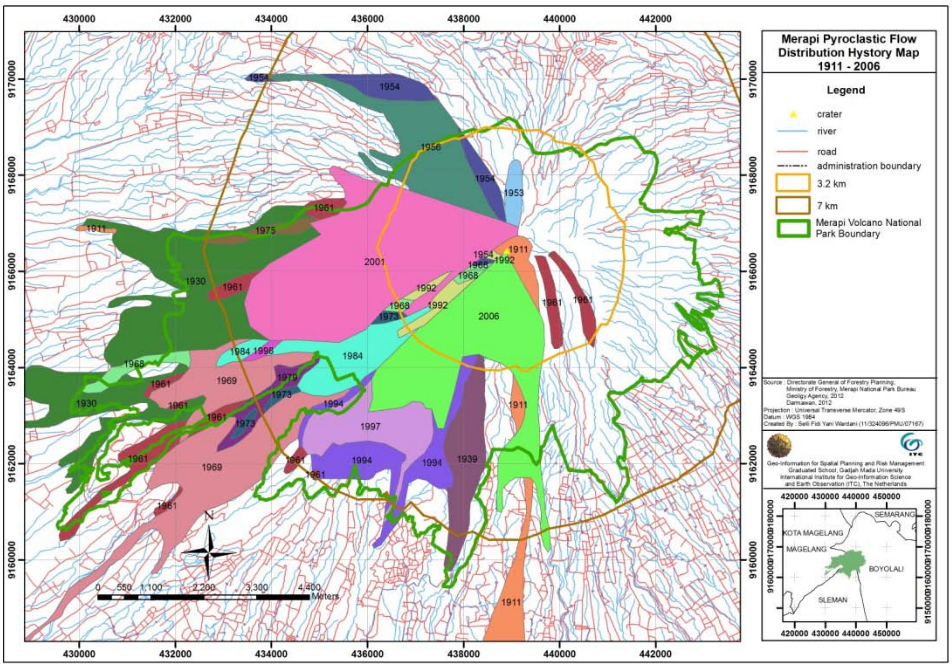


Figure 4. Merapi Pyroclastic Flow Distribution History Map 1911 - 2006 (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry; Geology Agency; Darmawan, 2012)

The rehabilitation map of MVNP (Appendix 1) from Merapi Volcano National Park Bureau (2011) was used to identify the rehabilitation area and the land cover map of MVNP (Figure 3) was used to identify the broadleaf and Pine trees areas. The map of 2010 pyroclastic flow and pyroclastic surge (Figure 5) was obtained by digitizing the 2010 pyroclastic flow and pyroclastic surge map which was made by Darmawan (2012). He made the map based on the interpretation of 2010 GeoEye which is recorded 7 months after the eruption and SPOT 5 images after the eruption and modeled pyroclastic map using Titan2D Software. He assumed the pyroclastic surge will not be seen in the 2010 GeoEye imagery because it had been removed by the rain. The Titan2D model was validated based on 2010 GeoEye and SPOT 5 imageries and field checking.

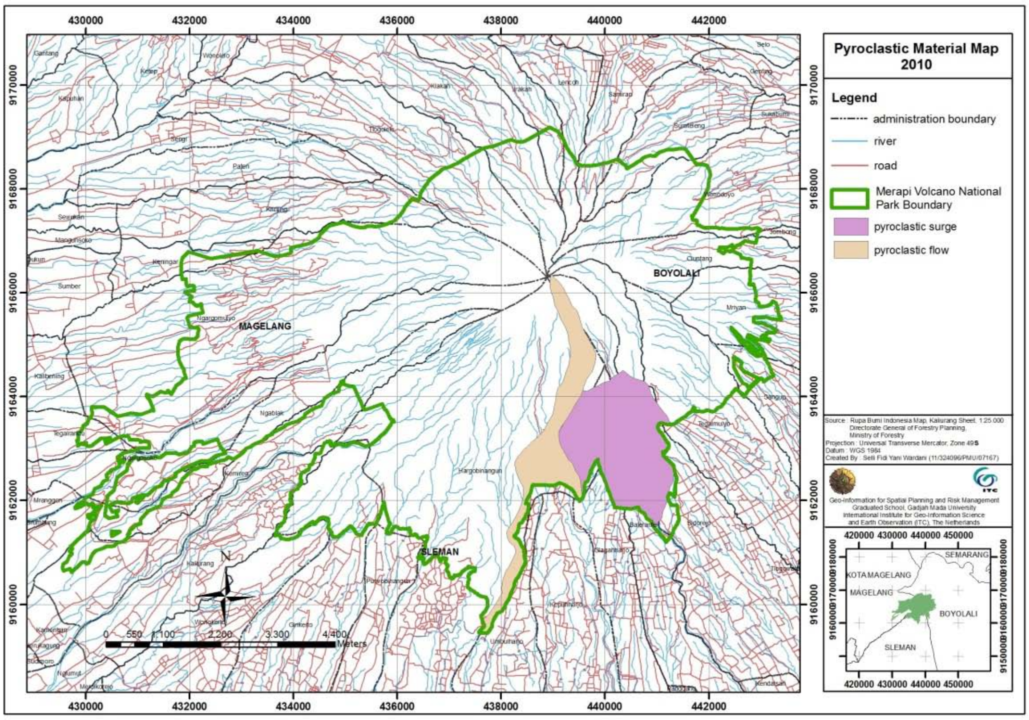


Figure 5. Pyroclastic Flow and Pyroclastic Surge Area after 2010 eruption in Merapi Volcano National Park (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate general of Forestry Planning, Ministry of Forestry; Darmawan, 2012)

3.2.3. Software

The software which were used in this study are ArcGIS, eCognition, SPSS and office software. That software were used in preprocessing, processing and analysis the data. eCognition software segmented objects based on scale, color, smoothness and compactness. It is commonly used by ITC student for object based image analysis study. The SPSS was chosen as statistical analysis tool since we have the skill on this software.

3.2.4. Equipments

The equipments that were used for in this study are presented in Table 3. The equipments were used in fieldwork and in the laboratory analysis.

Table 3. Equipments Used for Study

No.	Equipment	Function
1.	Garmin GPSmap 76CSx	Navigation system
2.	Digital Camera	To document the study
3.	Diameter tape	To measure diameter and wood length
4.	Surveyor tape, compass	Support equipments for sample plot
5.	Saw	To take sample of dead woods
6.	Weight measuring instrument	To weigh the sample of dead woods
7.	Herma Graduated Cylinder	To measure the volume of sample dead woods
8.	Oven	To dry the sample of dead wood

3.3. Method

The study area was divided into three categories which are area affected by pyroclastic flow, area affected by pyroclastic surge and the unaffected area (Figure 6).

The study conducted in unaffected area in order to obtain the segmented CPA from 2011 GeoEye imagery and develop the relation between segmented CPA and carbon by measuring the carbon based on allometric equation where DBH is the determinant factor obtained from field measurements. The model developed was used to generate remaining carbon stock and calculate carbon stock in the affected areas before eruption. The model also used to derive the natural carbon rate recovery; relation between time and carbon quantity by estimating carbon in recovery area at different times.

The estimation of carbon stock in the affected area was done by field measurement based on 2011 GeoEye satellite imagery and 2010 pyroclastic map. The area was stratified based on the surface distance of affected area to the crater. MVNP area was divided on purpose into 10 classes of surface distance. The estimation of carbon stock also conducted in rehabilitation area. The estimation of rehabilitation trees was done based on field measurement to find out the carbon stock of rehabilitation trees.

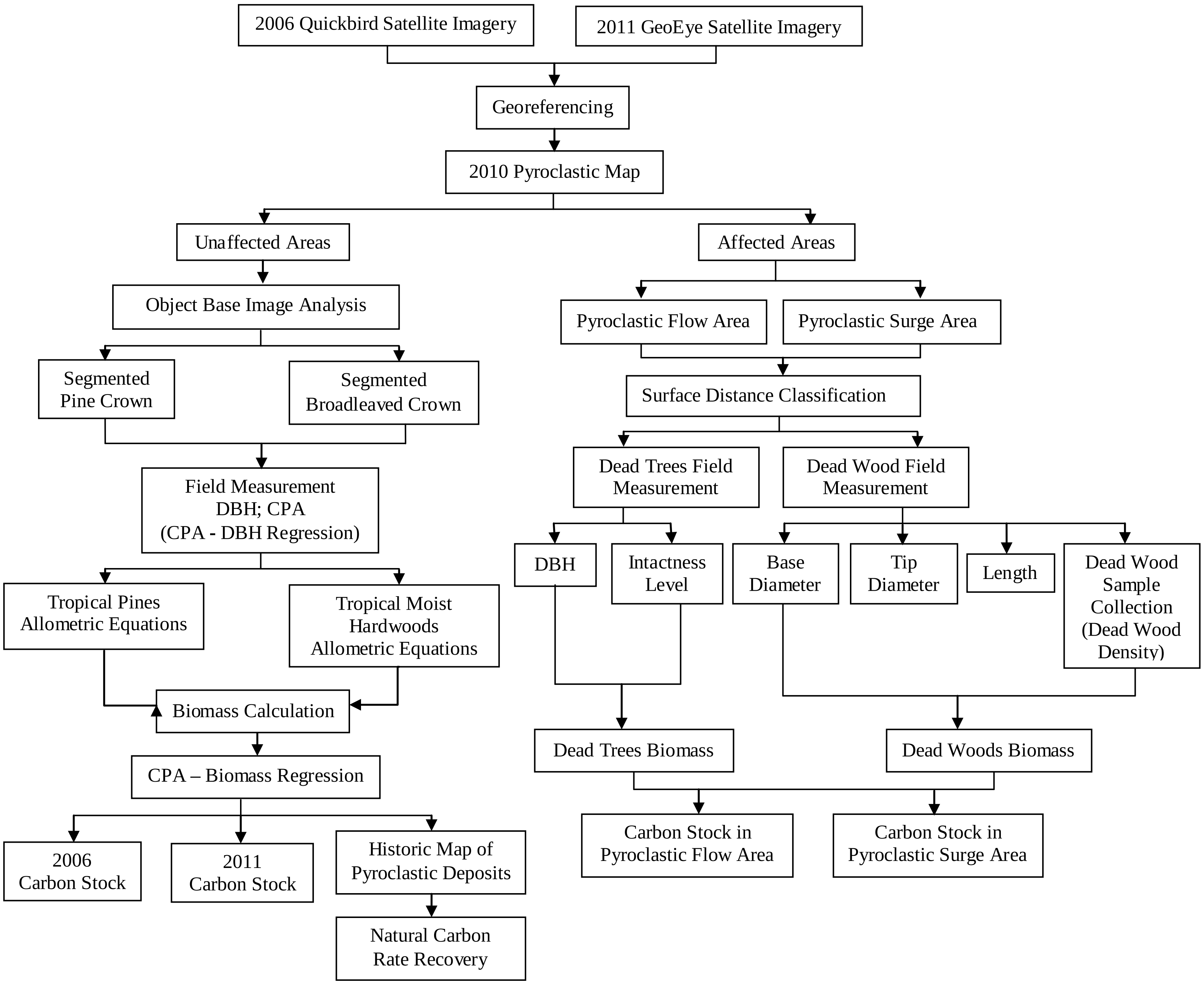


Figure 6. Research Flowchart

3.4. Carbon stock in Unaffected Area

3.4.1. Sampling Design

To get the model of CPA and DBH, the fieldwork was done by measuring the DBH and crown diameter of the tree which is the same with the segmented tree. The CPA which was obtained from the image is the result of the segmentation process. The segmentation process is run using eCognition software. Segmentation process was applied both to 2006 Quickbird and 2011 Geoeye. Both of satellite images were corrected in geometry method using ArcMap.

There are some segmentation methods in eCognition software which are chessboard segmentation, quadtree-based segmentation and multithreshold segmentation which are classified as top-down segmentation and multiresolution segmentation and classification-based segmentation which are categorized as bottom-up method. Multi-threshold segmentation is the top-down segmentation which is the most commonly used since the chessboard and quadtree-based segmentation provide the best results for the tile and divide objects into equal regions (Definiens, 2009).

Scale, color, smoothness and compactness are heterogeneity criteria which are used to create image segments (Figure 7). The multiresolution segmentation was chosen in this study since it produces good abstractionand shaping of objects. The initial ‘seed’ pixels are merged with neighboring pixels which have similar properties. The scale parameter can be applied to manage the size of objects and thereby the homogeneity and minimize the average heterogeneity of image objects.

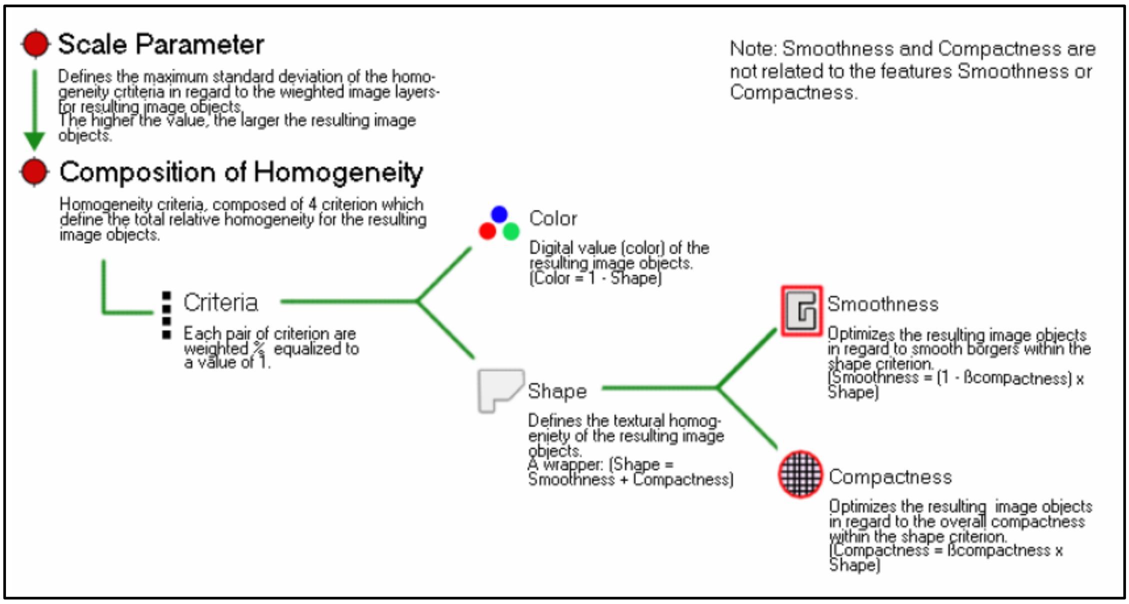


Figure 7. The Diagram of Multiresolution Concept (Definiens, 2009)

Decreasing the scale parameter will increase the number of objects (Navulur, 2007). Scale parameter is obtained using Estimation of Scale Parameters (ESP) tool. Using ESP tool from University of Salzburg, Paris - France, the scale parameter for 2011 GeoEye image are 18, 28, and 43 while the scale parameter for 2006 Quickbird image are 22, 30 and 41 (Figure 8 and 9 respectively). The best value are intersection from local variance (red) and rate of change (blue) as the first value of scale parameter, and then the rising value from rate of change for the next value.

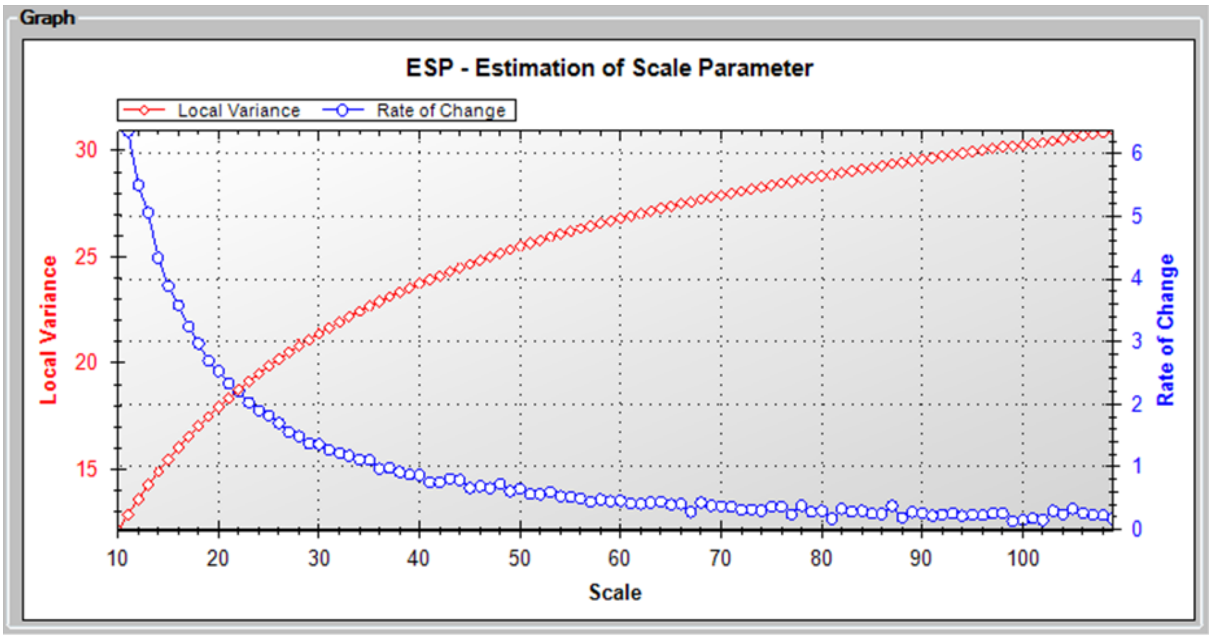


Figure 8. Scale Parameter of 2011 GeoEye imagery

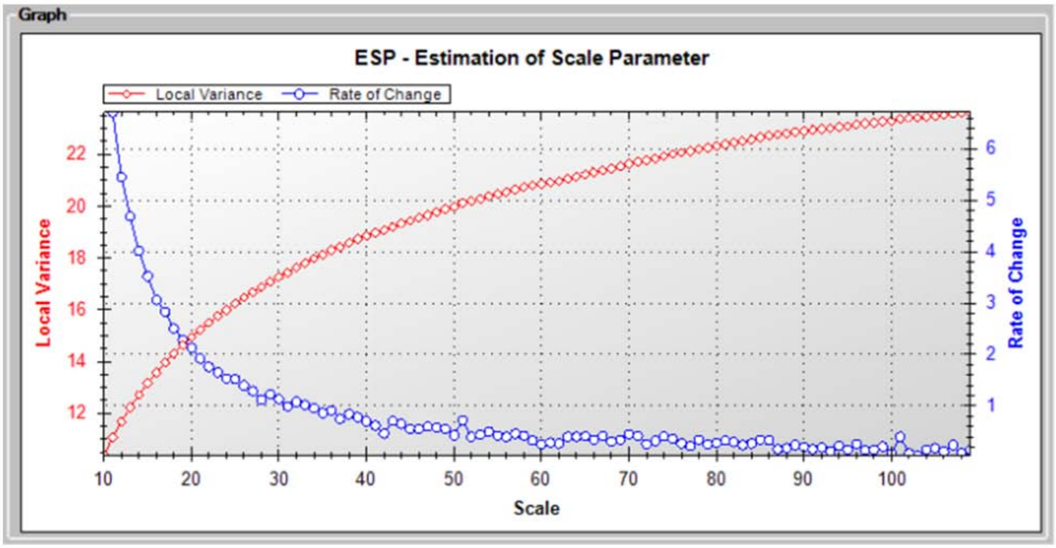


Figure 9. Scale Parameter of 2006 Quickbird Imagery

Multiresolution segmentation algorithm with 0.9 and 0.5 for compactness and shape respectively are used in this study. Compactness was used to optimize the object based on its compactness. The high value of compactness was set since the trees are relatively compact and stand out clearly from the background. Shape is related with color criteria which indicate the spectral value contribution to object homogeneity.

