Mediterranean land abandonment and associated biomass variation

A research performed in the Peyne area, France

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Preface

This report represents my Master thesis, that I carried out as one of my final objective in completing the Master Physical Geography at the University of Utrecht, The Netherlands.

First of all, I want to thank my supervisors at the Utrecht University, prof. dr. S.M. De Jong and dr. E.A. Addink, who both gave me useful advise during the process. Furthermore, I want to thank my field partner Annekarlijn de Rijcke, who accompanied me during the fieldwork. We did not know each other just before the start of the fieldwork, but we were a good match and I enjoyed her company both in and out of the field very much. I would also like to thank other participants, who did their fieldwork in the same period in Peyne, for the good atmosphere during these two months. Finally, I want to thank my family for mental support during the process, which took much longer than I hoped and expected.

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Figure on front page:
Biomass succession in the Peyne study area: Large abandoned vineyards
(near field plot 50, 526903; 8421177)

Abstract

Biomass is an important factor in environmental processes, such as erosion, carbon storage, climate change and land degradation. Human-induced changes in plant community systems and increased tourism and recreation result in more biomass stress and pressure on the water recourses, which have strong effects on ecosystems. This study investigated biomass variation, biomass change over a time span of 24 years and the causal factors for a Mediterranean area. The study was performed in the Peyne area, South France. For detecting the biomass variation and change a descriptive biomass model was made , which involved a linear regression model, based on the spectral bands of the Hymap image of 2008 and the biomass of 2009 which was measured in the field. The descriptive biomass model was applied on the Hymap image of 2008 and the Landsat TM image of 1984, which resulted in a biomass image of 2008 and 1984 and (after subtracting these two maps of each other) a biomass change image between 1984 and 2008. The biomass in 2008 ranged between 37 and 653 ton/ha with an average of 245 ton/ha and a standard deviation of 80 ton/ha. The results for the biomass in 1984 was very unreliable with biomass ranging between 168 and 173 ton/ha. The absence in variation could be attributed to the absence in variation in reflectance values. Since, the biomass change was unreliable, the causal factors were mainly discussed for the biomass variation in 2009. The variation in biomass was discussed in terms of different factors: geology, soils, elevation, slope, aspect and human influence. Geology and soils were found to be important factors in determining biomass variation. This variation was mainly caused by variation in available soil moisture and soil thickness. Also environmental factors, such as elevation, aspect and slope were proved to be related to biomass changes. Elevation was found to positive related to biomass, while slope was negative correlated to biomass. Biomass varied also per aspect class. Humans had an influence on the biomass too: areas under the influence of reforestation had a larger biomass in 2009 than areas without influence. Furthermore, other human influences, such as paths, walls and other kind of influences, were proven to have no large influence on the biomass variation in 2009.

1. Introduction

The Mediterranean area has experienced large land cover and land use changes in the last decennia, due to a variation of increasing and decreasing population pressure (Pueyo and Beguería, 2007; Taillefumier and Piégay, 2002, Debussche et al., 1999; Hill et al., 2008; Gonard, et al., 2001; Chauchard, et al., 2007; Sluiter, 2005). The most pronounced change is land abandonment (García et al., 2007). Baudry (1991) defined land abandonment as "a change towards a less intensive pattern in land use or as the total termination of the use and managing of the soils, and are left to there own spontaneous dynamics" (Sluiter & De Jong, 2007). However, due to an increase of population since the last decennia, biomass has been suffering from stress (Sluiter, 2005; Massada et al., 2009).

Biomass is an important factor in environmental processes, such as erosion, carbon storage, climate change and land degradation (Garnier et al., 2004; Nijland et al., 2009). Furthermore, human-induced changes in plant community systems and increased tourism and recreation result in more biomass stress and pressure on the water recourses. This have strong effects on the ecosystems (Cortez et al., 2007; Massada et al., 2009; Fernández, et al., 2004; Hill et al., 2008). Therefore, mapping, quantifying and monitoring of biomass changes is widely recognized as a key element in studying global change (Rogan et al., 2009). However, biomass dynamics and biomass characteristics are difficult to detect and to determine. Also relating these biomass changes to factors, that cause these changes, is difficult (Massada et al., 2009). This study investigates biomass variation in 2009 and biomass change between 1984 and 2008 and the causal factors for a Mediterranean area. The study was performed in the Peyne area, South France.

1.1 Aims of the study

Two aims are answered in terms of several study questions, which are given below.