Hierarchy classification was applied in this research with tree levels of classification (Figure 10). Class hierarchy grouped the object and the group is classified in hierarchical structure. The first level has a purpose to distinguish no data (cloud, shadow, and zero value of digital number), non-vegetation and vegetation. Brightness approach with a threshold value of brightness was used to identify cloud and shadow classes. Vegetation and non-vegetation classes were separated by selecting a sample on the image based on some supported image information, such as mean, standard deviation, brightness, compactness, roundness, and rectangular fit.

Details of objects of first level are identified, disaggregated and classified in second level using Nearest Neighbor classification based on collecting sample area of classification. On this level, vegetation classes were divided into trees class and non-trees class.

Watershed transformation, morphological operation and removing undesired object were done before the classification process. Separating one crown from the others in eCognition was done by watershed transformation algorithm. Watershed transformation was used to avoid overlapping tree crown. The concept of watershed transformation is that digital image is considered as watershed catchment. Watershed transformation inverted the distance of the pixel to its image object border which makes the maximal distance become the minimal distance. The crown was considered as the valley. When the valley was flooded from its minima to the maxima, the other valley which is adjacent will not accept the water if the distance value of the adjacent valley is lower than the maxima value of the flooded valley so the valley (tree) will not overlap.

Based on the field survey in which the average of tree canopy diameter is 8 meter, the length factor used is 16 pixels, which 1 pixel is equal 0.5 meter for GeoEye satellite, and 0.61 meter for QuickBird satellite. The default number for a circular mask width of 10 pixels was set in morphological operation which has purpose to generate the circular object as crown representation. In the step ‘removing undesired object’, the objects that have an area of less than 16 pixels were removed, meaning areas of less than 4 m^2 will not be recognized as individual tree.

The Landsat TM satellite imagery 31 July 2009 was used to determine distribution of broadleaf and needle leaf at the third level. The needle leaf vegetation is clearly different because of their unique composition, shape, and color.

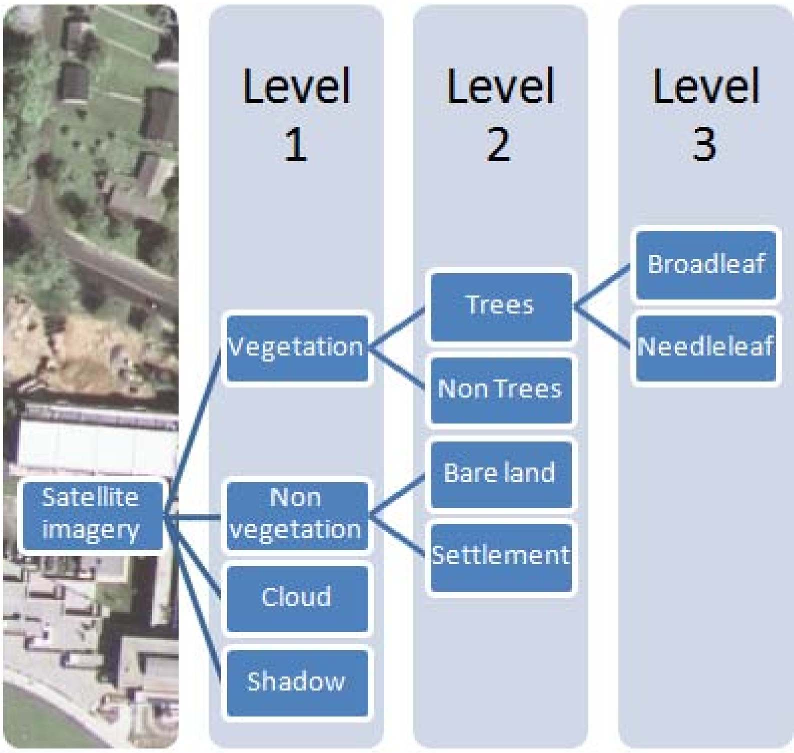


Figure 10. Classification Process in Ecognition

The result of segmentation was validated by fitting the segmented CPA with manual digitizing CPA of the trees. The purpose of the test was to check the completeness of the segmentation which represents the quality of segmentation for extracting the object. The result of segmentation was categorized as matching with the real object if it overlaps by at least 50 % with the result of manual digitizing. Figure 11 shows the condition of 50% matching object. Figure 11a is the condition of overlapping objects more than 50 %, Figure 11b represents the matching objects which have same size and shape but differ in position, Figure 11c and 11d illustrate the overlapped objects which match in position but differ in spatial extent (Zhan et al., 2005).

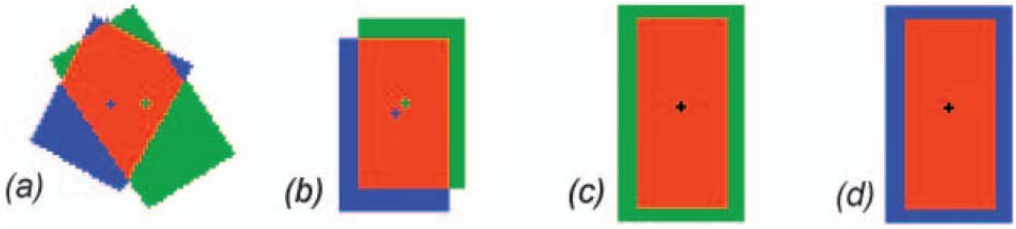


Figure 11. The Overlapping Objects in Segmentation Process (Zhan et al., 2005)

Li et al. (2012) categorized the accuracy of segmentation into 3 types which are true positive (TP) if the object is correctly segmented, false negative/omission error (FN) if the object assigned to the nearby object, in this study we categorized the CPA which less than 50 % matching and miss segmented object into this type, the last type is false positive/commission error (FP) if the object does not exist but it was segmented. TP, FN and FP will lead to perfect segmentation, under-segmentation, and over-segmentation, respectively.

Goutte and Gaussier, 2005; Sokolova et al., 2006 as cited in Li et al. (2012) calculate the accuracy based on the value of recall/r which represents object detection rate (equation 1), precision/p which represents the correctness of the detected object (equation 2), and F-score which indicates the overall accuracy taking both commission and omission errors into consideration (equation 3). The range of r, p and F score is 0 – 1. Higher values indicate higher accuracy of segmentation.

$$r = \frac{TP}{TP + FN} \quad \text{(equation 1)}$$

$$p = \frac{TP}{TP + FP} \quad \text{(equation 2)}$$

$$F = 2 \text{ x } \frac{r \text{ x } p}{r + p} \quad \text{(equation 3)}$$

Another method to validate the segmentation can be done by calculating the goodness of fit (D-value) of the segmentation (Clintonet al., 2010). The D-value (equation 6) is generated based on the under segmentation (equation 4) and over segmentation (equation 5).

$$\text{Over segmentation}_{ij} = 1 - \frac{\text{area (xi} \cap \text{yj)}}{\text{area (xi)}} \quad \text{(equation 4)}$$

$$\text{Under Segmentation}_{ij} = 1 - \frac{\text{area (xi} \cap \text{yj)}}{\text{area (yj)}} \quad \text{(equation 5)}$$

$$D_{ij} = \sqrt{\frac{Oversegmentation_{ij}{}^2 + Undersegmentation_{ij}{}^2}{2}} \quad \text{(equation 6)}$$

Where xi = training objects, assumed polygons, relative to which the segmentation is to be judged and yj = the set of all segments in the segmentation and area (xi ∩yj) is the area of thegeographic intersection of training object xi and segment yj

The D-value indicates the closeness to an ideal segmentation result. The value of D-value is range from 0 – 1. High D-value indicates the low accuracy of segmentation. The decreasing D-value indicates the high level of overlapped objects.

3.4.2. Carbon Stock in Unaffected Area Data Collection

The number of needle leaf trees which were measured in the field is 60 and the number of broadleaf trees that were measured is 58 trees. The Figure 12 shows the location of broadleaves and pine sample trees. The trees which were collected were the same trees with the result of crown segmentation of 2011 GeoEye satellite imagery. The 60% of the measured field data (DBH) was used to build the model and 40% was used to validate the model (Gill et al., 2000).

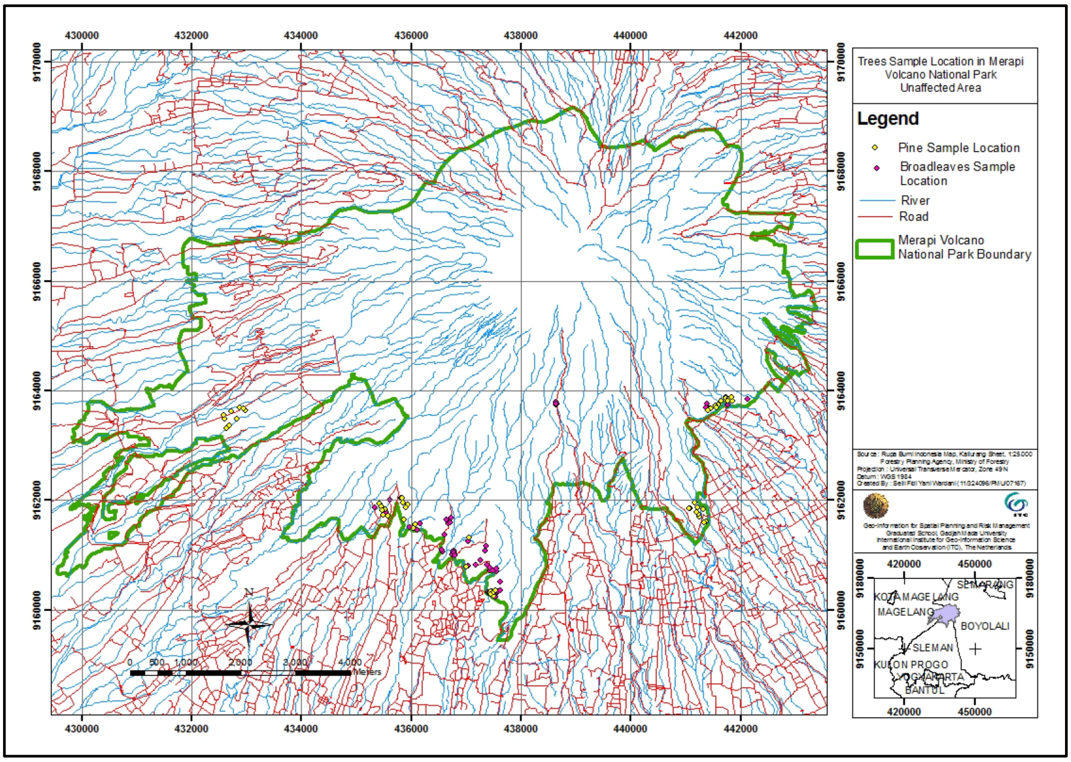


Figure 12. Location of Broadleaves and Pine Sample Trees (Rupa Bumi Indonesia Map, Kaliurang Sheet 1 : 25000; Directorate General of Forestry Planning, Ministry of Forestry)

3.4.3. Allometric Equation

The amount of carbon stock cannot be directly obtained from the satellite imagery. The allometric equation which correlates DBH with total biomass can link the carbon stock with segmented CPA, the result of segmentation process, since the DBH is related with the CPA. Modified Brown allometric equations were used to estimate above ground woody biomass in MVNP. Since forest cover in MVNP are Pine forest, mixed forest and secondary forest, Brown equation for tropical moist hardwoods (equation 7) and tropical pines (equation 8) (IPCC, 2003) were applied. MVNP which has average rainfall by 2500 – 3000 mm/year (Bureau of Merapi Volcano National Park) is classified as moist climatic zone (Brown, 1997).

$$Y = \exp[-2.289 + 2.649 \cdot \ln(DBH) - 0.021 \cdot (\ln(DBH))^2] \text{ (equation 7)}$$

$$Y = 0.887 + [(10486 \cdot (DBH)^{2.84}) / ((DBH^{2.84}) + 376907)] \text{ (equation 8)}$$

where:
Y= aboveground dry matter, kg (tree)-1
DBH =diameter at breast height, cm
ln = natural logarithm
exp = "e raised to the power of"

3.4.4 Data Analysis

To develop model between CPA from the segmented image and DBH, the DBH of the segmented crown from the image was measured in the field. The measured dataset was divided into 2 datasets. The first dataset was used to build the model and the second was used to validate the developed model. Linear, logarithmic, quadratic and power regression was applied to build model of DBH and CPA regression and CPA and Carbon regression.

Error of the model developed was calculated to estimate the difference of carbon stock model and carbon stock of field measurement (equation 9). The model which has the lowest error was chosen to estimate the carbon stock (Chave et al., 2005).

$$Error = 100 \times (Carbon_{predict} - Carbon_{measured})/Carbon_{measured} \text{ (equation 9)}$$

3.4.5. Statistical Analysis

The regression analysis was applied to build DBH-CPA model and CPA-carbon model of needle and broadleaves. Simple linear, power, quadratic (polynomial order 2) and logarithmic regression was developed and tested to generate the selected model. The power and quadratic function is commonly used to estimate above ground biomass. Ketterings (2001) used power function form to predict above ground biomass in mixed secondary forest. Chave et al. (2005) who compared some statistical model equation of above ground biomass proposed logarithmic model and polynomial model to equal the overestimation of mass of large trees.

3.5. Carbon stock in Affected Area

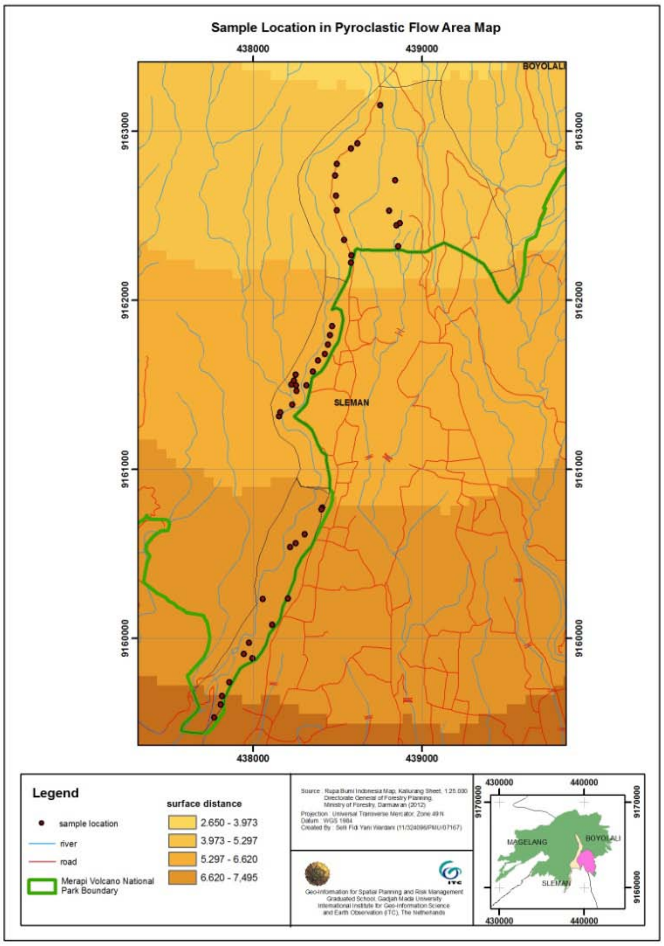
3.5.1. Sampling Design

Areas of pyroclastic flow and pyroclastic surge were divided into 3 (three) classes based on the surface distance to the Merapi volcano crater. The study focused on pole and trees stage since they give high contribution on carbon stock. Seedlings give less contribution to carbon stock (Mandal et al., 2012). The estimation of dead trees and dead woods was done in random sampling plots. The numbers of sample plot which were made in each class were 15 (fifteen) plots (Figure 13; Table 4). The Indonesia National Standard of Carbon Measurement, SNI 7724:2011(2011) does not specify the minimum number of plot. But it requires the maximum allowable standard error of 20%.

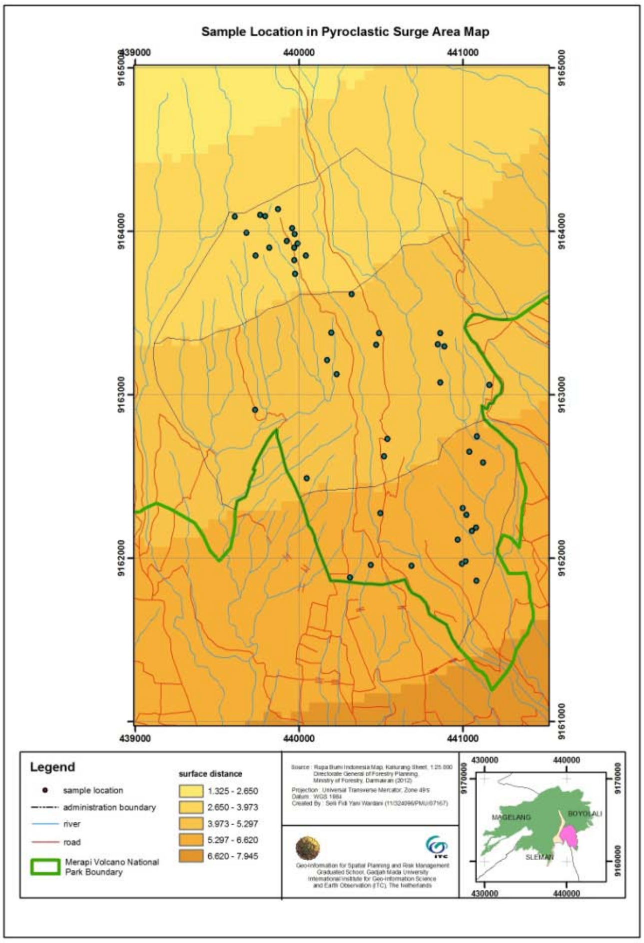
Determination of sample points was done using the create random points operation on Data Management Tools in ArcGIS software. The number of random sampling points made is more than 15 (fifteen) per distance class because when a plot cannot be made for reasons of accessibility, that plot can be left out and replaced by another plot. The size of sampling plots was 10 m x 10 m for poles, dead woods and dead trees with diameter 10 cm to < 20 cm. Trees, dead woods and dead trees with diameter $\geq$ 20 cm were registered in plot 20 m x 20 m.

Table 4. Sampling Plot Number of Pyroclastic Flow and Pyroclastic Surge Area and Their Distribution

Location	Surface Distance (m)	ID	Number of Plots	Area (ha)
Pyroclastic Flow	> 3973 - 5297	Class 2	15	94
Pyroclastic Flow	> 5297 - 6620	Class 3	15	23
Pyroclastic Flow	> 6620 - 7945	Class 4	15	31
Pyroclastic Surge	> 2650 - 3973	Class 1	15	98
Pyroclastic Surge	> 3973 - 5297	Class 2	15	212
Pyroclastic Surge	> 5297 - 6620	Class 3	15	95



a



b

Figure 13. Sample Plots in Pyroclastic Flow (a) and Pyroclastic Surge Area (b) (Rupa Bumi Indonesia Map, Kaliurang Sheet 1 : 25000; Directorate General of Forestry Planning, Ministry of Forestry; Darmawan, 2012)

3.5.2. Dead Trees and Dead Wood Data Collection

According to SNI 7724:2011 (2011), dead trees is standing dead vegetation which its metabolism process has stopped while dead wood is the component of dead trees such as stem, branch and twig that have fallen. Furthermore Manuri et. al, (2011) define dead wood as all parts of a dead tree that are collapsed and have a diameter more than 10 cm. The estimation of biomass in the affected area was done based on field measurement in the sample plots. Diameter of dead trees in pyroclastic flow and pyroclastic surge area was measured.

Wood samples were collected from the field for laboratory analysis to obtain the wood density of dead wood. The wood density measurement needs to be done since the decomposition process influence the carbon stock in the dead wood. The wood samples were classified based on their decomposition level which are good, moderate and decomposed (Figure 14). The wood with good condition is barked, hard wood, and hard to cut by a saw. The decomposition which occurred in good wood is 10 %. The bark of the wood with moderate decomposition is partially loose and decomposition which occurred in moderate condition is 10 % - 50 %. The decomposed wood is very brittle and easy to cut with a machete or chainsaw, the decomposition which occurred is more than 50 % (Manuri et Al., 2011). The numbers of wood samples for each decomposition level are 10.

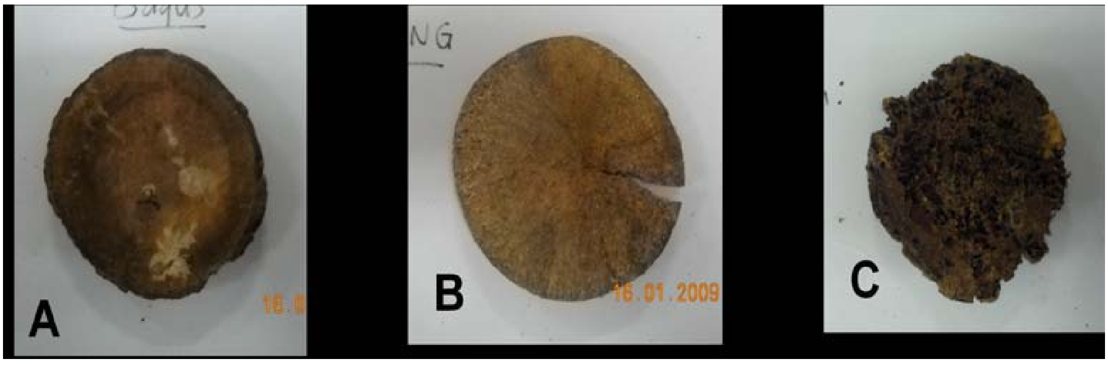


Figure 14. Decomposition Levels of Dead Wood, Good (A), Moderate (B) and Decomposed Wood (C)

3.5.3. Data Analysis

The carbon content in dead trees tends to be less due to the process of decomposition. Assuming decomposition level is low at the new dead tree, the dead trees biomass can be estimated by multiplying the allometric equation with correction factor of the intactness of the dead tree (Manuri et. al, 2011). The intactness factor of dead trees without leaves (Figure 15a) is 0.9, the intactness factor of dead trees without leaves and twigs is 0.8 (Figure 15b) and the intactness factor of dead trees without leaves, branches and twigs is 0.7 (Figure 15c).

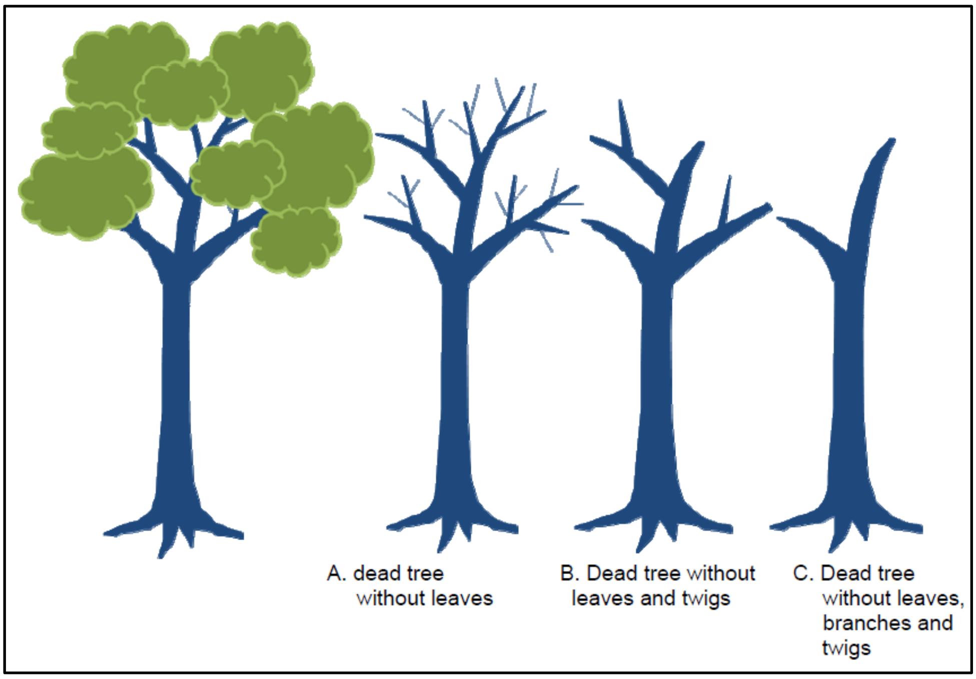


Figure 15.Intactness Level of Dead Trees (SNI 7724:2011, 2011)

To estimate carbon of the dead wood, diameter of base and tip and the total length of dead wood were measured. It is assumed that the amount of dead wood will be more in area affected by pyroclastic flow while dead trees will be dominant in area affected by pyroclastic surge since the material of pyroclastic flow more dense than pyroclastic surge material.

Dead wood biomass is influenced by its volume and its wood density (equation 10 and equation 11) (SNI 7724:2011, 2011). Wood density is obtained by dividing the wood dry weigh by its volume.

$$B_{dw} = Vdw \times WD_{dw} \quad \text{(equation 10)}$$

$$V_{dw} = 0.25 \prod (d_b + d_t/2 \times 100)^2 \times p \quad \text{(equation 11)}$$

Note:
V_{dw} is the volume of dead wood (m3);
d_b is the diameter of the base of the dead wood (cm);
d_t is the diameter of the tip of the dead wood (cm);
p is the length of the dead wood (m);
π is 22/7 or 3.14
B_{dw} is the dead wood biomass (kg);
WD_{dw} is the dead wood density (kg/m3).

The wood samples from the field (Figure 16) were soaked until they were saturated and the volume is measured. The saturated woods are dried for 5 days until the dry weight is constant.

Figure 16. Good (A), Moderate (B) and Decomposed (C) Woods Sample for Wood Density Measurement

Carbon stock of dead trees, dead wood and carbon stock in above ground biomass in unaffected area can be calculated by multiplying the biomass with the percentage value of carbon content, 0.47 (SNI 7724:2011, 2011).

3.5.4. Statistical Analysis

Kolmogorov Smirnov Test was firstly applied to determine whether parametric analysis or non-parametric analysis will be used to analyze the data. Kolmogorov Smirnov Test was applied to know the distribution of the data. The data is normally distributed if the probability value is more than significant level (0.05). The parametric analysis is applied to data which is normally distributed while non parametric analysis is applied to data that not normally distributed.

3.6. Carbon Rate Recovery

Recovery areas are the areas which were affected by previous pyroclastic flow event before 2010 eruption. It was derived by delineating the historic map of pyroclastic flow in MVNP (Figure 4) which shows pyroclastic map of MVNP in different year from 1911 to 2006.

The rate of carbon recovery was established based on relation between age and carbon stock of recovery area. Age was derived from pyroclastic flow events at different times. The estimation of carbon stock in recovery area was done by applied the developed model of CPA-carbon of broadleaved to recovery area.

The monitoring of natural carbon rate recovery was only done in broadleaves area since Pine was planted by Perhutani which is a State-Owned Enterprise in the form of Public Corporation who has role in managing forest resources in Java and Madura. Before MVNP became a national park, it was a Perhutani area. Hence, the pine is not naturally regenerated.

The artificial carbon rate recovery cannot be measured since the rehabilitation activity in MVNP was just conducted in 2011 and 2012. It was impossible to build a model of artificial carbon rate recovery based on only 2 data series. Therefore the activities carried out in the rehabilitated area was monitoring of carbon stocks.

There are 4 areas of rehabilitation. Each rehabilitation area was randomly sampled. The number of sampling plot in rehabilitation area was difference depend on the size of the area since the space of plant rehabilitation is systematic. The plant rehabilitation were in seedling and sapling stages so the sampling plots were set are 2 m x 2 m for sapling and 5 m x 5 m for saplings (Table 5 and Figure 17).

Table 5. The Rehabilitation Plot in Merapi Volcano National Park

Rehabilitation Areas	Year of Rehabilitation	Number of Plot	Area (ha)
Gandog (Kalikuning)	2011	20	70
Tegalmulyo (Deles)	2011	20	30
Selo	2011	10	20
Ngargomulyo	2012	45	169

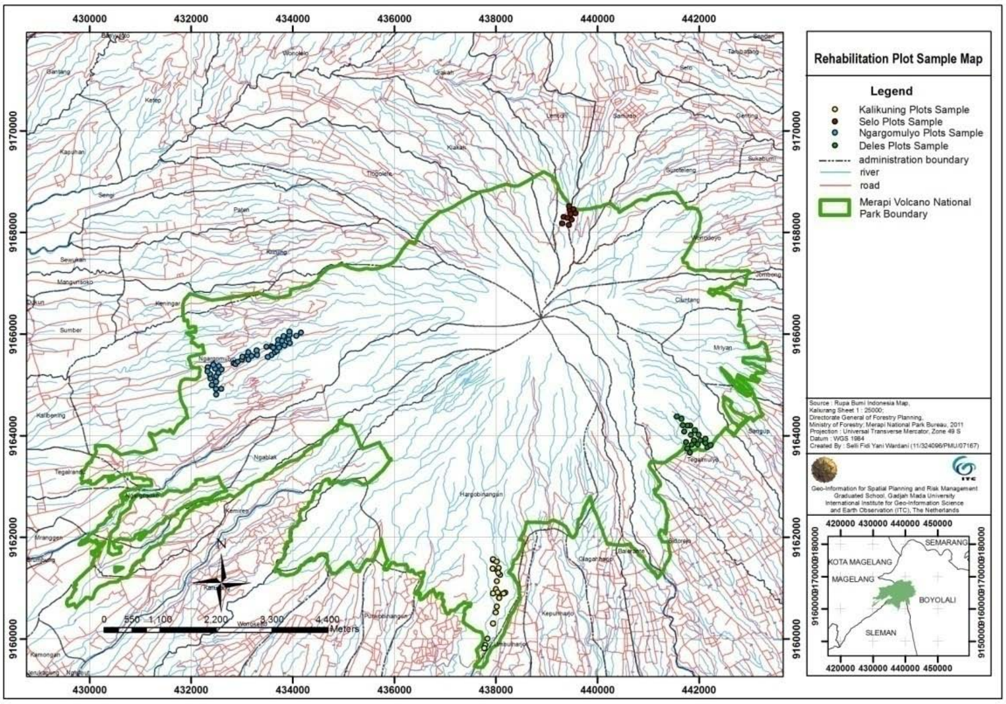


Figure 17. Rehabilitation Sample Plots Map (Rupa Bumi Indonesia Map, Kaliurang Sheet 1 : 25000; Directorate General of Forestry Planning, Ministry of Forestry; Merapi National Park Bureau, 2011)

3.7. DBH, CPA, Carbon Growth of Dominant Trees in MVNP

3.7.1. Sampling Design and Data Collection

The shortest period between eruptions of Merapi volcano is 4-6 years. The DBH and CPA of saplings, poles and trees of dominant trees in MVNP were collected in the field in order to know the pattern of the growth of DBH, CPA and carbon of dominant trees in MVNP. It was also performed to determine the growth of CPA in 1 year since the satellite imagery which was used to develop CPA-carbon stock model in this study is 2011 satellite imagery while measured DBH in the field is 2012 DBH which was selected based on 2011 satellite imagery.

Based on the fieldwork, the identified dominant trees in MVNP are *Schima wallichii, Erythrina variegata, Lithocarpus elegans, Pinus merkusii, Altingia excelsa and Acacia decurrens*. Data of trees was used the tree which was inventoried in unaffected area to build developed model of CPA and carbon. The DBH and CPA of sapling were measured in random 5 m x 5 m plots and poles were measured in random 10 m x 10 m plots. By knowing their diameter increment their age will be generated. The diameter increment of dominant trees was obtained based on literature study.

3.7.2. Data Analysis

The relation of DBH and age of *Pinus merkusii, Altingia excelsa and Acacia decurrens* was develop based on the yield table. Relation between DBH and age of *Schima wallichii, Erythrina variegata, and Lithocarpus elegans* was develop based on DBH measurement in the field because they are not in the list of yield table. As the age of them was generated, the relation between CPA and age of the dominant trees in MVNP will be generated (Table 6).

Table 6. Mean Diameter Increment and Relation of Age and CPA Field of Dominant Trees in MVNP

Species	Mean Diameter Increment cm/year	Regression of Age and CPA_Field y = CPA ; x = Age
Schima wallichii	0.63 (Boojh, R and Ramakrishnan, 1984)	y=0.234x^1.283 R^2=0.85
Erythrina variegata	2.5 (Whistler, W. A. and C. R. Elevitch, 2006)	y=1.203x^1.238 R^2=0.748
Altingia excelsa	y=2.678x^0.689 (Suharlan, A., K. Sumarna, et al. (1975) R2=0.723	y = 9.389X^0.561 R^2=0.236
Lithocarpus elegans	0.211 (Minarto, E., 2009)	y=0.245x^0.976 R2=0.595
Pinus merkusii	y=2.38x^0.895 (Suharlan, A., K. Sumarna, et al. (1975) R2=0.835	y=0.516x^1.339 R^2=0.303
Acacia decurrens	y=6.631x^0.564 (Suharlan, A., K. Sumarna, et al. (1975) R2=0.717	y=0.114x^1.246 R^2=0.85

Regression of age and CPA of the trees was developed based on power regression. Study by Shimano (1997) concluded that power-sigmoid functional model is the best model of DBH and CPA relationship. The CPA growth will slow as the growth of DBH. Another study by Peper et al. (2001) shown that the CPA growth will fast in their first 15 years period of their life but the will slow in their second 15 years life.

3.7.3. Statistical Analysis

The Kolmogorov Smirnov test was applied to DBH, CPA, and carbon stock of dominant trees in MVNP to know the distribution of the data. The non parametric post hoc test will be applied if the data is not normally distributed while parametric post hoc test will be applied if the data is normally distributed.

CHAPTER IV
RESULT

4.1. Carbon Stock in Unaffected Area

Figure 18 shows the final result of segmentation process of 2011 GeoEye satellite imagery. Green polygons represent the CPA of broadleaved and yellow polygons represent the CPA of Pine tree.