Aim (1): To detect the biomass variation in 2009 and biomass change between 1984 and 2008 in the study area based on high spatial resolution images.

(1) What is the measured biomass for the chosen field plots?
(2) Is their an overall relationship between biomass and high spatial resolution images?
(3) What is the biomass change between 1984 and 2008 based on the found relationship?

Aim (2): To detect the factors that are controlling biomass variation and biomass changes.

(4) What are the environmental factors for each plot?
(5) What is the human influence for each plot?
(6) What is the relationship between biomass and each factor?

1.2 Detecting biomass variation

Biomass exists of above-ground and below-ground biomass, such as trees, scrubs, vines and roots. Due to the difficulty of collecting data of below-ground biomass, most previous study is focused on above-ground biomass (Lu, 2006). This study uses above-ground biomass to detect biomass patterns.

Changes in biomass can be detected by several methods, such as remote sensing and collecting biomass information in the field (Lu, 2006). Remote sensing techniques are suitable tools for detecting biomass changes, because images offers spatially continuous datasets on biomass parameters (Nijland et al., 2009). Biomass can not directly be estimated from these images. Detecting biomass changes can also be achieved by using spectral biomass indices and images. Spectral biomass indices can be used for monitoring biomass by enhancing the spectral contribution of green biomass and by minimizing the contribution of soil background, variation of solar irradiance, sun angle and atmosphere (Lu, 2006).

Another option is to measure biomass in the field. Destructive field measurements are the most accurate way to collect information about biomass. Destructive field measurements involve the removal of all leafs in order to measure the biomass. However, these measuments are destructive, time consuming and labour intensive. Furthermore, one needs a sufficient amount of data before one can detect changes (Lu, 2006). Another type of field measurements is to derive biomass by using (existing) allometric equations. An example of such an allometric equation is the equation of Ogaya et al. (2003), who made different biomass equations based on biomass measurements. These equations were proved to be highly significant and effective: a correlation of 0.99 and 0.98 for two different species was found.

1.3 Factors relating to biomass variation

Biomass varies both in space and time. Biomass and biomass growth depend on three main resources, which are needed for the growth: water, light and nutrients. The primary sources for water are precipitation, ground water and air moisture (Bonet, 2004). Light is needed for photosynthesis, which is part of the carbon balance, e.g. the balance between the carbon gains by photosynthesis and carbon losses by respiration (Mooney & Godron,1983). Nutrients are chemical elements, found in the upper soil layer, and have different origins: living organisms, weathering of mineral soils, decomposition of organic matter, nitrogen fixation, atmospheric gasses, deposition of atmospheric particles and precipitation (Smith & Smith, 2001). Variation in the biomass resources and in biomass are determined by environmental factors, since they control variability of water, light and nutrients (Sluiter, 2005):

(1) Climate
(2) Geology
(3) Soils
(4) Slope
(5) Aspect
(6) Elevation
(7) Human influence
(8) Fires

Climate

Climate determines the water availability and the potential solar radiation. Water availability is assumed to be the most limiting factor in the Mediterranean region for biomass development and plant distribution (Sluiter & De Jong, 2007; Bonet, 2004). Potential solar radiation is also an important factor for biomass dynamics (Sluiter & De Jong, 2007). Solar radiation influences the temperature and the water movements, which influences the biomass (Holland & Steyn, 1975; Sluiter, 2005).

Geology

The parent rock material has a strong influence on succession patterns and regional differences of species and properties. Geology determines the soil formation and thereby influences the biomass (Sluiter & De Jong, 2007). Geology influences the resistance against erosion and the ability to hold water. Furthermore, the presence and dip of impermeable layers effect groundwater flow and runoff, and thus effect biomass patterns (Taillefumier & Piegay, 2003).

Soils

The physical characteristics of soils have a large influence on the biomass. Characteristics, such as depth, texture, pore space, structure, water holding capacity, soil crusts, and nutrients, have a crucial effect on biomass dynamics. With that, soils partly determine the biomass regeneration and composition (García et al., 2007).

The structure of soils, especially the compaction rate of soils, has a large influence on the water holding capacity (García et al., 2007). An indication of the water availability of soils can be derived from the soil moisture retention curve (pF-curve). The soil moisture retention curve describes the relation between suction (ψ) and volumetric moisture content (θ) (Hendriks, 2008). Compacted soils have a larger available moisture than less compacted soils. Since some species need more water than other species (Bonet, 2004), the variation in compaction of soils influences the biomass composition (García et al., 2007). Compaction also influences the fertility of the soil, by means of restricting plant growth, establishment and altering water movement trough the soils (García et al., 2007).