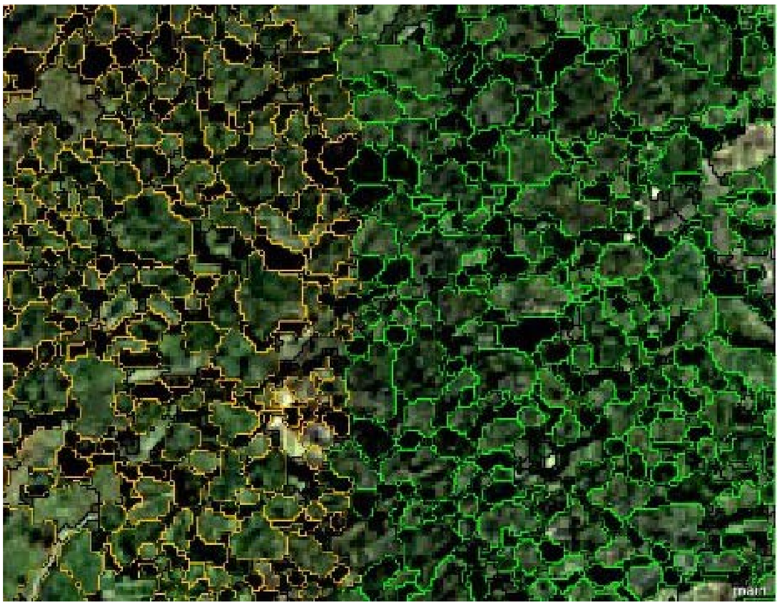
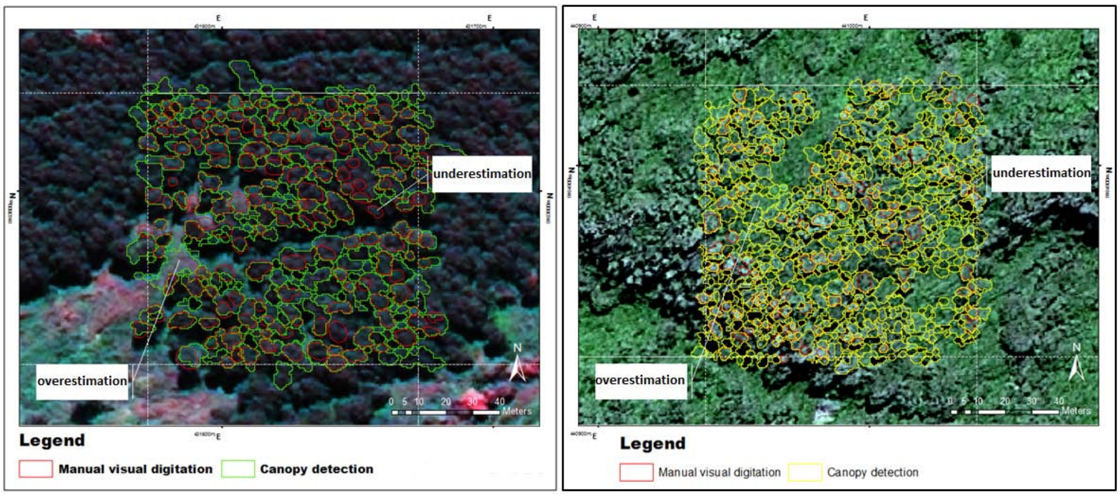


Figure 18. Final Output of 2011 GeoEye Segmentation

The validation of segmentation was done in order to know whether the segmentation was overestimated or underestimated (Figure 19). The red polygons represent the manual digitations while yellow and green polygons indicate the automatic segmented crown using eCognition software.



a b

Figure 19. The validation of crown projection area segmentation of 2006 Quickbird (a) and 2011 GeoEye (b) Satellite Imagery

Segmentation validation method by measuring its D-value (Clinton et al., 2010) will give the objective result but due to the limited time method by Zhan et al. (2005) and Liet al. (2012) was adapted to validate the segmentation. Comparing manual digitations and automatic segmentation, there are 4 types of polygon which are:

a. overlapped at least 50 % (TP),
b. less than 50 % overlapped (FN),
c. not segmented automatically (FN) and
d. segmented automatically but actually there was no an existing tree (FP).

Table 7 shows the percentage of 2006 and 2011 segmentation validation. The TP of 2011 segmented needle leaf and broadleaved are 51 % and 37 % respectively while TP of 2006 segmented needle leaf and broadleaved are 66 % and 50 % respectively. The % TP (1:1 correspondence overlapped crown) indicates the matching of segmented crown and visual crown. The over segmentation of broadleaved tree on 2011 Geoeye imagery is above 50 % but overall the calculation of F score which indicate the accuracy of segmentation is above 0.5 means that the accuracy of algorithm which was used to segment the object more than 50 %. The accuracy of 2006 overlapped crown is higher than 2011 overlapped crown (Table 7).

Table 7. The Segmentation Validation of 2006 Quickbird and 2011 GeoEye

Tree	Number of Tree	1:1 correspondence (>=50% crown overlap) TP		1:1 correspondence (<50% crown overlap) FN		Missing trees				r	p	F
		n	accuracy (%)	n	accuracy (%)	under estimate FN	%	over estimate FP	%			
2011												
Needle leaf	468	241	51	36	8	4	1	187	40	0.86	0.56	0.68
broadleaf	390	143	37	27	7	9	2	211	54	0.80	0.40	0.54
2006												
Needle leaf	216	142	66	3	1	11	5	60	28	0.91	0.70	0.79
broadleaf	364	183	50	27	7	18	5	136	37	0.80	0.57	0.67

Developed model of CPA-Carbon Broadleaved and Pine Trees based on Linear, Logarithmic, Quadratic and Power regression and its error are presented in Table 8.

Table 8. Developed Model of DBH-CPA and CA-Carbon of Broadleaved and Pine Trees

Developed Model	**R^2**	**Error (%)**
Broadleaved		
DBH-CPA		
Linear DBH=-0.069CPA+42.121	0.023	3.18
Logarithmic DBH= -2.213lnCPA+46.426	0.015	2.67*
Quadratic DBH =-0.001CPA^2+0.048CPA+39.990	0.028	6.55
Power DBH = 46.652CPA^-0.083	0.036	11.85
CPA-Carbon		
Linear Carbon=-0.964CPA+898.544	0.001	7.28
Logarithmic Carbon=10.648lnCPA+819.302	0.00007	6.37*
Quadratic Carbon=-0.13CPA^2+16.791CPA+576.517	0.027	16.68
Power Carbon=912.006CPA^-0.209	0.037	50.73

Developed Model	R^2	Error (%)
Pine		
DBH-CPA		
Linear DBH=0.104CPA+41.462 R2=0.053	0.053	5.97
Logarithmic DBH=5.461lnCPA+27.457 R2= 0.097	0.097	6.12
Quadratic DBH=-0.005CPA^2+0.725CPA+31.065 R2=0.207	0.207	2.86*
Power DBH=31.359CPA^0.098 R2=0.077	0.077	10.00
CPA-Carbon		
Linear Carbon=3.954CPA+504.154	0.063	15.28
Logarithmic Carbon= 203.547lnCPA-14.874	0.110	15.59
Quadratic Carbon=-0.186CPA^2+26.013CPA+134.692	0.221	10.31*
Power Carbon= 240.370CPA^0.222	0.068	33.89

The Table 8 shows that logarithmic regression model has the lowest value of error for DBH-CPA and CPA-Carbon relation of broadleaves trees. Error of DBH-CPA relationship based on the validation dataset is 2.67 and error of CPA-Carbon relationship is 6.37. The model which has the lowest error for DBH-CPA relationship of Pine trees is quadratic (polynomial order 2) regression as well as CPA-Carbon relationship with the error are 2.86 and 10.31 respectively. Therefore the logarithmic regression (equation 12) was used to estimate carbon stock of broadleaved while quadratic regression (equation 13) was used to estimate Pine carbon stock based on segmented CPA. Thus, the models used in this research are:

Developed Model of CPA-Carbon Relation of Broadleaved Trees

Carbon=10.648lnCPA+819.302 (equation 12)

Developed Model of CPA-Carbon Relation Pine Trees

Carbon=-0.186CPA^2+26.013CPA+134.692 (equation 13)

The result of carbon stock calculation of broadleaves and Pine is presented in Table 9. Based on the table 9, the 2011 total carbon stock in the unaffected area in both Pine and Broadleaves is higher than 2006. In contrast carbon stock in pyroclastic flow area and pyroclastic surge area in 2011 is lower than 2006. The carbon stock maps of Pine and

Broadleaved in MVNP in 2006 and 2011 show by Figure 20, 21, 22 and 23.

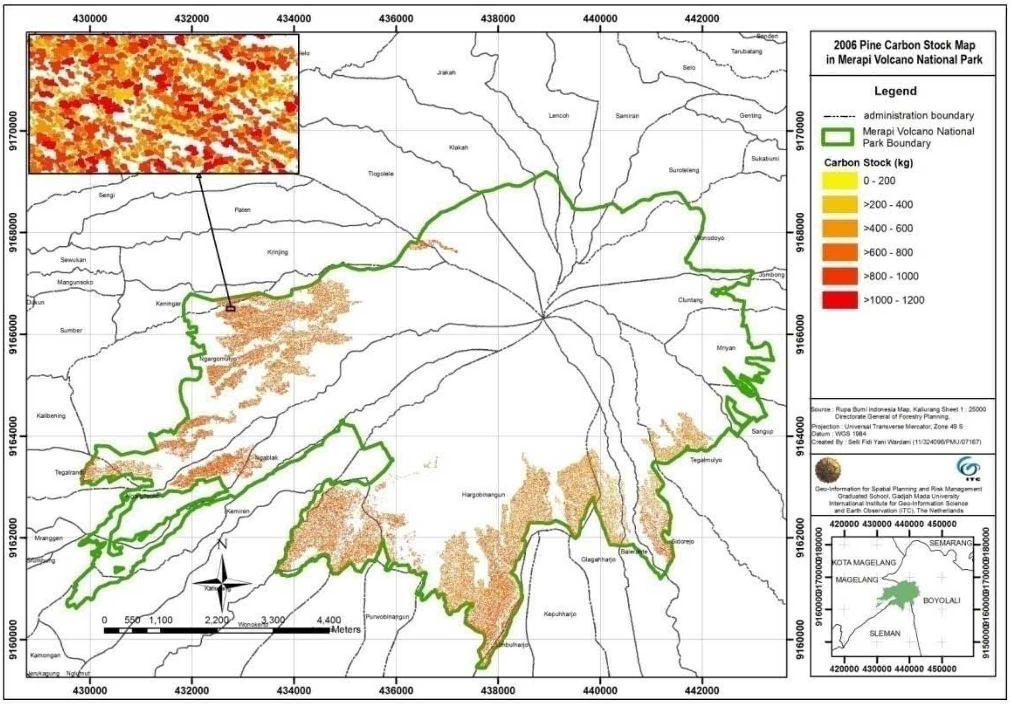


Figure 20. The 2006 Pine Carbon Stock Map in Merapi Volcano National Park (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry)

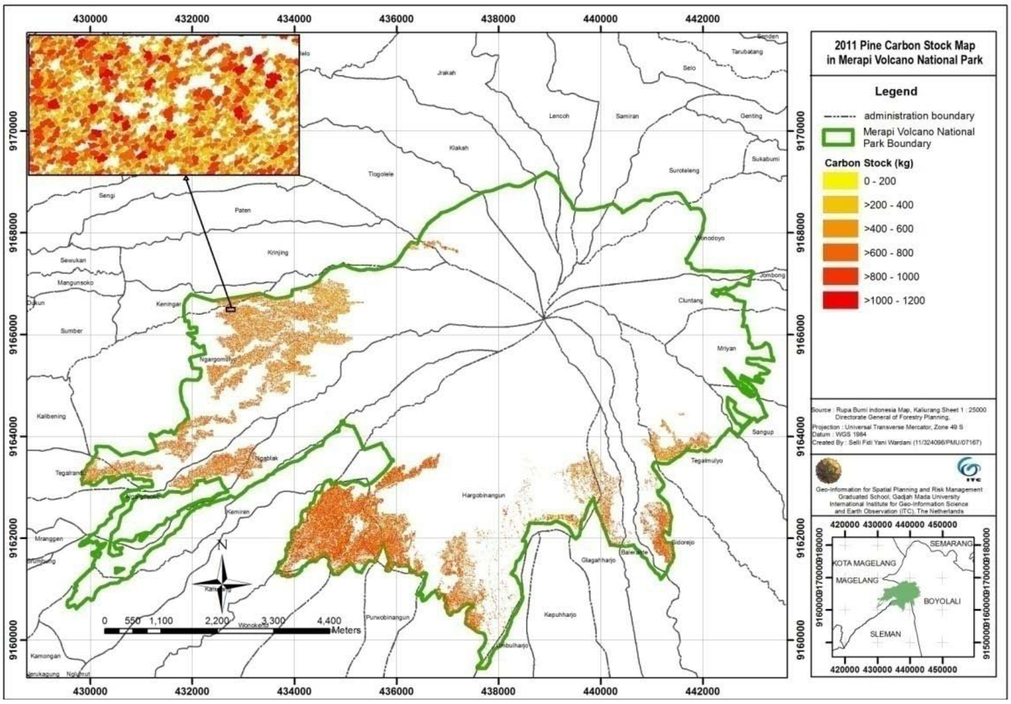


Figure 21. The 2011 Pine Carbon Stock Map in Merapi Volcano National Park (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry)

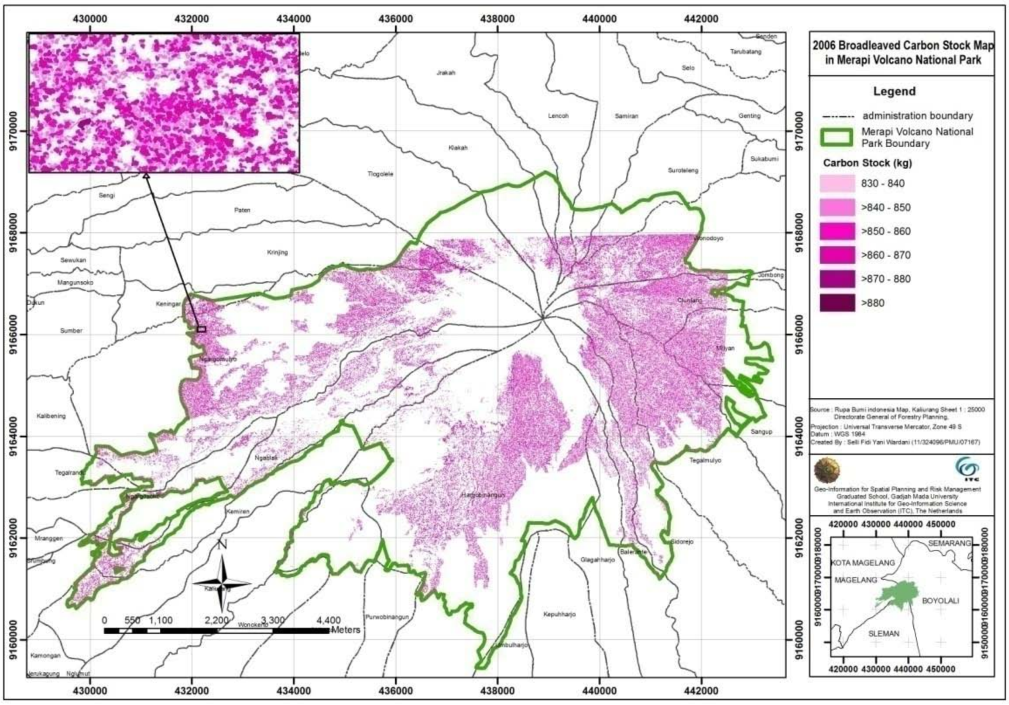


Figure 22. The 2006 Broadleaved Carbon Stock Map in Merapi Volcano National Park (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry)

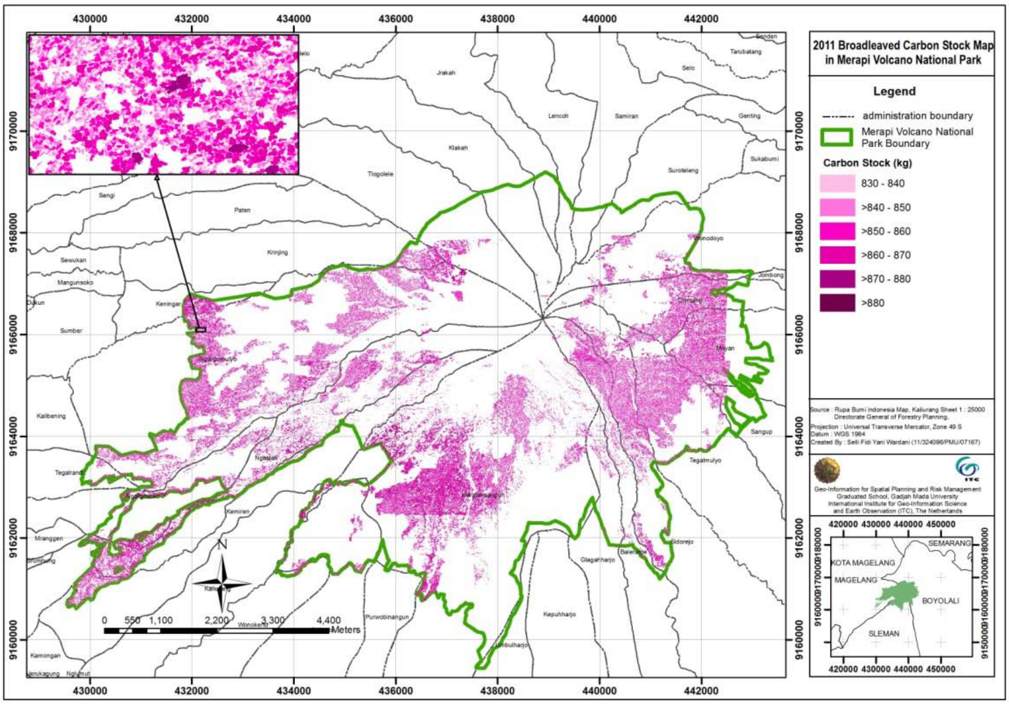


Figure 23. The 2011 Broadleaved Carbon Stock Map in Merapi Volcano National Park (Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry)

Table 9.Carbon stock of Broad leaf and Pine Tree Based on CPA-Carbon Developed

Year	Total Carbon Stock (kg/ha)		Carbon in Unaffected Area (kg/ha)		Carbon Stock (kg/ha)			
					Pyroclastic Flow Area		Pyroclastic Surge Area	
	Pine	Broadleaves	Pine	Broadleaves	Pine	Broadleaves	Pine	Broadleaves
2011	119,782	142,699	143,528	145,951	9,414	48,343	72,402	128,473
2006	114,552	121,336	116,301	121,676	102,673	50,497	113,849	152,920

Based on the model, total 2011 remaining Pine carbon stock in MVNP was 119,782 kg/ha while total remaining broadleaves carbon stock was 142,699 kg/ha. Total broadleaved carbon stock in unaffected area was 145,951 kg/ha while the total remaining carbon stock of Pine trees in unaffected area was 143,528 kg/ha (Table 9). The 2011 CPA-Carbon model developed was applied to 2006 imagery to estimate 2006 carbon stock. Total 2006 pine carbon stock was 114,552 kg/ha and total 2006 Broadleaved carbon stock was 121,336 kg/ha.

Pine carbon stocks that were likely to have been in the affected areas in 2006 before 2010 eruption were 102,673 kg/ha in pyroclastic flow area and 113,849 kg/ha in pyroclastic surge area. The 2006 broadleaves carbon stock that was likely to have been in the pyroclastic flow and pyroclastic surge area were 50,497 kg/ha and 152,920 kg/ha respectively (Table 9). The CPA density and tree density of affected area before the eruption are 2,586 m^2/ha and 139 trees/ha respectively in pyroclastic flow area and 3,354 m^2/ha and 208 trees/ha respectively in pyroclastic surge area (Table 10).

Total carbon loss in pyroclastic area was estimated by subtracting carbon stocks that were likely to have been in the affected areas by remaining carbon stock in affected area. In this case total carbon loss was estimated based on subtracting of 2006 carbon stock that were likely to have been in the affected areas by the remaining carbon stock based on field measurement. The total carbon loss was 405,100 kg.