The chemical composition of the soil is also important, and deals with litter depth, carbon-nitrogen ratio (C/N) and soil moisture (Garnier et al., 2004). Organic carbon plays an important role in succession stage. Litter accumulation is the result of biomass development and is generally related to organic pools (Bonet, 2004). The rate of nitrogen accumulation has been related to the abundance of particular plant types (García et al., 2007). Differences in nitrogen resources affect the proportion of annual or perennial grasses (Bonet, 2004). The carbon-nitrogen ratio involves the presence of organic matter in the soil. Larger C/N values indicates a small amount of humus. Another chemical aspect of soils is the pH-value. Species, composition and abundance are related to the pH-value of the soil. Increasing pH-values result in an increase of species richness (Fernandez et al., 2004).

Other characteristics of soils that determine biomass dynamics are the nutrient availability, the amount of stoniness and soil crusts. Studies indicate that the nutrient availability within the soil explains important differences in species richness between soils (Sluiter & De Jong, 2007). The presence of large stones and soil crusts effect the erosion and infiltration rate of the soil. Bare soils enhance the direct impact of raindrops, resulting in the dispersion of aggregates, compaction of the soil and an increase in infiltration rate. On the contrary, large stones, soil crusts and biomass increase the surface roughness, resulting in the opposite effect: a decrease of overland flow velocity (Kutiel et al., 1998).

Slope, aspect, elevation

Other environmental factors that influence biomass are slope, elevation and aspect. Elevation and slope influence the biomass regeneration, characteristics, succession path and distribution pattern (Fernandez et al., 2004). When elevation increases, temperature decreases and rainfall increases. Furthermore slope and elevation influence the water path: areas located in the valley receive water from all directions, since water is draining towards the lowest point. This indicates that areas in the valleys are wetter than areas located on high elevations and large slopes, and thus have a different succession pathway and biomass regeneration (Kutiel et al., 1998). The same holds for the variation in aspect over an area. A difference exists between north oriented slopes and south orientated slopes. Slopes facing to the south receive more sunlight, are warmer and thus drier in comparison to slopes facing to the north, which are cooler and wetter. Biomass is higher on slopes directed to the north due to this difference in incoming radiation (Kutiel et al., 1998).

Human influence

Human influence covers a large number of processes. Agricultural practices, such as tillage, crop rotation, ploughing, compaction, terraces, and the burning of agricultural land, alters the soil characteristics. Soils that are under the influence of long term tillage, suffer from losses in organic matter, increased nitrification and loss of soil structure. Soil compaction can be caused by tillage and changes the hydraulic, aeration and diffusive properties of the soil (García, 2007). Also burning of agricultural land effects biomass dynamics (Debussche et al., 1999).

Logging and grazing are another type of human influence. Logging involves the removal of biomass and causes a decrease in biomass productivity. Grazing has the similar effect as logging, but nutrients are at least partly restored through faeces and urine. When grazing pressure is high, the regeneration of biomass is difficult, since the opportunity for recruitment of new trees will decrease (Mooney & Godron, 1983).

Another aspect of human influence is the continuous land abandonment during the last century in the Mediterranean area. The land abandonment has resulted in the expansion of scrubs, rangelands and forests (Chauchard et al., 2007; Cortez et al., 2007; Garnier et al., 2004; Holland & Steyn, 1975).

Fires

Fires, both natural as anthropogenic, can lead to permanent changes in the composition of biomass and in ecosystem functioning (Mouillot et al., 2003). A difference exists between frequent fires and less frequent fires. Frequent fires lead to a decrease in forest areas and an increase in shrublands. Less frequent fire induce more complex heterogeneity and greater landscape diversity (Trabaud & Galtié, 1996).

2. Study area

2.1 Location

The study area is located in southern France, approximately 60 km west of Montpellier (fig 1; appendix I). The study area is drained by the Peyne and has an artificial constructed lake in the centre of the study area (Lake Vailhan), which was constructed in 1987. The study area has a surface area of 33.4 km² and the elevation varies between 90 and 350 m above sea level.

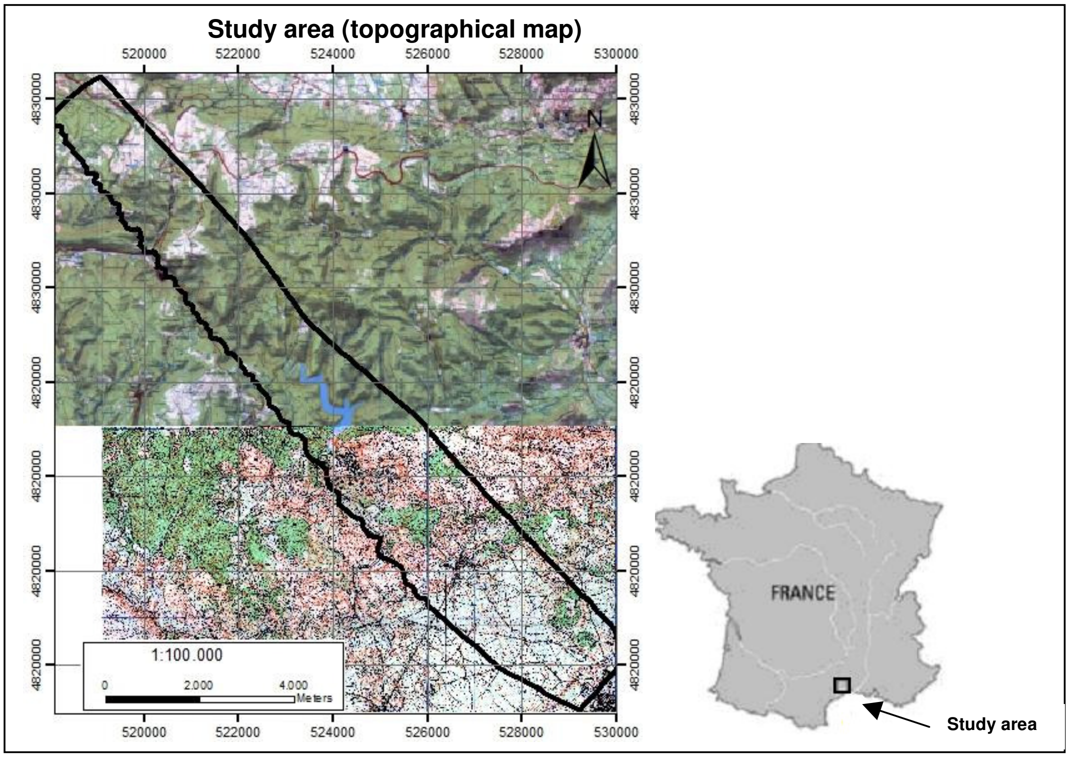


Figure 1: The study area.

2.2.Vegetation

The vegetation cover in the study area is very dense, especially around lake Vailhan. In the south of the study area, the vegetation cover is less developed due to the presence of agricultural lands. The vegetation cover consists of different matorral type, with the holm oak (*Quercus ilex*) as the dominant species (fig 3). The *Quercus ilex* is an evergreen oak species which can easily survive under dry conditions (Ogaya et al., 2003). Another prominent species is the *Arbutus unedo*, which is an evergreen scrub or small strawberry tree. Other less pronounced species are: *Erica arborea*, *Pinus sylvestris*, *Buxus sempervirens*, *Quercus pubescens*, *Colutea arborescens* and *Prunus padus* (table 1). The other species, as well as the abbreviation of all species, can be found in table 1.