Table 10. The 2006 CPA and Trees Density

Affected Area	2006 CPA Segmented	CPA Area (m^2)	Number of Trees
PF 261 ha	Pine	556,237	29,633
	Broadleaved	119,213	6,740
	Total	675,450	36,373
	Density	2,586	139
PS 406 ha	Pine	774,586	47,122
	Broadleaved	592,239	37,656
	Total	136,6825	84,778
	Density	3,354	208

4.2. Carbon Stock of Dead Trees and Dead Wood in Pyroclastic Flow Area

Based on the field observation, dead trees and dead wood which were found in the field were Pine trees. So Pine allometric equation was used to estimate the dead trees carbon stock and the samples of the dead wood which was collected in the field to estimate the wood density was Pine wood. In the pyroclastic flow area there were no poles and trees. The only tree stage that was found in the pyroclastic flow area was *Acacia decurrens* in sapling stage. *Acacia decurrens* is the pioneer which is grown in MVNP after the eruption. In pyroclastic surge area, there are *Schima wallichii* and *Acacia decurrens* in pole stage. The tree stage which was found in surge area is Pine. The result of carbon stock estimation in affected area is presented in Table 11.

Table 11. Total Sampled Carbon Stock and Carbon Stock Classification in Pyroclastic Flow and Pyroclastic Surge Area (include values per ha)

Affected Area	Surface Distance (m)	Area (ha)	Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Pole Carbon (kg)	Trees Carbon (kg)	Total Sample Carbon (kg)	Total carbon (kg)	Total carbon (kg/ha)	Carbon Stock Class
Pyroclastic Flow	>3973 – 5297 (Class 2)	94	0	5	0	0	5	739	8	high
	>5297 – 6620 (Class 3)	23	0	2	0	0	2	62	3	low
	> 6620 – 7945 (Class 4)	31	6,270	8	0	0	6,278	319,141	10,463	high
Pyroclastic Flow Carbon Stock			6,270	14	0	0	6,284	319,943	2,174	
Proportion (%)			99.78	0.22	0	0				
Pyroclastic Surge	>2650 – 3973 (Class 1)	98	2,764	0.16	0	0	2,764	453,176	4,606	low
	>3973 – 5297 (Class 2)	212	2,380	3	131	0	2,515	890,705	4,191	low
	>5297 – 6620 (Class 3)	95	27,329	4	100	6,281	33,714	5,355,625	56,191	high
Pyroclastic Surge Carbon Stock			32,473	8	232	6,281	38,993	6,699,506	16,493	
Proportion (%)			83.28	0.02	0.59	16.11				
Total Carbon Stock Affected Area								7,019,449	12,685	

The estimation of carbon stock of dead trees and dead wood in pyroclastic flow area was done in 3 (three) classes of surface distance (Table 4). The closest surface distance area to the crater that is accessible is surface distance class 2. Less than that distance is not accessible due to the unstable condition of the soil (Figure 24).

Figure 24. Location of Pyroclastic Flow Area with Surface Distance Less than 3973 m, Red Arrows Indicate the Direction of Pyroclastic Flow

To estimate dead woods biomass in pyroclastic flow and surge area the wood density of dead woods is needed. The result of Kolmogorov Smirnov test shows that woods density data is normally distributed. One Way ANOVA test for dead woods density (Appendix 2) shows the F-test is 0.426 is less than F-table 3.354 which indicates the dead woods density is the same for each decomposition state. The wood densities of dead wood with good, moderate and decomposed level of wood decomposition rate are 0.65, 0.56 and 0.55 kg/m^3 respectively.

Dead trees sample carbon stock in pyroclastic flow area on surface distance class 2, class 3 and class 4 are 0, 0 and 6,270 kg respectively. There was no carbon stock in form of dead trees on surface distance class 2 and class 3 in pyroclastic flow area (Appendix 3-5). The greatest value of sample carbon stock of dead trees and dead woods in pyroclastic flow area were 6,270 kg and 8 kg respectively which were located in the area which has the farthest surface distance from the crater, class 4 (Table 11).

Based on Kolmogorov Smirnov Test, dead trees and dead wood carbon stock data in all surface distance classes in pyroclastic flow area were not normally distributed so non parametric Kruskal-Wallis test which aims to examine the significance of the difference carbon stock in each surface distance was applied to analysis this data.

Kruskal-Wallis test for dead woods in pyroclastic flow area (Appendix 6) shows that there was no difference between dead woods carbon stocks in pyroclastic flow in each surface distance. That was shown by asymptotic significance 0.098 which is greater than significant level 0.05.

The asymptotic significance of dead trees in pyroclastic flow area based on Kruskal-Wallis test was 0 which is less than the significant level 0.05, which means that dead trees carbon stock is influenced by surface distance class (Appendix 7).

Since there was a relation between surface distance and dead trees carbon stock, the post hoc test was applied to know the relation between group variable. Mann-Whitney Test was chosen as the post hoc test for dead trees carbon stock data which is not normally distributed (Table 12, Appendix 8). The asterisk symbol indicate that a symptotic significance is lower than significant level 0.05 means there is a difference between two groups of surface distance. Based on the test, there were no different of dead trees carbon stock in surface distance of class 2 and class 3 while dead trees carbon stock in surface distance class 4 was significantly different with the other surface distance classes. So that dead trees carbon stock on surface distance class 2, class 3 can be classified into 1 (one) group as a low group of dead trees carbon stock while dead trees carbon stock on surface distance class 4was high.

There were no dead trees were found in area affected by pyroclastic flow in surface distance class 2 and class 3. Dead trees were found in pyroclastic flow surface distance of class 4 on 7 sample plots. Total sample dead trees carbon stock was 6,270 kg. With the area of class 4 surface distance was 305,012 m^2, the total dead trees carbon stock was 10,463 kg/ha.

Table 12. Mann-Whitney Test of Dead Trees Carbon Stock in Pyroclastic Flow Area

Surface Distance Class	class 2	class 3	class 4
class 2	-	1	0.03*
class 3	1	-	0.03*
class 4	0.03*	0.03*	-

Dead trees carbon stock in pyroclastic flow area was compared to dead wood carbon stock. Table 11 shows the total sample dead trees carbon stock was higher than total sample dead wood carbon stock. Based on Mann Whitney Test (Appendix 9), dead trees and dead wood carbon in pyroclastic flow area was significantly different. Total dead trees carbon stock and total dead woods carbon stock were 10,450 kg/ha and 23 kg/ha respectively.

4.3. Carbon Stock of Dead Trees and Dead Wood in Pyroclastic Surge Area

Carbon stock pools which has the highest carbon stock in pyroclastic surge area was dead tree while dead wood has the lowest carbon stock (Table 11, Appendix 10-12).

Kruskal-Wallis Test shows relationship between dead trees and dead woods in pyroclastic surge area and its surface distance to the crater. Results show that dead trees carbon stock was influenced by it surface distance (Appendix 13). That result is represented by its asymptotic significance, 0.039, which is less than the significant level 0.05. In the other hand dead wood carbon stock in each surface distance is no different. The asymptotic significance, 0.059, is higher than the significant level 0.05 (Appendix 14).

The Mann-Whitney test was applied to dead trees carbon stock in pyroclastic surge area data to check the difference of each class of surface distance since the dead trees carbon stock is influenced by its surface distance. The result, presented with asterisk, indicates that the surface distance which has significantly different dead trees carbon stock were surface distance class 2 and surface distance class 3 (Table 13 and Appendix 15).

Table 13. Mann-Whitney Test of Dead Trees Carbon Stock in Pyroclastic Surge Area

Surface Distance Class	**class 1**	**class 2**	**class 3**
class 1	-	0.116	0.111
class 2	0.116	-	0.023*
class 3	0.111	0.023*	-

4.4. Carbon Stock in Pyroclastic Flow and Pyroclastic Surge Area

The result of Kolmogorov Smirnov test indicates data of dead trees and dead wood carbon stock data in pyroclastic flow and pyroclastic surge area was not normally distributed. Kruskal-Wallis Test shows that both of carbon stock in pyroclastic flow and pyroclastic surge area was affected by surface distance (Appendix 16 and 17).

Total sample plots carbon stock in pyroclastic flow area class 2 and class 3 were 5 kg and 2 kg respectively. The form of carbon stock in surface distance class 2 and class 3 was dead woods carbon stock. The numbers of sample plots are 15 on each surface distance class with 400 m^2 of each plot (Appendix 3-5). The form of carbon stock in area with surface distance class 4 was dead trees and dead woods carbon stock. Total sample carbon stock of 15 plots with 400 m^2 area was 6,278 kg (Table 11). Mann-

Whitney Test was done to compare the carbon stock in each class surface distance in pyroclastic flow area (Table 13). The Table shows that carbon stock in area of surface distance class 2 with area of surface distance class 3 was significantly different as well as carbon stock in area of surface distance class 3 and area of surface distance class 4 (shown by asterisk). Carbon stock in area with class 2 and class 4 surface distances were same so it can be classified into one group (Table 14).

Table 14. Mann-Whitney Test of Carbon Stock in Pyroclastic Flow Area

Surface Distance Class	**class 2**	**class 3**	**class 4**
class 2	-	0.033*	0.161
class 3	0.033*	-	0.011*
class 4	0.161	0.011*	-

Total carbon stocks of sample area in pyroclastic surge area were 2,764 kg in surface distance class 1, 2,515 kg in surface distance class 2 and 33,714 kg in surface distance class 3 (Table 11). Based on Mann-Whitney Test (Table 15), carbon stock in area with surface distance class 3 was different with carbon stock in surface distance class 1 and class 2. Total carbon stock in area with surface distance class 3 is the highest so carbon stock in class 3 surface distance was categorized as high while in others two surface distances were low.

Table 15. Mann-Whitney Test of carbon stock in Pyroclastic Surge Area

Surface Distance Class	**class 1**	**class 2**	**class 3**
class 1	-	0.412	0.026*
class 2	0.412	-	0.015*
class 3	0.026*	0.015*	-

The distribution of total data of carbon stock in each sample plot on each class surface distance in pyroclastic flow area and pyroclastic surge area was tested using Kolmogorov Smirnov Test. Based on Kolmogorov

Smirnov Test, the data of total dead trees and dead woods carbon stock was not normally distributed so non parametric statistical analysis Mann-Whitney Test was applied to compare carbon stock in pyroclastic flow and pyroclastic surge area (Appendix 18). Asymptotic significance of Mann-Whitney test of total carbon stock data was 0.004 (<0.05). It means that carbon stock in pyroclastic flow and pyroclastic surge was different. Carbon stock in pyroclastic surge area was higher than carbon stock in pyroclastic flow area. The total carbon stock of pyroclastic flow area was 2,174 kg/ha and pyroclastic surge was 16,493 kg/ha (Table 11).

All these results are based on very few samples.The Indonesia standard carbon estimation not regulates the standard of number plot sampling. It only require sampling error < 20 %. Based on the ANOVA test, the sampling error of dead wood carbon stock in pyroclastic flow and pyroclastic surge was below 20 % while sampling error of dead trees carbon stock in pyroclastic flow and pyroclastic surge area is high (Appendix 19-22). The number of sampling plot could represent the distribution of the data. Normal distributed data is resulted from lot of sampling plot (Student, 1908). The few samples of dead wood and dead trees in pyroclastic flow and pyroclastic surge in this study caused the distribution of dead trees and dead wood is not normally distributed. The total carbon stock in affected area was generated by multiplying total sample carbon stock by total area. Those will affect the accuracy of carbon stock estimation of carbon stock in pyroclastic flow and pyroclastic surge area.

4.5. Carbon Rate Recovery

The carbon rate recovery was generated based on relation between age of pyroclastic flow event as independent variable and carbon stock in recovery areas as dependent variable (Table 16). The 2011 CPA-Carbon developed model was applied to estimate carbon stock in recovery area.

Linear, Power, Quadratic and Logistic regression was built to relate age of pyroclastic flow event and carbon stock in recovery areas (Table 17). Linear regression was chosen as developed model of age of pyroclastic flow event and carbon stock in recovery areas.

Table 16. Carbon Stock in MVNP based on Year

No.	Year	Carbon (kg/m2)
1	1930	16
2	1956	2
3	1969	7
4	1973	6
5	1975	7
6	1979	10
7	1984	4
8	1994	8
9	1997	16
10	1998	5
11	2001	10

Table 17. Regression Model of the Age of Pyroclastic Flow and Carbon Stock in MVNP Recovery Areas

No.	Regression Model	R^2
1	Quadratic $y = 0.005x^2 - 0.468x + 15.12$	0.418
2	Linear $y = 0.025x + 7.402$	0.013
3	Power $y = 12.88x^{-0.18}$	0.035
4	Logistic $y = 1/0.135*1.002^x$	0.004

Rehabilitation activity in MVNP was carried out in 2011 and 2012. Trees which were used for rehabilitation trees were *Schima wallichii*, *Syzygium cumini, Inocarpus fagiferus, Syzygium polyanthum and Cinnamomum verum.* Mean of seedlings diameter of rehabilitation tree were 0.32 cm while mean of saplings diameter of rehabilitation tree are 0.8 cm. Rehabilitation activities in 2011 were done in Gandog, Tegalmulyo and Selo. Rehabilitation trees carbon stock in those area were 0.006 kg/m^2, 0.006 kg/m^2 and 0.002 kg/m^2 respectively while carbon stock of 2012 rehabilitation trees in Ngargomulyo area was 0.002 kg/m^2 (Table 18). Total 2011 rehabilitation trees carbon stock was 51 kg/ha and total 2012 rehabilitation trees carbon stock was 21 kg/ha.

Table 18. Carbon Stock in Rehabilitation Trees

Rehabilitation Area	Year of Rehabilitation	Seedling Sampling Carbon Stock (kg)	Seedling Carbon Stock (kg)	Sapling Sampling Carbon Stock (kg)	Sapling Carbon Stock (kg)	Total Carbon Stock (kg)	Total Carbon Stock (kg/m2)
Gandog	2011	0.08	666	2	3406	4071	0.006
Tegalmulyo	2011	0.07	247	2	1468	1715	0.006
Selo	2011	0.06	293	0.01	11	304	0.002
Total Rehabilitation Carbon Stock						6090	
Ngargomulyo	2012	0.07	714	2	2772	3486	0.002
Total Rehabilitation Carbon Stock						3486	

4.6. DBH, CPA, Carbon Growth of Dominant Trees in MVNP

The DBH, CPA and Carbon of dominant trees in MVNP in first year of their life and sixth year of their life are presented in Table 19.

Table 19. The First and Sixth Year of DBH, CPA and Carbon Stock of Dominant Trees in MVNP

Species	**DBH (cm)**		**CPA (m^2)**		**Carbon (kg)**	
	Year 1	**Year 6**	**Year 1**	**Year 6**	**Year 1**	**Year 6**
Schima wallichii	0.6	3.8	0.5	2.3	0.01	0.1
Erythrina variegata	2.5	15	1.2	11.1	0.5	3.2
Altingia excelsa	2.7	16.1	3.5	25.7	0.6	3.8
Lithocarpus elegans	0.2	1.3	0.6	1.4	0.001	0.004
Acacia decurrens	6.6	39.8	0.4	1.3	6.6	39.8
Pinus merkusii	2.4	14.3	0.8	5.7	0.6	3.4

The Kolmogorov-Smirnov test was applied to check the distribution of DBH, CPA and carbon stock of dominant trees in MVNP (Appendix 23-

25). The results show that the data was normally distributed so the Paired Sample T Test was applied to the data (Appendix 23-25). Based on the test, the CPA and Carbon stock of dominant trees in MVNP of first year was not different with the CPA and Carbon stock of dominant trees in MVNP of sixth year. While the first year and sixth year of DBH of dominant trees in MVNP was significantly different.

CHAPTER V
DISCUSSION

5.1. Carbon in Unaffected Area

Total remaining carbon stock in affected area based on field measurement was lower than carbon stock based on CPA-Carbon model. This can be due to the overestimation of segmented crown. The overestimation of 2011 segmented needle leaf and broadleaved were 40 % and 54 % respectively while overestimation of 2006 segmented needle leaf and broadleaved were 28 % and 37 % respectively. Though there was an over segmentation but overall the accuracy of segmentation based on the calculation of F score which indicate the accuracy of segmentation was above 0.5 means that the accuracy of algorithm which was used to segment the object more than 50 % and the model can be applied to estimate carbon stock (Li et al., 2012).

The over segmentation can occur due to the algorithm approach and some parameters which were used such as shape, texture and digital number (both of mean and standard deviation) in segmentation process were not give a good result. Some objects that were actually not the tree were recognized as a tree by the algorithm and the parameters because it has similar characteristics with canopy such as the rocky land with small vegetation cover.

The uncertainty of tree segmentation can be caused by the spacing threshold of the trees. The large threshold can be applied in sparse forests since the trees in sparse forest are isolated. However, determination of appropriate in dense forests is difficult. Forest image is textured. The high threshold will lead to under-segmentations because the border which can be identified based on the texture disappears. Low threshold will identify lots of border and lead to over segmentations (Carleer et al., 2005 and Li et al., 2012). In this study the overall F score is above 0.5. That indicates the algorithm is acceptable to be applied (Li et al., 2012). Walter (2004) who studied change detection using in landscape, 23 % incorrectly classified landscape change. He concluded that the few pixels which are located in on large area will classify in the same class with the large area because object based image analysis uses the existing object geometry.

5.2. Carbon in Dead Trees and Dead Woods

Carbon stock in form of dead trees did not exist in pyroclastic flow area on surface distance class 2 and class 3. Pyroclastic flow move along and touch the ground surface. The trees in those areas which were fallen as the effect of pyroclastic flow became the dead wood which was found and estimated in the field as dead wood carbon stock.

Study about pyroclastic flow in Mexico, Mount St.Helens in Washington State in the USA, and Vesuvius in Italy shown that pyroclastic flow volcanoes immediately affected the vegetation. Vegetation destroyed and buried by pyroclastic flow due to heterogeneous, unsorted and hot mass of pyroclastic flow (Dale et al., 2005).

Pyroclastic flow area in MVNP is between Gendol River and Kuning River which became the main line of pyroclastic flow to the south (Yulianto et al., 2012). The end of pyroclastic flow which traveled the Kuning River is shown in Figure 5. It explains that the area with surface distance class 4 has high amount of dead trees carbon stock because the area is far from the crater so the speed and temperature of pyroclastic flow has decreased (Crandell et.al, 1984, Darmawan, 2012 and Surono et al., 2012). Numbers of survived plants are high in the area far from the crater since the area close to the crater more severe than far area to the crater (Dale et al., 2005)

Kelfoun et al. (2000) studied the damaged trees by ash-cloud surges and block-and-ash flows from 1994 Merapi eruption. They classified the damaged trees into 3 classes which are singed tree, broken trees and blown-down trees. The leaves of singed trees are dried and their branches are not broken. Different from singed trees, the leaves of broken trees are stripped off and their branches or trunks are broken. The fallen trees are categorized as blown-down trees. The results show that the singed trees existed in area 800 m from the damaged area, more than 90 % broken trees occurred in damaged area and 50 – 90 % trees were blown-down in the area covered by the block-and-ash flow deposits. In this study, there was found carbon pool in form of pole stage and tree stage in the pyroclastic surge area. The poles were *Acacia decurrens* and *Schima wallichii* while the trees are Pine. The Pine trees and *Acacia decurrens* pole were existed in the pyroclastic surge surface distance class 3. Carbon stock in this surface distance classes categorized high. Poles, *Acacia decurrens* and *Schima wallichii,* were also existed in pyroclastic surge area with surface distance class 2 but there were no trees on pyroclastic surge area class distance 2 and the carbon stock in this area is classified as a low level. The highest carbon stocks of dead trees were located in pyroclastic flow and surge in surface distance class farthest from the crater.