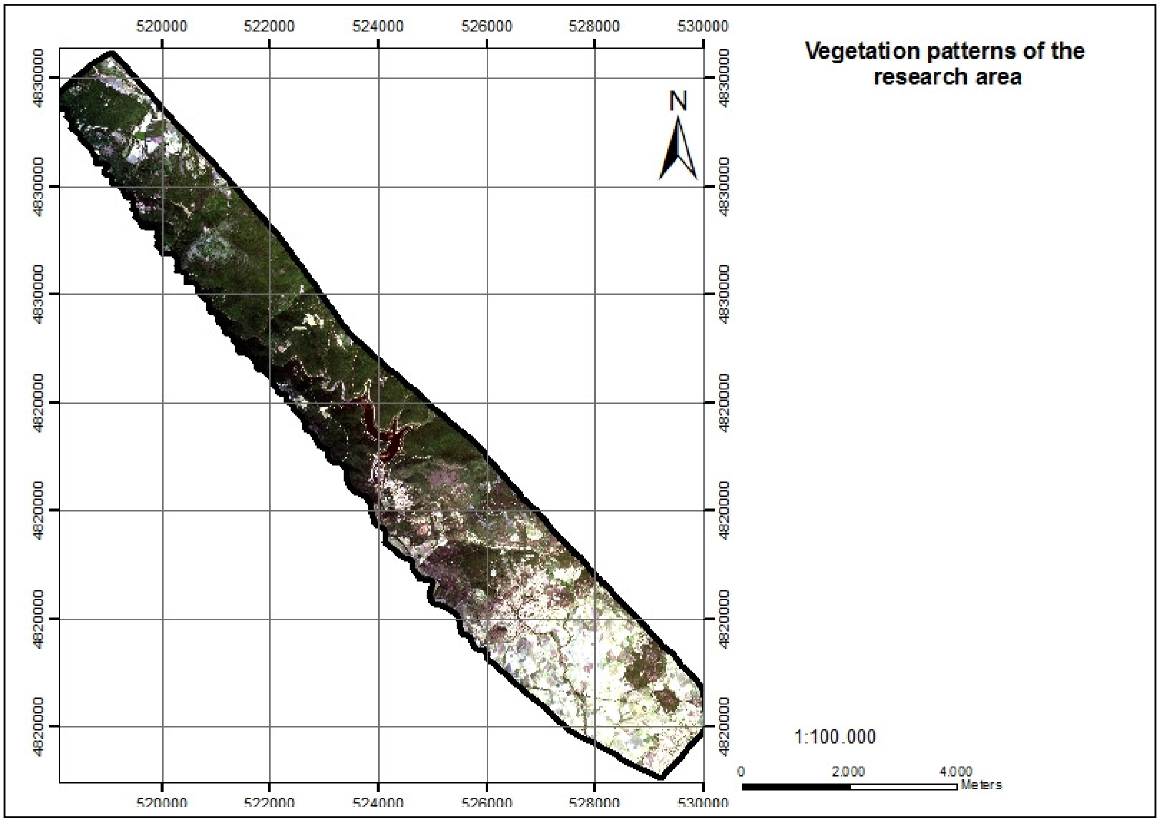


Figure 2: True color composite of the Hymap image of 2008.

Biomass code	Latin name	Common name
Ace	*Acer Monspessulanum*	Montpellier Maple
Aun	*Arbutus unedo*	Strawberry tree
Bus	*Buxus Sempervirens*	Box
Cas	*Castanea sativa*	Sweet chestnut
Coa	*Colutea Arborescens*	Bladder senna
Ear	*Erica arborea*	Tree heath
Jas	*Jasminum fruticans*	Bush jasmine
Jun	*Juniperus communis*	Juniper
Lig	*Ligustrum vulgare*	Privet
Pil	*Pistacia Lentiscus*	Mastic tree
Prp	*Prunus padus*	Bird cherry
Psy	*Pinus sylvestris*	Pine tree
Qco	*Quercus coccifera*	Kermes oak
Qil	*Quercus ilex*	Holm oak
Qpu	*Quercus pubescens*	Downy oak
Rus	*Ruscus aculeatus*	Butcher's broom
Spj	*Spartium junceum*	Spanish broom
Ulx	*Ulex parviflorus*	Gorse

Table 1: Species in the study area in 2009.

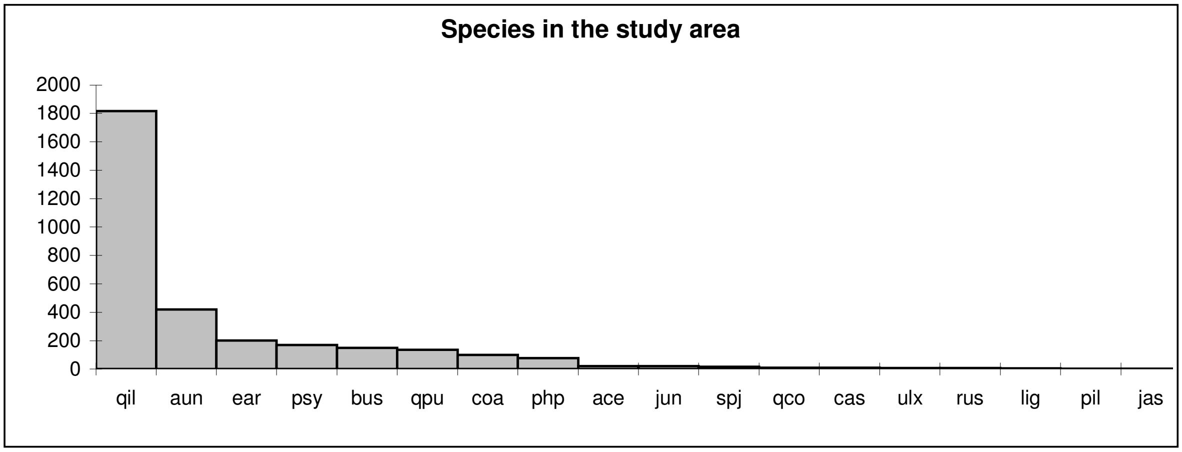


Figure 3: Measured species in the study area in 2009, with on the y-axis the frequency (trees). The abbreviations can be found in table 1.