On the other hand, dead wood carbon stock in pyroclastic flow area is not influenced by surface distance means that the dead wood carbon stock are same in each class surface distance. MVNP 2009 land cover map (Figure 3) shows that the former land cover of area affected by pyroclastic flow is Pine forest. Since Pine was planted by Perhutani with specific spacing so that the dead wood carbon stocks which are fallen caused by pyroclastic flow and laid over the area in each surface distance are same.

Carbon stock in pyroclastic surge area was higher than carbon stock in pyroclastic flow. In pyroclastic surge area also found poles and trees biomass. That is because pyroclastic flow material is more destructive than pyroclastic surge material. The density of cloud of gases and rock debris of pyroclastic surge is lower than pyroclastic flow. Pyroclastic flow carried hot volcanic materials. The temperature maximum that can be reached by pyroclastic flows is around 350°C to more than 550°C when it deposited.

Since pyroclastic flow is more powerful and its temperature is higher than pyroclastic surge material, pyroclastic fow can cause all the trees are downed and more damaging than pyroclastic surge (Crandell et al., 1984).

The remaining carbon stock in affected area is underestimated since there is utilization of dead trees and dead wood in affected area by the community.

There was utilization of dead wood by Kalikuning community. Based on the interview with the community, they utilized the dead woods for fire wood. The peak of wood taking was at June to August 2012. For about 5 % of Kalikuning community took the wood in the peak season. They did that because they were not involved in tourism activities. They took the wood for household and for sale. The maximum wood that can be carried was 50 kg. They cut the dead wood into several pieces. The frequency to take the wood was 2 – 3 days a week. So the carbon which was utilized for fire wood during the peak season of wood taking was about 10,152 kg. Nowadays only 2 or 3 persons take the wood so the carbon which was utilized for fire wood was estimated approximately 4,230 kg. This reduced the amount of remaining carbon in the field

The dead trees in pyroclastic surge area, Pine, were utilized to build the house (Figure 25). Communities whose house was affected by pyroclastic surge and lived around Merapi Volcano refused to be relocated. They went back to their village after the eruption and rebuilt their house using Pine trees. They were Balerante and Kalitengah Lor villager. Based on the information from the community, 160 head of household Kalitengah Lor utilized Pine tree to rebuild their house, while in Balerante Pine tree was utilized to rebuild house by 48 head of household. To build their house they need 10 to 15 Pine trees, they need 4 m trunk to make some part of their house. The diameter of the trees which was utilized approximately was 25 cm.

Figure 25. Utilization of Wood by the Community to Rebuild Their House

Based on that information, can be estimated the carbon that was taken from the forest for household. Assuming that the trees are dead trees with good condition (intactness factor is 0.9), the carbon stock which was stored outside the in form of house were 257,394 kg in Kalitengah Lor and 77,218 kg in Balerante.

Though total carbon stock in affected area was reduced but total remaining carbon stock in 2011 was increase. Statistic analysis of dominant species in MVNP shows significant growth of DBH in 5 years (2006-2011). Since the DBH growth will lead to an increase of carbon stock.

Located in Merapi volcano area, MVNP is prone to Merapi eruption. Merapi Pyroclastic Flow Distribution History Map 1911 – 2006 map which was overlapped with maximum distance of pyroclastic flow deposit produced by the eruption with different VEI shows that MVNP always in the range of 3.2 km and 7 km pyroclastic flow deposit produced by 4 – 6 year periodic.

5.3. Carbon Rate Recovery

The estimation of natural carbon rate recovery was only monitored in broadleaves area since Pine was planted by Perhutani. Based on the fieldwork the pioneer species after the eruption is *Acacia decurrens* which is an introduced species. Its diameter 2 years after the eruption was below

10 cm which indicate that the stage of *Acacia decurrens* is sapling which give low contribution in carbon stock. The *Acacia decurrens* was not found predominantly in the broadleaved area when segmented CPA was validated in the field. The pattern of the growth of *Acacia decurrens* is beyond the scope of this study.

The carbon stock in this study was developed based on the CPA. The natural carbon rate recovery was built based on regression which correlated age of pyroclastic flow event and carbon stock in recovery area.

Study about carbon sequestration in Mangrove Forest Planted in Thailand by Kridiborworn et al. (2012) developed relationship between carbon stock and age of *R. apiculata*. Their relationship was logistic regression. Logistic regression means that carbon stock will increase as the age increase but in older trees the growth of carbon stock will slow as the age increases.

Study of DBH and CPA relationship by Shimano, K. (1997) shown that the higher the DBH the larger the CPA but the growth of CPA will decrease as DBH increase means the mature forest stores a lot of carbon but it hardly sequesters extra carbon. A young growing forest sequesters a lot more carbon during the growth. That indicated that the CPA growth will decrease as age increases so the carbon growth rate will also decline but overall the carbon stock is increase as the age of trees increase. Study by Alexandrov (2007) showed that increase in age causes an increase in biomass.

Linear regression was selected to developed model of pyroclastic age event and carbon stock relation in MVNP by considering the 4 – 6 years Merapi volcano eruption period. Study by Peper et al. (2001) concluded that the DBH and CPA growth is fast on its first 15 years but slow in its second 15 years. Since the Merapi volcano eruption period is 4 – 6 years which is below the first stage of tree life, 15 years, the carbon growth in MVNP will increase in 4 – 6 years Merapi volcano eruption period.

Therefore linear regression was chosen to correlate age of pyroclastic flow event and carbon stock in recovery area.

The artificial carbon rate recovery cannot be developed since there is only 1 year growth data of rehabilitation trees. Rehabilitation trees were planted 1 year after the eruption. In the early years after the volcano eruption, plant will suffer to the drought due to the sandy soil (Dale et al., 2005). Plants that were used to rehabilitate the MVNP are *Schima wallichii, Erythrina variegate, Syzygium cumini and Inocarpus fagiferu. Schima wallicii* is semi tolerance species which need light for its growth *(*Harja et al., 2012). *Erythrina variegate*is tolerance species that need full light for growing (Whistler and Elevitch, 2006). *Syzygium cumini* is intolerant specie which requires light to grow (Sheikh, 1993). *Inocarpus fagiferu* is usually found in the open area which full of light although the seed can grow in the understory (Pauku, 2006).

Based on the fieldwork, reeds are growth in the rehabilitation area. Lots of rehabilitation trees are lower than the reed. Since they are intolerant species which require the light, their growth is slow even some of rehabilitation trees is dead.

The 2010 eruption was the 100 periodic eruptions with VEI 4 after the VEI 4 last event in 1872 (Costa et al., 2012). The pyroclastic flow deposit in 1872 is not included in the historic map of pyroclastic deposits of MVNP from 1911 to 2006. The monitoring of carbon recovery during 2 events of Merapi eruption VEI 4 cannot be estimate since the 1872 eruption is not recorded in the pyroclastic deposits map of MVNP. Analysis of carbon recovery was done in area affected by 1997 pyroclastic flow event since linear regression was selected to estimate carbon stock in recovery area. Applying equation of natural carbon rate recovery $y = 0.025x + 7.402$, so after 14 year recovery, carbon stock in 1997 recovery area will become 77,520 kg/ha on the condition without intervention. The value is lower than carbon stock estimation in 1997 recovery area based on developed model CPA-carbon logarithmic regression y =10.648lnCPA+819.302, carbon stock was 150,530 kg/ha.

The regeneration of tree after the eruption could be occurring in 2 ways which are transport of the seed to the area and growth and reproduction of plant that survived. Plants that were invaded soon after the eruption are the pioneer and expected long-term vegetation are climax. The climax condition is hard to reach because the intervention in the environment (Daleet al., 2005). Based on the fieldwork the pioneer species in MVNP is *Acacia decurrens*. The growth pattern of *Acacia decurrens* is not part of this study.

The estimation of carbon rate recovery was estimated based on CPA-Carbon model of 2011 GeoEye satellite imagery. It was difficult to validate the data of carbon stock in recovery area since the eruption is the past event. The carbon stock in recovery area will affect the estimation of natural carbon rate recovery in MVNP. Vegetation structure may have changed in the past and the remaining carbon stock of survival trees in recovery area could also count as carbon recovery. That would affect the accuracy of estimation carbon stock in recovery area

5.4. Research Limitation

The nature and social condition of MVNP influence carbon stock in affected area. The affected area which is close to the crater is difficult to reach because of the labile soil. So the carbon stock of affected area is underestimated because not all of the affected areas observed. Community activities around MVNP also cause the underestimation of carbon stock in affected area because they utilize the wood for daily needs.

The CPA-Carbon relation was developed based on segmented CPA of 2011 GeoEye satellite imagery. The attribute value of 2011 GeoEye satellite imagery will influence the quality of imagery and affect the carbon estimation. The sun elevation angle at acquisition time was 49°43’ and the sun azimuth angle was 39°42’. Sensor azimuth angle was 78°31’ and sensor elevation angle was 67°45’ means the off-nadir angle of the 2011 was 22°14’ (Astrand, 2011). High nadir angle (Meixner and Leberl, 2010) and low sun elevation (Jacobsen and Büyüksalih) will result to oblique image. Figure 26 illustrated the conifer crown which is viewed from various directions (Sheng et al., 2001).

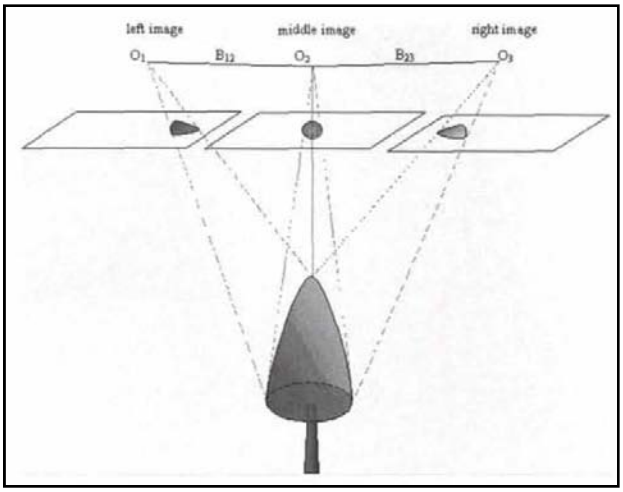


Figure 26. Various View of Pine Crown from Several Direction(Sheng et al., 2001)

Based on sun elevation and off-nadir angle, the 2011 GeoEye satellite imagery is oblique (Figure 27) and the crown projection area was elongated. Those conditions affect the accuracy of carbon stock estimation in MVNP.

Figure 27. Oblique Image of 2011 GeoEye Satellite Imagery

5.5. Research Application

The oblique image which was used in this study affect the accuracy of carbon estimation in MVNP. The segmentation accuracy of 2011 segmented needle leaf and broadleaved in this study are 51 % and 37 % respectively while accuracy of 2006 segmented needle leaf and broadleaved are 66 % and 50 % respectively. Those percentages was lower than the segmentation accuracy of the others study.

Study by Baral (2011) showed the segmentation accuracy of *Shorea robusta* dominant tree in Chitwan District, Nepal using Geo-Eye satellite imagery is 77.6 % while the segmentation accuracy using Worldview satellite 74.4 % (Baral, 2011). Another study conducted in Enschede on nature conservation and recreation forest which has been converted into mixed forest by Geremew (2011) show that accuracy segmentation of broadleaved tree and coniferous tree using Quickbird satellite imagery are 73 % and 67 % respectively. Shrestha who studied needle leaf and broadleaved carbon stock in needle leaved and mixed broad-leaved forests in Dolakha District, Nepal using GeoEye satellite imagery show the segmentation accuracy by 66 % for needle leaf and broadleaved 56 %.

Although the accuracy of the segmentation results of this study is low but overall the F Score which indicate the accuracy of segmentation is above 0.5. Means the model can be applied to estimate carbon stock.

The carbon stock measurements or forest potentials measurements using high-resolution imagery can be applied in plantations forest in Indonesia. Based on Government Regulation Number 6 of 2007 jo Government Regulation No. 3 of 2008 and Minister of Forestry Regulation No. P.36/Menhut-II/2009 jo Minister of Forestry Regulation No. P.11/Menhut-II/2013 the holder of license timber forest utilization can utilize environmental services in production forests in the form of carbon sequestration. The application of segmentation process using high resolution satellite imagery in plantation forest to estimate carbon stock or forest potential may give high segmentation accuracy since systematic spacing in forest plantation could result few overlapped tree crown. The using of satellite imagery can reduce forest inventory time due to vast area of forest plantation. The segmentation could also be applied to measure potential of forest. LiDAR satellite imagery is needed to estimate forest yield since the tree volume is influence by tree height.

CHAPTER VI
CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The results of the study can be summarized to answer the research question. The answers of research question are as follow bellow:

1. How much is carbon stock in the unaffected area?
   a. What is the relation between carbon and CPA

      Having the lowest error, logarithmic regression equation (Carbon=10.648lnCPA+819.302) was used to estimate carbon stock of broadleaf while quadratic regression equation (Carbon=-0.186CPA^2+26.013CPA+134.692) was used to estimate Pine carbon stock based on segmented CPA.
   b. How much is the remaining above ground biomass/carbon that is stored in MVNP in 2011 in unaffected areas which are divided into Pine and broadleaf trees?

      Based on CPA-Carbon developed model, total broadleaved carbon stock in unaffected area was 145,951 kg/ha while the total remaining carbon stock of Pine trees in unaffected area was 143,528 kg/ha.
   c. How much above ground biomass/carbon which is stored in MVNP in 2006, based on the CPA-carbon model of 2011?

      The 2006 carbon stock which was estimated based on 2011 CPA-Carbon model was 121,336 kg/ha for broadleaved trees and 114,552 kg/ha for Pine trees.
2. How much carbon was stored in the affected areas before eruption
   a. What was the tree density and Crown Projection Area/CPA density in affected areas, before eruption

      The CPA density and tree density of affected area before the eruption were 2,586 m^2/ha and 139 trees/ha respectively in pyroclastic flow area and 3,354 m^2/ha and 208 trees/ha respectively in pyroclastic surge area.

b. What was the above ground woody carbon stock in affected areas before eruption

Total above ground woody carbon stock in affected areas before eruption which was obtained from 2006 Quickbird estimated based on CPA-Carbon developed model were 153,170 kg/ha in pyroclastic flow area and 266,770 kg/ha in pyroclastic surge area.

3. What is remaining carbon stock in areas affected by pyroclastic flow and pyroclastic surge?

a. How much the proportion of carbon stock in dead woods?

Total dead wood carbon stock in pyroclastic flow area was 23 kg/ha or 0.22 % of total carbon stock in pyroclastic flow area and total dead wood carbon stock in pyroclastic surge area was 13 kg/ha or 0.02 % of total carbon stock in pyroclastic surge area.

b. How much the proportion of carbon stock in dead trees?

Total dead tree carbon stock in pyroclastic flow area was 10,450 kg/ha or 99.78 % of total carbon stock in pyroclastic flow area and total dead tree carbon stock in pyroclastic surge area was 54,122 kg/ha or 83.28 % of total carbon stock in pyroclastic surge area.

c. What is the effect of distance from the crater on the remaining carbon?

Carbon stock in pyroclastic flow and pyroclastic surge area is influenced by its surface distance. In pyroclastic flow area, area with surface distance class 2 had total carbon stock 8 kg/ha categorized high carbon stock, area with surface distance class 3 has total carbon stock 3 kg/ha categorized low carbon stock and area with surface distance class 4 had total carbon stock 10,463 kg/ha categorized high carbon stock. Total carbon stock in pyroclastic surge area with surface distance class 1, class 2 and class 3 were 4,606 kg/ha, 4,191 kg/ha and 56,191 kg/ha respectively. Total carbon stock in pyroclastic surge area surface distance class 1, class 2 was classified low carbon stock while total carbon stock in pyroclastic surge area surface distance class 3 was classified high carbon stock.

d. What is the difference of remaining carbon stock in pyroclastic flow and pyroclastic surge area?

   Carbon stock in pyroclastic surge area was higher than carbon stock in pyroclastic flow. Based on field measurement total remaining carbon stock in pyroclastic flow area was 2,174 kg/ha while total carbon stock in pyroclastic surge area was 16,493 kg/ha.

e. What is the total carbon loss

   Total carbon loss in pyroclastic area was generated based on subtracting of 2006 carbon stock that were likely to have been in the affected areas by the remaining carbon stock based on field measurement. The total carbon loss was 405,100 kg. The reduction of carbon stock in pyroclastic area is caused by the material of pyroclastic flow and pyroclastic surge also caused by the human activities around affected area in MVNP.

4. What is the rate of carbon recovery in MVNP?

   Natural carbon rate recovery in MVNP was estimated based on linear regression y = 0.025x + 7.402. The 1 year growth of rehabilitation trees is 0.002 – 0.006 kg/m2.

Since 19th century Merapi volcano erupts 4-6 years periodically. The 4-6 years Merapi period eruption has VEI ≤ 2 with the deposit of pyroclastic flow ≤ 7 km from the crater. The directions of pyroclastic flow are varies. All area of MVNP is on the range of ≤ 7 km pyroclastic flow deposit. The southwest and west part of MVNP is in the range of VEI 3 with 12 km pyroclastic flow deposit. That conditions makes the MVNP is always susceptible to pyroclastic flow event. This condition will become a problem because the role of national park as nature conservation area and provider of environmental services and play a role in carbon sequestration in the future based on Government Regulation Number 28 Year 2011 and Number 49 Year 2011will be disrupted.

The natural carbon rate growth in MVNP was y = 0.025x + 7.402. The carbon stock that could be lost in area which affected by the eruption which is occurred in 4-6 years is 7.5 - 7.6 kg/m2. Located in Merapi volcano with periodic eruption the carbon stock in MVNP will always disrupted. In order to carry out the MVNP role in carbon sequestration, management interventions in carbon stock in MVNP is needed through rehabilitation and restoration activities in areas that are not prone to the effects of eruption.