2.3 Geology

The area is situated at the fringe of the ‘Massif Central’ and comprises many geological substrates of different ages. The formations differ from sandstone, limestone, dolomite, volcanic tuffs and volcanic basalt (Sluiter, 2005). Figure 4 shows a generalisation of the 59 geological units based on the attributes of the map legend, made by Sluiter (2005).

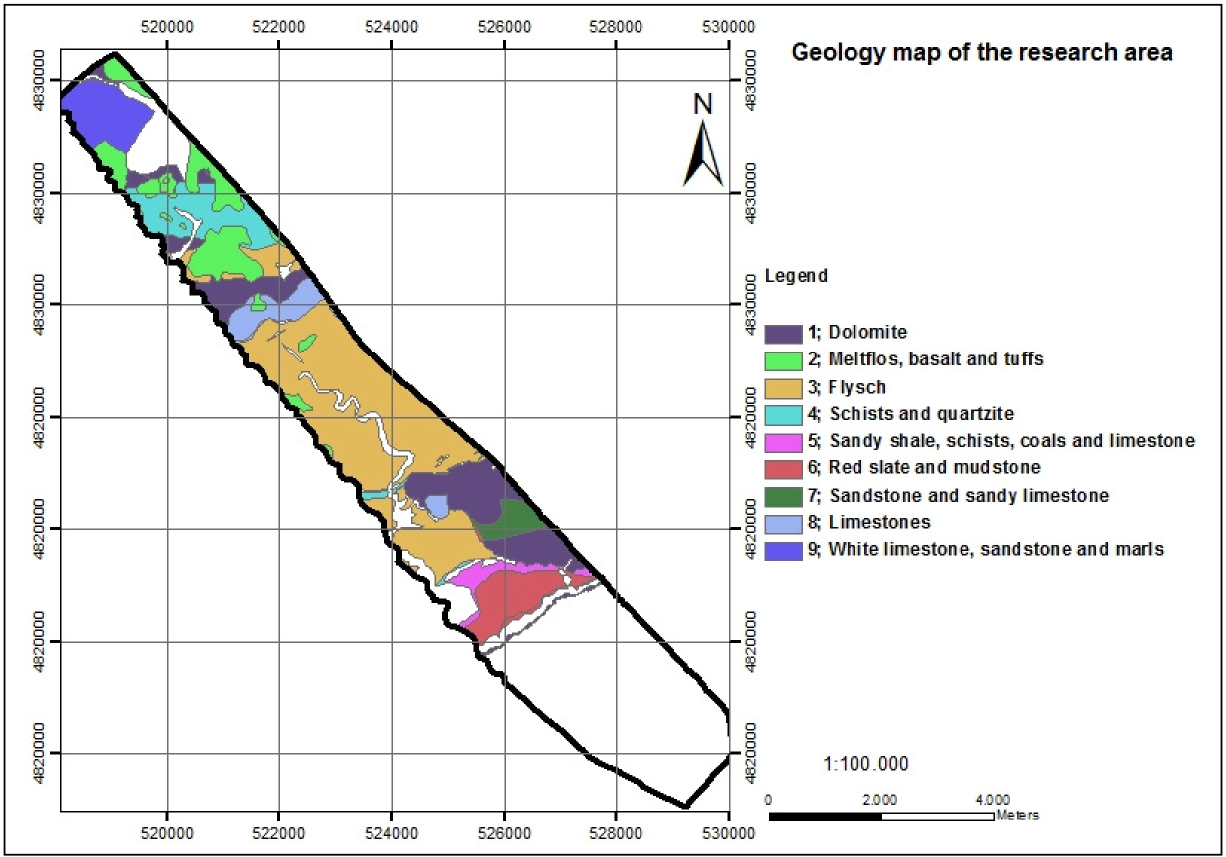


Figure 4: Geological formations in the study area, based on a generalisation made by Sluiter (2005).