6.2. Recommendations

During the study, there are some ideas that can be developed and recommended for further research of carbon stock in MVNP.

1. The use of good quality high resolution satellite imagery will improve the accuracy of carbon stocks estimation based on CPA-Carbon relationship. Integrating the high resolution image with LiDAR can be considered to estimate carbon stock in MVNP.
2. The further research about artificial carbon rate recovery is recommended since there is not enough data series to establish the relationship between time and artificial carbon stock when this study was conducted.
3. The use of accurate land cover map after 2010 eruption will increase the accuracy of broadleaf and Pine tree carbon stock estimation.
4. Further study of regeneration will give more accurate results in natural carbon rate recovery in MVNP.
5. The map of Merapi volcano susceptible area in MVNP is needed to create good planning of rehabilitation and restoration in MVNP.

References

Alexandrov, G. A. 2007. *Carbon stock growth in a forest stand: the power of age. Carbon Balance and Management Journal* **2**(1):1-5

Astrand, P. J. 2011. *VHR Image Acquisition Specifications for the CAP Controls (CwRS and LPIS QA).* Ispra, Italy: European Commission Joint Research Centre Institute for Environment and Sustainability Monitoring Agricultural Resources Unit

Avsar, M. D. 2004. *The Relationships Between Diameter at The Breast Height, Tree Height and Crown Diameter in Calabrian Pines (Pinus brutia Ten.) of Baskonus Mountain, Kahramanmaras, Turkey. Journal of Biological Sciences* **4**(4):437-440

Baral, S. 2011. *Mapping Carbon Stock Using High Resolution Satellite Images in Sub - Tropical Forest of Nepal*. MSc thesis, ITC

Bautista, A. A. L. 2012. Biomass carbon estimation and mapping in the subtropical forest of Chitwan, Nepal : a comparison between VHR geoeye satellite images and airborne LiDAR data. MSc thesis, ITC

Blaschke, T.; Johansen, K.; and Dirk, T. 2011. *Object based image analysis for vegetation mapping and monitoring*. In Weng, Q, *Advances in environmental remote sensing: Sensors, algorithms, and applications*, pp 141-266. United States: CRC Press, Taylor and Francis

Boojh, R. and Ramakhrisnan. 1982. *Growth and Architecture of Two Altitudinal Population of Schima wallichii*. In *Proceedings of the Indian National Science Academy Part B Biological sciences* **8**(4): 534-545

Bureau of Merapi Volcano National Park, Ministry on Forestry. 2011. *Survey Kondisi Tumbuhan dan Satwa Liar Taman Nasional Gunung Merapi Paska Erupsi Tahun 2010*. Yogyakarta: Directorate General of Forest Protection and Nature Conservation, Ministry of Forestry

Bureau of Merapi Volcano National Park, Ministry on Forestry. 2011. *ALBUM PETA Restorasi Ekosistem Taman nasional Gunung Merapi Pasca Erupsi 2010*. Yogyakarta: Directorate General of Forest Protection and Nature Conservation, Ministry of Forestry

Bureau of Merapi Volcano National Park, Ministry on Forestry. Un-dated. *Kondisi Fisik*. URL: http://tngunungmerapi.org/?page_id=215. Accessed date: 24-May-2012

Brown, S. 1997. *Estimating Biomass and Biomass Change of Tropical Forests: a Primer*. On-line document; URL: http://www.fao.org/docrep/w4095e/w4095e00.htm. Access date: 6-November-2012

Carleer, A.P.; Debeir, O.; and Wolff, E. 2005. *Assessment of Very High Spatial Resolution Satellite Image Segmentations. Photogrammetric Engineering & Remote Sensing Journal* **71**: 1285-1394

Chatterjee, K. (2003). *Causes of Greenhouse Gas Emissions Climate Change*. In P. Martens, P.; Rotmans, D.; Jansen, D.; and Vrieze, K., *Climate Change : An Integrated Perspective*, **1:** 143-200. Dordrecht: Kluwer Academic

Chave , J.; Andalo, C.; Brown, S.; Cairns, A.; Chambers, J. Q.; Eamus, D.; Folster, H.; Fromard, F.; Higuchi, N.; Kira, T.; Lescure, J. P.; Nelson, W.; Ogawa, H.; Puig, H.; Rie´ra, B.; and Yamakura, T. 2005. *Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia* **145**(1): 87-99

Clinton, N.; Holt, A.; Scarborough, J.; Yan, L.; and Gong, P. 2010. *Accuracy Assessment Measures for Object-based Image Segmentation Goodness. Photogrammetric Engineering and Remote Sensing* **76**(3): 289-299

Costa, F.; Andreastuti, S.; Bouvet de Maisonneuve, C.; and Pallister, J. S. 2012. *Petrological insights into the storage conditions, and magmatic processes that yielded the centennial 2010 Merapi explosive eruption. Journal of Volcanology and Geothermal Research* in press, corrected proof

Crandell, D. R.; Booth, B.; Kusumadinata, K.; Shimozuru, D.; Walker, G. P. L and Westercamp, D. 1984. *Source-book for volcanic-hazards zonation*. France: UNESCO

Dale, V. H.; Delgado-Acevedo, J.; and MacMahon, J. 2005. *Effects of modern volcanic eruptions on vegetation*. In Marti, J and Ernst, G. G. J, *Volcanoes and The Environment*, pp 227-249**.** Cambridge: Cambridge University Press

Darmawan, H. 2012. *Pemodelan Aliran Awan Panas Dengan Menggunakan TITAN2D Untuk Memprediksi Bahaya Awan Panas Gunungapi Merapi Pasca Erupsi 2010*. MSc thesis, UGM

Definiens. 2009. eCognition Developer 8 User Guide. Munchen : Definiens AG

Definiens. 2009. eCognition Developer 8 Reference Book. Munchen : Definiens AG

Geology Agency. Un-dated. Sejarah Merapi. URL: http://merapi.bgl.esdm.go.id/informasi_merapi.php?page=informasi-merapi&subpage=sejarah. Accessed date: 17-November-2012

Geremew, W. T. 2011. Assessment of Above Ground Carbon Stock in Coniferous and Broadleaf Forest, Using High Spatial Resolution Satellite Images. MSc thesis, ITC

Gill, S. J.; Biging, G. S.; Murphy, E. C. 2000. *Modeling conifer tree crown radius and estimating canopy cover. Forest Ecology and Management* **126**:405-416

Gonzalez, P.; Asner, G. P.; Battles, J. J.; Lefsky, M. A.; Waring, K. M.; Palace, M. 2010. *Forest carbon densities and uncertainties from LiDAR, QuickBird, and field measurements in California. Remote Sensing of Environment* **114**(7): 1561-1575

Gschwantner, T.; Schadauer, K.; Vidal, C.; Lanz, A.; Tomppo, E.; di Cosmo, L.; Robert, N.; Englert Duursma, D.; and Lawrence, M. 2009. *Common tree definitions for national forest inventories in Europe. Silva Fennica* **43**(2): 303–321

Hairiah K, Ekadinata A, Sari RR, Rahayu S. 2011. *Pengukuran Cadangan Karbon: dari tingkat lahan ke bentang lahan. Petunjuk praktis. Edisi kedua*. Bogor: World Agroforestry Centre

Harja, D.; Vincent, G.; Mulia, R.; and van Noordwijk, M. 2012. Tree *shape plasticity in relation to crown exposure*. *Trees* **26**(4): 1275-1285

Hay, G.J. and Castilla, G. 2008. *Geographic Object-Based Image Analysis (GEOBIA): A new name for a new discipline*. In Blaschke, T.; Lang, S.; and Hay, G.J. (Eds.), *Object-Based Image Analysis Spatial Concepts for Knowledge-Driven Remote Sensing Applications*, pp 75-89. Berlin: Springer

Hemery, G. E.; P. S. Savill.; and Pryor, S. N. 2005. *Applications of the crown diameter–stem diameter relationship for different species of broadleaved trees*. *Forest Ecology and Management* **215**(1–3): 285-294

Intergovernmental Panel on Climate Change (IPCC). 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Kanagawa, Japan: Institute for Global Environmental Strategies

Intergovernmental Panel on Climate Change (IPCC). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Kanagawa, Japan: Institute for Global Environmental Strategies

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Synthesis Report*. Geneva, Switzerland: The Intergovernmental Panel on Climate Change

Intergovernmental Panel on Climate Change (IPCC). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge: Cambridge University Press

Jacobsen, K. and G. Büyüksalih. Un-dated. *Topographic mapping from space*. On-line PDF document; URL: http://www.ipi.uni-hannover.de/uploads/tx_tkpublikationen/Jacobsen_istanbul_01.pdf. Accessed date: 4-February-2013

Janzen, H. H. 2004. *Carbon cycling in earth systems—a soil science perspective. Agriculture, Ecosystems & Environment* **104**(3): 399-417

Kelfoun, K.; Legros, F.; and Gourgaud, A. 2000. *A statistical study of trees damaged by the 22 November 1994 eruption of Merapi volcano (Java, Indonesia): relationships between ash-cloud surges and block-and-ash flows*. *Journal of Volcanology and Geothermal Research* **100**(1–4): 379-393

Ketterings, Q. M.; Coe, R,; van Noordwijk, M.; Ambagau, Y.; and Palm, C. A. 2001. *Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management* **146**(1–3): 199-209

Kridiborworn, P.; Chidthaisong, A.; Yuttitham, M.; and Tripetchkul, S. 2012. *Carbon Sequestration by Mangrove Forest Planted Specifically for Charcoal Production in Yeesarn, Samut Songkram. Journal of Sustainable Energy & Environment* **3**: 87-92

Köhl, M.; Magnussen, S.; and Marchetti, M. 2006. *Sampling Methods, Remote Sensing and GIS Multiresource Forest Inventory*. Berlin: Springer

Lavigne, F.; Thouret, J. C.; Voight, B.; Suwa, H.; Sumaryono, H. 2000. *Lahars at Merapi volcano, Central Java: an overview.* Journal of Volcanology and Geothermal Research **100**(1–4): 423-456

Li, W.; Guo, Q.; Jakubowski, M. K.; and Kelly, M. 2012. *A New Method for Segmenting Individual Trees from the LiDAR Point Cloud. Photogrammetric Engineering & Remote Sensing* **78**: 75-84

Lu, D. 2005. *Integration of vegetation inventory data and Landsat TM image for vegetation classfication in the western Brazilian Amazon . Forest Ecology and Management* **213**: 369–383

Mandal, R. A.; Dutta, I. C.; Jha, P. K.; Karmacharya, S.; yadav, K.; Thapa, U.; and Haque, S. 2012. *Effects of Deforestration anf Forest Degradation on Forest Carbon Stock in Collaborative Forests, Nepal. International Journal Of Conservation Science* **3** (4): 325-338

Manuri, S.; Putra, C. A. S.; and Saputra, A. D. 2011. *Tehnik Pendugaan Cadangan Karbon Hutan*. Palembang : Merang REDD Pilot Project – German International Cooperation (MRPP-GIZ)

Meixner, P and Leberl, F. 2010. *Interpreting Building facades from Vertical Aerial Images Using The Third Dimension*. In *ISPRS Technical Commission IV & AutoCarto Symposium ASPRS/ CaGIS 2010 Fall Specialty Conference*. Orlando: ISPRS

Minarto, E. 2009. *Forest Dynamics of Peat Swamp Forest in Sebangau, Central Kalimantan. Biodiversitas* **10**: 187-194

Navulur, K. 2007. *Multispectral Image Analisys Using The Object Oriented Paradigm*. US: CRC Press.

Newhall, C. G. and Self, S. 1982. *The Volcanic Explosivity Index (VEI) - an Estimate of Explosive Magnitude For Historical Volcanism. Journal of Geophysical Research-Oceans and Atmospheres* **87**: 1231-1238.

Newhall, C. G.; Bronto, S.; Alloway, B.; Banks, N. G.; Bahar, I.; del Marmol, M. A.; Hadisantono, R. D.; Holcomb, R. T.; McGeehin, J.; Miksic, J. N.; Rubin, M.; Sayudi, S. D.; Sukhyar, R.; Andreastuti, S.; Tilling, R. I.; Torley, R.; Trimble, D.; and Wirakusumah, A. D. 2000). *10,000 Years of explosive eruptions of Merapi Volcano, Central Java: archaeological and modern implications. Journal of Volcanology and Geothermal Research* **100**(1–4): 9-50.

Pandiwijaya, A. 2011. *Pendugaan Perubahan Cadangan Karbon di Taman Nasional Gunung Merapi*. Skripsi, IPB.

Pareta, K. and U. Pareta. 2011. *Forest Carbon Management Using Satellite Remote Sensing Techniques a Case Study of sagar District (M. P.). E-International Scientific Research Journal* **3**(4): 335-348

Pauku, R. L. 2006. Species *Profiles for Pacific Island Agroforestry-Inocarpus fagifer (Tahitian chestnut)*. On-line PDF document; URL: http://agroforestry.net/tti/Inocarpus-Tahitianchestnut.pdf. Accessed date: 5-March-2013

Peper, P. J.; McPherson, E. G.; and Mori, S. M. 2001. *Equation for Predicting Diameter, Height, Crown Width, and Leaf Area of san Joaquin Valley Street Trees. Journal of Arboriculture* **27**(6): 306-317

Priyatno, D. 2012. *Belajar Praktis analisis Parametrik dan Non Parametrik Dengan SPSS*. Yogyakarta: Gava Media

Shah, R. 2011. *Comparison of Individual Tree Crown Delineation Method for Carbon Stock Estimation Using Very High Resolution Satellite Images*. MSc thesis, ITC

Sheikh, M. I. 1993. *Trees of Pakistan*. On-line PDF document; URL: http://pdf.usaid.gov/pdf_docs/pnabw250.pdf: 5-March-2013

Sheng, Y.; Gong, P.; and Biging, G.S. 2001. *Model-Based Conifer-Crown Surface Reconstruct ion from High-Resolut ion Aerial Images. Photogrammetric Engineering & Remote Sensing* **67**: 957-965

Shimano, K. 1997. *Analysis of the Relationship between DBH and Crown Projection Area Using a New Model. Journal of Forest Research* **2**(4): 237-242.

Shrestha, S. K. 2011. *Carbon stock estimation using very high resolution satellite imagery and individual crown segmentation : a case study of broadleaved and needle leaved forest of Dollakha, Nepal*. MSc thesis, ITC

SNI 7724:2011. 2011. *Measurement and calculation of carbon stocks – Field measurement for estimating forest carbon stocks (ground based forest carbon accounting)*. Indonesia: Standardization and Enviroment. Ministry of Forestry

Student. 1908. *Probable Error of a Correlation Coefficient*. On-line PDF document; URL: http://www.jstor.org/stable/2331474?origin=JSTOR-pdf. Accessed date: 7-March-2013

Suharlan, A.; Sumarna, K.; and Sudiono, J. 1975. *Tabel Tegakan Sepuluh Jenis Kayu Industri (Yield Table of Ten Industrial Wood Species)*. Bogor: Forestry Research and Development Agency, Ministry of Forestry

Surono; Jousset, P.; Pallister, J.; Boichu, M.; Buongiorno, M. F.; Budisantoso, A.; Costa, F.; Andreastuti, S.; Prata, F.; Schneider, D.; Clarisse, L.; Humaida, H.; Sumarti, S.; Bignami, C.; Griswold, J.; Carn, S.; Oppenheimer, C.; and Lavigne, F. 2012. *The 2010 explosive eruption of Java's Merapi volcano—A '100-year' event. Journal of Volcanology and Geothermal Research* **241–242**: 121-135.

Tilling, R. I. 2005. *Volcano Hazards*. In Marti, J and Ernst, G. G. J, *Volcanoes and The Environment*, pp 55-89**.** Cambridge: Cambridge University Press

Thouret, J. C. (2010). *Volcanic hazard and risks: a geomorphological perspective*. In Alcántara-Ayala, A and Goudie, A. S., *Geomorphological Hazards and Disaster Prevention*, pp 13-32. Cambridge: Cambridge University Press.

Voight, B.; Constantine, E. K., Siswowidjoyo, S.; and Torley, R. 2000. *Historical eruptions of Merapi Volcano, Central Java, Indonesia, 1768–1998. Journal of Volcanology and Geothermal Research* **100**: 69-138.

Walter, V. 2004. *Object-based classification of remote sensing data for change detection. ISPRS Journal of Photogrammetry and Remote Sensing* **58**(3–4): 225-238.

Whistler, W. A. and Elevitch, C. R. 2006. Species Profiles for Pacific Island Agroforestry-Erythrina variegata (coral tree). On-line PDF document;

URL: http://agroforestry.net/tti/Erythrina-coraltree.pdf. Accessed date: 13-January-2013

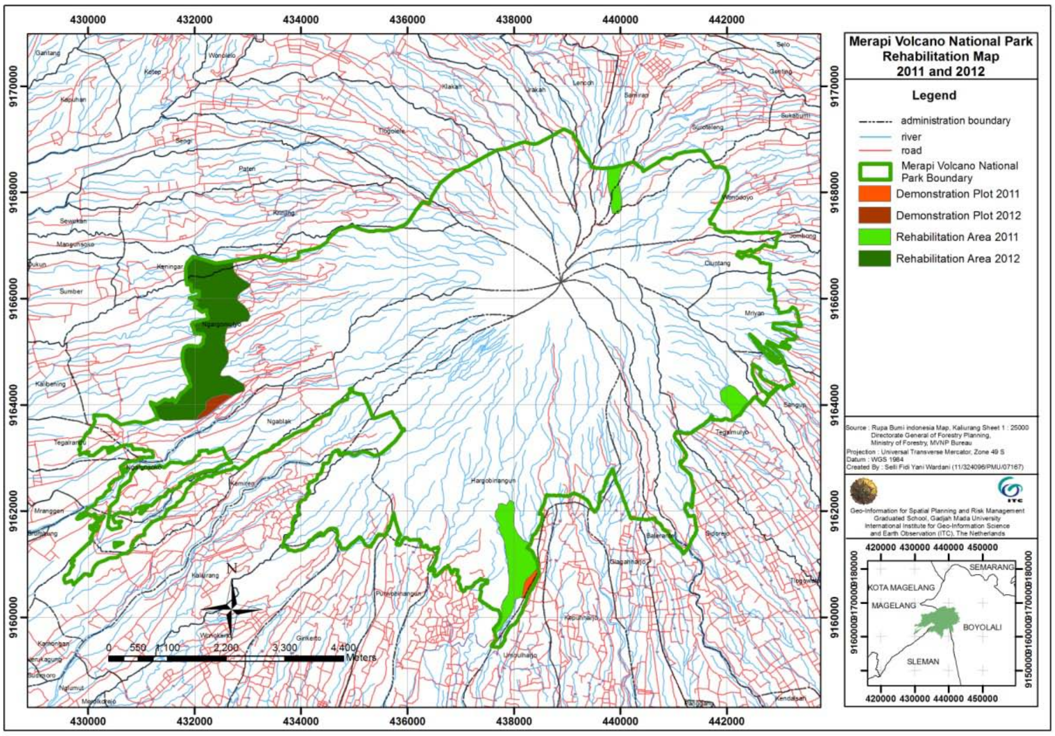
Xie, Y.; Sha, Z.; and Yu, M. 2007. *Remote sensing imagery in vegetation mapping: a review. Plant Ecology* **1**: 9-23

Yulianto, F.; Sofan, P.; Khomarudin, M. R.; Haidar, M. 2013. *Extracting the damaging effects of the 2010 eruption of Merapi volcano in Central Java, Indonesia. Natural Hazards* **66**(2): 229-247.