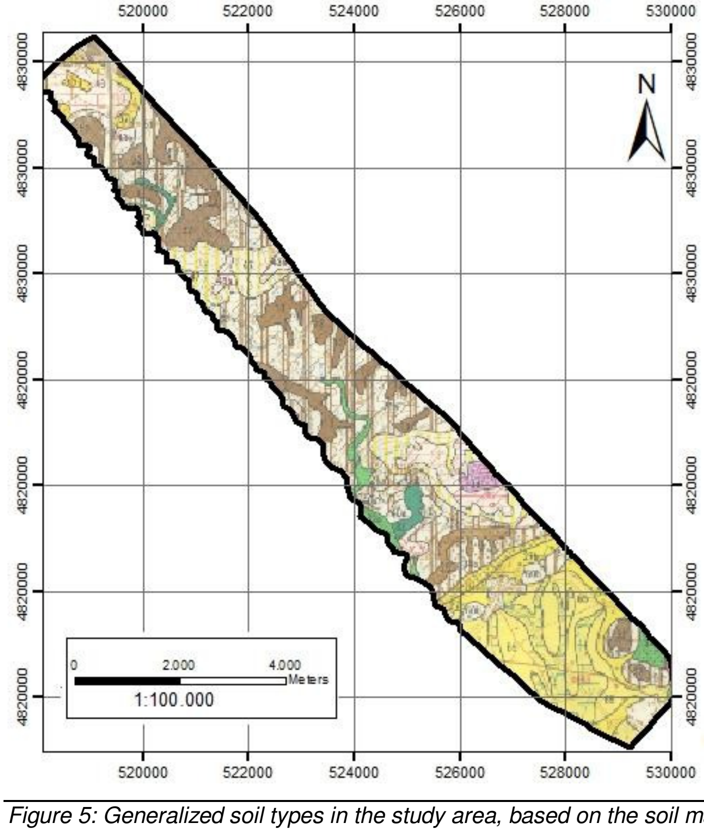
In the northern part of the study area dolomite (1), meltflows, basalts, tuffs (2), schists, quartzite (4), white limestones, sandstones and marls (9) are found. The centre of the study area is mainly characterized by flysch (3). The southern part of the study area consists of dolomite (1), sandy shale, schists, coals, limestones (5), red slate, mudstones (6), sandstones, sandy limestones (7) and limestones (8) (fig 4).

2.4 Soils

The soils differ from regosols and lithosols to brown and calcareous soils. Seventeen soil classes are present in the study area , which is based on the soil map of Bonfils (1993) (fig 5). Only 11 soil classes were visited during the study (soil number 1-11).

The northern part of the study area is characterized by modal brown soils (1), andosols (4), acid lithosoils, brown soils (6), lithosols, fertillized calcaire soils (10) and calcic soils (11). In the centre of the study area modal brown soils (1), eutrophic brown soils (2), calcareous regosols (3), acid lithosoils and brown soils (6) are found. The southern part of the study area consists of eutrophic brown soils (2), fluvisols (5), regols (7) humified podzols (8), lithosols and fertillized calcaire soils (10) (fig 5).

Soil map of the study area



Soil no	Soils based on Bonfils	Description
1	13	Modal brown soils
2	29	Eutrophic brown soils
3	47	Calcareous regosols
4	52	Andosols
5	83	Fluvisols
6	21a	Acid lithosoils and brown soils
7	34b	Regosols
8	3d	Humified podzols
9	41a	Dolomite soils and regosoils
10	43	Lithosoils and fertilized calcaire soils
11	57	Calcic soils
12	64	Another type of calcaire soils
13	65	Another type of calcaire soils
14	60b	Soils under the influence of erosion
15	82a	Soils under the influence of erosion
16	40	Lithosoils
17	51	Another type of brown eutropic soils

Figure 5: Generalized soil types in the study area, based on the soil map of Bonfils (1993)

2.5 Elevation, slope and aspect

The elevation in the study area varies between 90 and 450 meter. The highest elevated area is found in the northern part of the study area; a relative low area is located in the southern part (fig 6). The slope and aspect map is found in figure 7 and 8.