Zhan, Q.; Molenaar, M.; Tempfli, K.; and Shi, W. 2005. *Quality assessment for geo-spatial objects derived from remotely sensed data. International Journal of Remote Sensing* 2**6**: 2953–2974

APPENDICES

Appendix 1. Merapi Volcano National Park Rehabilitation Map 2011 and 2012



Sources : Rupa Bumi Indonesia Map, Kaliurang Sheet, 1:25000; Directorate General of Forestry Planning, Ministry of Forestry; Merapi National Park Bureau, 2011

Appendix 2. One Way ANOVA Test for Dead Woods Density

Descriptives

Wood Density (kg/m3)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min.	Max.
Good	10	.6500	.20868	.06599	.5007	.7993	.40	1.00
Moderate	10	.5611	.39113	.12369	.2813	.8409	.40	1.67
Decomposed	10	.5500	.12197	.03857	.4627	.6373	.33	.67
Total	30	.5870	.26016	.04750	.4899	.6842	.33	1.67

ANOVA

Wood Density (kg/m3)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.060	2	.030	.426	.657
Within Groups	1.903	27	.070		
Total	1.963	29			

Appendix 3. Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Flow - Surface Distance >3973 - 5297 m (Class 2)

Random Sampling Plots				**Dead Trees Carbon (kg)**	**Dead Woods Carbon (kg)**	**Total**
No.	**Coordinate**		**Elevation**			
	x	**Y**				
1	438578	9162222	1184	-	0.38225298	0.382253
2	438538	9162357	1228	-	0.108874602	0.108875
3	438495	9162531	1251	-	0.329883745	0.329884
4	438484	9162738	1283	-	0	0
5	438579	9162896	1331	-	0.719117588	0.719118
6	438615	9162927	1341	-	1.843342599	1.843343
7	438751	9163154	1381	-	0.468284369	0.468284
8	438494	9162806	1289	-	0.220599649	0.2206
9	438489	9162619	1283	-	0	0
10	438579	9162266	1184	-	0.006076499	0.006076
11	438839	9162708	1320	-	0.048169301	0.048169
12	438804	9162529	1290	-	0.249708633	0.249709
13	438848	9162443	1251	-	0.046715437	0.046715
14	438867	9162455	1248	-	0.001875463	0.001875
15	438858	9162319	1198	-	0.290914314	0.290914
	Total			**0**	**4.715815178**	**4.715815**

Appendix 4.Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Flow - Surface Distance >5297-6620 m (Class 3)

Random Sampling Plots				**Dead Trees Carbon (kg)**	**Dead Woods Carbon (kg)**	**Total**
No.	**Coordinate**		**Elevation**			
	x	**Y**				
1	438423	9161682	1074	-	0.235060955	0.235061
2	438442	9161738	1079	-	0.068072353	0.068072
3	438454	9161792	1079	-	0.105060646	0.105061
4	438467	9161846	1086	-	0.127564399	0.127564
5	438251	9161560	1055	-	0	0

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Total
No.	Coordinate		Elevation			
	x	Y				
6	438225	9161502	1048	-	0	0
7	438241	9161524	1050	-	0	0
8	438252	9161497	1046	-	0	0
9	438256	9161463	1037	-	0	0
10	438152	9161312	1004	-	0	0
11	438158	9161336	1003	-	0	0
12	438231	9161382	1022	-	0	0
13	438315	9161497	1056	-	0	0
14	438353	9161576	1051	-	0.452644557	0.452645
15	438382	9161642	1055	-	0.685610061	0.685610
	Total			**0**	**1.674012971**	**1.674013**

Appendix 5.Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Flow - Surface Distance > 6620 – 7945 m (Class 4)

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Total
No.	Coordinate		Elevation			
	x	Y				
1	437768	9159531	859	0	0	0
2	437806	9159608	870	263.4609309	0	263.4609
3	437814	9159658	868	0	0	0
4	437858	9159740	881	0	0	0
5	437995	9159880	905	0	0	0
6	437943	9159907	862	0	0.263979974	0.26398
7	437975	9159973	863	224.8162579	0.090017952	224.9063
8	438112	9160078	929	2078.483348	0	2078.483
9	438054	9160231	882	1315.412586	2.20874998	1317.621
10	438217	9160539	887	0	1.213662544	1.213663
11	438250	9160561	913	938.9731464	1.621371681	940.5945
12	438303	9160615	965	945.2832774	0.267327395	945.5506
13	438407	9160772	986	503.8445283	1.636484093	505.481
14	438403	9160763	979	0	0.342675727	0.342676
15	438206	9160235	952	0	0.013776127	0.013776
	Total			**6270.274075**	**7.658045474**	**6277.932**

Appendix 6. Kruskal-Wallis Test for Dead Woods in Pyroclastic Flow Area

Ranks

	Class Distance (m)	N	Mean Rank
carbon (kg)	>3973 - 5297 m	15	27.13
	>5297-6620 m	15	17.40
	> 6620 – 7945 m	15	24.47
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	4.650
df	2
Asymp. Sig.	.098

a. Kruskal Wallis Test

b. Grouping Variable: Class Distance (m)

Appendix 7. Kruskal-Wallis Test for Dead Trees in Pyroclastic Flow Area

Ranks

	Class Distance (m)	N	Mean Rank
carbon (kg)	>3973 - 5297 m	15	19.50
	>5297-6620 m	15	19.50
	> 6620 – 7945 m	15	30.00
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	16.060
df	2
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: Class Distance (m)

Appendix 8. Mann-Whitney Test of Dead Trees Carbon Stock for surface distance >3973 – 5297 m and > 6620 – 7945 m in Pyroclastic Flow Area

Ranks

	Class Distance (m)	N	Mean Rank	Sum of Ranks
carbon (kg)	>3973 - 5297 m	15	12.00	180.00
	> 6620 – 7945 m	15	19.00	285.00
	Total	30		

Test Statistics[b]

	carbon (kg)
Mann-Whitney U	60.000
Wilcoxon W	180.000
Z	-2.937
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.029[a]

a. Not corrected for ties.

b. Grouping Variable: Class Distance (m)

Appendix 9. Mann-Whitney Test of Dead Trees and Dead Wood Carbon Stock in Pyroclastic Flow Area

Rank

	carbon_Pool_kg	N	Mean Rank	Sum of Ranks
Carbon_Stock_kg	Dead Trees (kg)	45	37.18	1673.00
	Dead Wood (kg)	45	53.82	2422.00
	Total	90		

Test Statistics[a]

	Carbon_Stock_kg
Mann-Whitney U	638.000
Wilcoxon W	1673.000
Z	-3.440
Asymp. Sig. (2-tailed)	.001

a. Grouping Variable: carbon_Pool_kg

Appendix 10. Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Surge - Surface Distance >2650 - 3973 m (Class 1)

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Total
No.	Coordinate		Elevation			
	x	y				
1	439970	9163826	1594	133.6060949	0	133.6061
2	440039	9163853	1588	320.6879805	0	320.688
3	439990	9163927	1613	0	0	0
4	439957	9164021	1627	151.6035103	0.034440316	151.638
5	439971	9163987	1629	0	0	0
6	439924	9163943	1621	639.2293449	0.03619304	639.2655
7	439969	9163903	1623	0	0.00357688	0.003577
8	439973	9163743	1536	0	0.018114357	0.018114
9	439870	9164138	1706	391.9055134	0.06572445	391.9712
10	439605	9164093	1540	243.0162411	0	243.0162
11	439733	9163855	1538	184.4115394	0	184.4115
12	439761	9164103	16731538	543.8885383	0	543.8885
13	439816	9163901	1536	123.5186286	0	123.5186
14	439676	9163993	1537	31.78065236	0	31.78065
15	439790	9164095	1537	0	0	0
	Total			**2763.648044**	**0.158049044**	**2763.806**

Appendix 11. Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Surge - Surface Distance >3973 - 5297 m (Class 2)

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Poles Carbon (kg)	Total
No.	Coordinate		Elevation				
	x	y					
1	440045	9162491	1235	0	0		0
2	440517	9162626	1259	0	0.039329991		0.03933
3	440538	9162731	1292	0	0.032868351		0.032868
4	440227	9163128	1342	0	0.016669113		0.016669
5	440860	9163076	1326	1527.077136	2.124877427	44.98747863	44.98747863
6	440845	9163310	1361	162.9245558	0.272098567		163.1967
7	440885	9163299	1371	299.2176634	0		299.2177
8	440470	9163307	1392	0	0.1254743		0.125474
9	439730	9162909	1279	0	0		0
10	441160	9163062	1314	121.580666	0		121.5807
11	440861	9163380	1376	269.1615151	0.263033312	86.35845291	355.7830013
12	440488	9163379	1408	0	0.290683757		0.290684

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Poles Carbon (kg)	Total
No.	Coordinate		Elevation				
	x	y					
13	440169	9163213	1374	0	0.311224717		0.311225
14	440320	9163617	1446	0	0.002908701		0.002909
15	440195	9163381	1405	0	0.004110629		0.004111
	Total			**2379.961536**	**3.483278866**	131.3459315	**2514.790746**

Appendix 12. Carbon Stock in Dead Trees and Dead Woods in Pyroclastic Surge - Surface Distance >5297-6620 m (Class 3)

Random Sampling Plots				Dead Trees Carbon (kg)	Dead Woods Carbon (kg)	Poles Carbon (kg)	Trees Carbon (kg)	Total
No.	Coordinate		Elevation					
	x	y						
1	441122	9162586	1217	671.2019558	0.645034076			671.847
2	440996	9162308	1207	2800.913905	0.190488682			2801.104
3	441038	9162654	1239	2061.695737	0.052844999			2061.749
4	441084	9162747	1216	1166.356942	0.538095943			1166.895
5	440993	9161968	1154	2969.279377	0			2969.279
6	441015	9161984	1153	1857.50427	0			1857.504
7	440494	9162277	1201	0	0			0
8	440966	9162115	1177	2866.813393	0			2866.813
9	441053	9162167	1169	0	1.377567648			1.377568
10	441080	9161863	1136	0	0		6280.682435	6280.682435
11	440435	9161959	1172	0	0	58.89923227		58.89923227
12	440686	9161956	1114	0	0			0
13	441078	9162189	1172	10566.91117	0.758800074			10567.67
14	440310	9161883	1166	0	0			0
15	441019	9162266	1197	2368.635828	0.529331882	41.4982738		2410.663434
	Total			**27329.31258**	**4.092163304**	100.3975061	6280.682435	**33714.48469**

Appendix 13. Kruskal-Wallis Test for Dead Trees in Pyroclastic Surge Area

Ranks

	Class Distance (m)	N	Mean Rank
carbon (kg)	>2560 - 3973 m	15	22.87
	>3973 - 5297 m	15	17.27
	>5297-6620 m	15	28.87
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	6.514
df	2
Asymp. Sig.	.039

a. Kruskal Wallis Test

b. Grouping Variable: Class Distance (m)

Appendix 14. Kruskal-Wallis Test for Dead Woods in Pyroclastic Surge Area

Ranks

	Class Distance (m)	N	Mean Rank
carbon (kg)	>2560 - 3973 m	15	17.00
	>3973 - 5297 m	15	27.33
	>5297-6620 m	15	24.67
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	5.666
df	2
Asymp. Sig.	.059

a. Kruskal Wallis Test

b. Grouping Variable: Class Distance (m)

Appendix 15. Mann-Whitney Test of Dead Trees Carbon Stock for surface distance >3973 - 5297 m and >5297-6620 m in Pyroclastic Surge Area

Ranks

	Class Distance (m)	N	Mean Rank	Sum of Ranks
carbon (kg)	>3973 - 5297 m	15	12.13	182.00
	>5297-6620 m	15	18.87	283.00
	Total	30		

Test Statistics[b]

	carbon (kg)
Mann-Whitney U	62.000
Wilcoxon W	182.000
Z	-2.274
Asymp. Sig. (2-tailed)	.023
Exact Sig. [2*(1-tailed Sig.)]	.037[a]

a. Not corrected for ties.

b. Grouping Variable: Class Distance (m)

Appendix 16. Kruskal-Wallis Test for carbon Stock in Pyroclastic Flow Area

Ranks

	Class Distance (m)	N	Mean Rank
carbon (kg)	>3973 - 5297 m	15	24.13
	>5297-6620 m	15	15.53
	> 6620 – 7945 m	15	29.33
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	8.771
df	2
Asymp. Sig.	.012

a. Kruskal Wallis Test

b. Grouping Variable: Class Distance (m)

Appendix 17. Kruskal-Wallis Test for carbon Stock in Pyroclastic Surge Area

Ranks

	Pyroclastic Area	N	Mean Rank
carbon (kg)	Pyroclastic Flow	15	20.83
	Pyroclastic Surge	15	17.73
	3.00	15	30.43
	Total	45	

Test Statistics[a,b]

	carbon (kg)
Chi-Square	7.667
df	2
Asymp. Sig.	.022

a. Kruskal Wallis Test

b. Grouping Variable: Pyroclastic Area

Appendix 18. Mann-Whitney Test for Carbon Stock in Pyroclastic Flow and Pyroclastic Surge Area

Ranks

	Pyroclastic Area	N	Mean Rank	Sum of Ranks
carbon (kg)	Pyroclastic Flow	45	37.60	1692.00
	Pyroclastic Surge	45	53.40	2403.00
	Total	90		

Test Statistics[a]

	carbon (kg)
Mann-Whitney U	657.000
Wilcoxon W	1692.000
Z	-2.893
Asymp. Sig. (2-tailed)	.004

a. Grouping Variable: Pyroclastic Area

Appendix 19. ANOVA of Dead Wood Carbon Stock in Pyroclastic Surge Area

Descriptives

carbon_stock_kg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
>2650-3973	15	.0105	.01981	.00511	-.0004	.0215	.00	.07
>3973-5297	15	.2322	.53782	.13886	-.0656	.5301	.00	2.12
>5297-6620	15	.2728	.41248	.10650	.0444	.5012	.00	1.38
Total	45	.1719	.39985	.05961	.0517	.2920	.00	2.12

Appendix 20. ANOVA of Dead Trees Carbon Stock in Pyroclastic Surge Area

Descriptives

carbon_stock_kg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
>2650-3973	15	184.2432	207.33717	53.53423	69.4237	299.0627	.00	639.23
>3973-5297	15	158.6641	392.57897	101.36346	-58.7389	376.0671	.00	1527.08
>5297-6620	15	418.0183	631.23227	162.98347	68.4535	767.5831	.00	2078.48
Total	45	253.6419	451.02671	67.23509	118.1384	389.1453	.00	2078.48

Appendix 21. ANOVA of Dead Wood Carbon Stock in Pyroclastic Flow Area

Descriptives

carbon_stock_kg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
>3973-5297	15	.3144	.47198	.12186	.0530	.5758	.00	1.84
>5297-6620	15	.1116	.20272	.05234	-.0007	.2239	.00	.69
>6620-7945	15	.5105	.75667	.19537	.0915	.9296	.00	2.21
Total	45	.3122	.54153	.08073	.1495	.4749	.00	2.21

Appendix 22. ANOVA of Dead Trees Carbon Stock in Pyroclastic Flow Area

Descriptives

carbon_stock_kg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
>3973-5297	15	.0000	.00000	.00000	.0000	.0000	.00	.00
>5297-6620	15	.0000	.00000	.00000	.0000	.0000	.00	.00
>6620-7945	15	418.0183	631.23227	162.98347	68.4535	767.5831	.00	2078.48
Total	45	139.3394	408.03719	60.82659	16.7515	261.9274	.00	2078.48

Appendix 23. Kolmogorov-Smirnov and Paired Samples test of Carbon Growth

One-Sample Kolmogorov-Smirnov Test

		Carbon_Year1	Carbon_Year6
N		6	6
Normal Parameters[a,b]	Mean	1.3972	8.3829
	Std. Deviation	2.58054	15.48327
Most Extreme Differences	Absolute	.450	.450
	Positive	.450	.450
	Negative	-.294	-.294
Kolmogorov-Smirnov Z		1.101	1.101
Asymp. Sig. (2-tailed)		.177	.177

a. Test distribution is Normal.

b. Calculated from data.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Carbon_Year1 - Carbon_Year6	-6.98577	12.90272	5.26751	-20.52635	6.55481	-1.326	5	.242

Appendix 24. Kolmogorov-Smirnov and Paired Samples test of CPA Growth

One-Sample Kolmogorov-Smirnov Test

		CPA_Year1	CPA_Year 6
N		6	6
Normal Parameters[a,b]	Mean	1.9502	7.8982
	Std. Deviation	3.66540	9.45939
Most Extreme Differences	Absolute	.414	.259
	Positive	.414	.259
	Negative	-.308	-.241
Kolmogorov-Smirnov Z		1.014	.635
Asymp. Sig. (2-tailed)		.255	.815

a. Test distribution is Normal.

b. Calculated from data.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	CPA_Year1 - CPA_Year6	-5.94801	6.05205	2.47074	-12.29925	.40323	-2.407	5	.061

Appendix 25. Kolmogorov-Smirnov and Paired Samples test of DBH Growth

One-Sample Kolmogorov-Smirnov Test

		DBH_Year1	DBH_Year6
N		6	6
Normal Parameters[a,b]	Mean	2.5050	15.0300
	Std. Deviation	2.27365	13.64192
Most Extreme Differences	Absolute	.303	.303
	Positive	.303	.303
	Negative	-.156	-.156
Kolmogorov-Smirnov Z		.742	.742
Asymp. Sig. (2-tailed)		.640	.640

a. Test distribution is Normal.

b. Calculated from data.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DBH_Year1 - DBH_Year6	-12.52500	11.36827	4.64108	-24.45527	-.59473	-2.699	5	.043

Appendix 26. Fieldwork Documentation