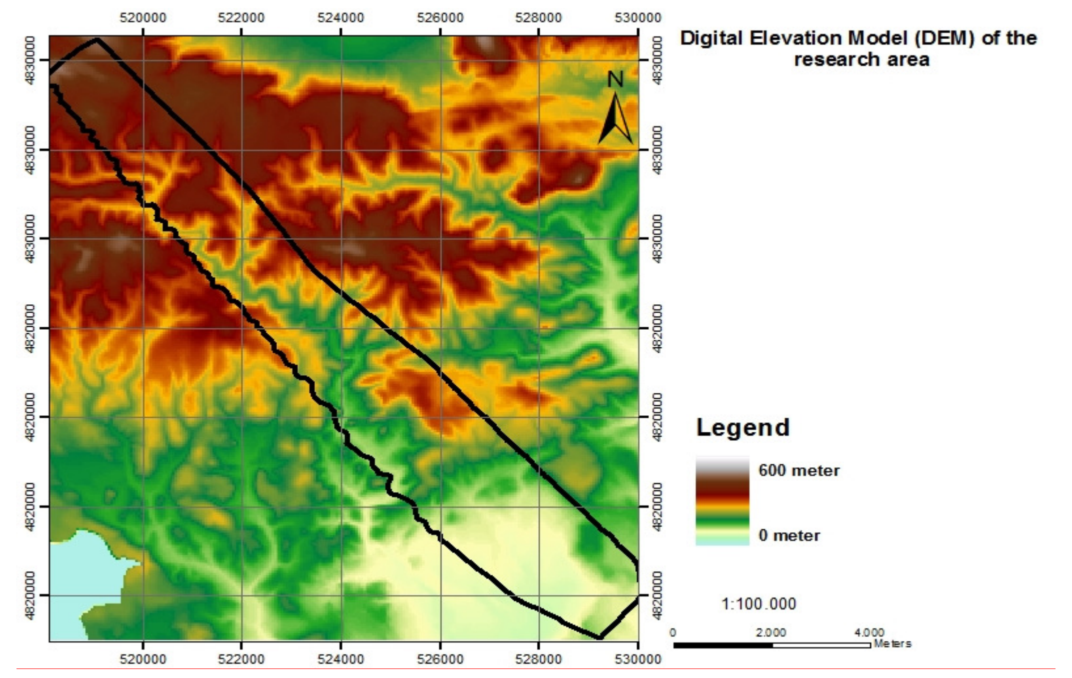


Figure 6: Digital Elevation Model (DEM) of the study area.

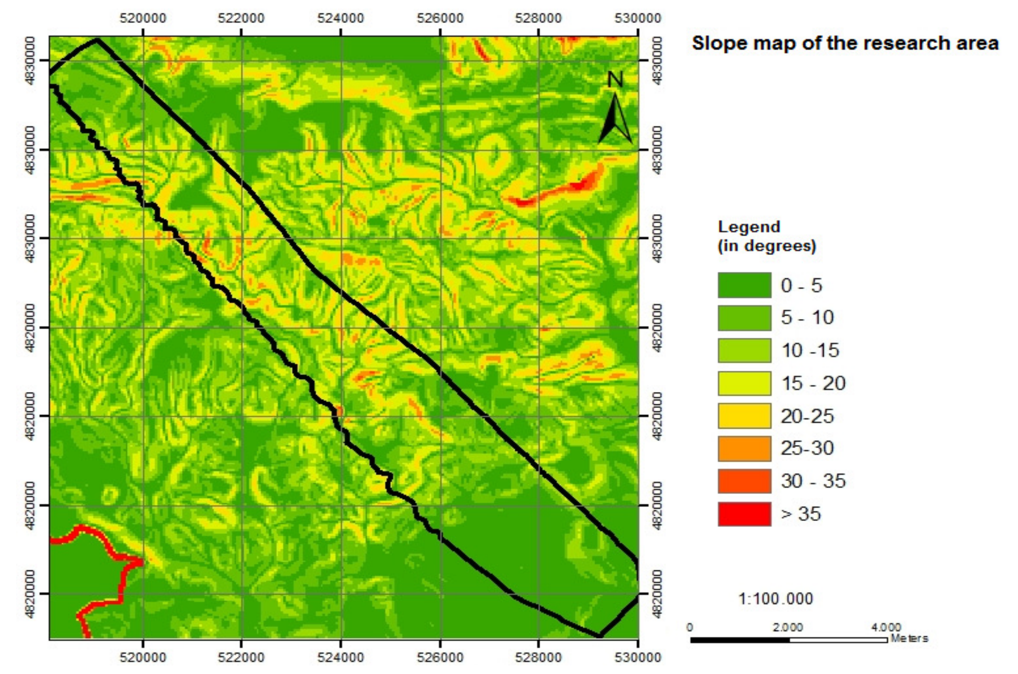


Figure 7: The slope map of the study area.

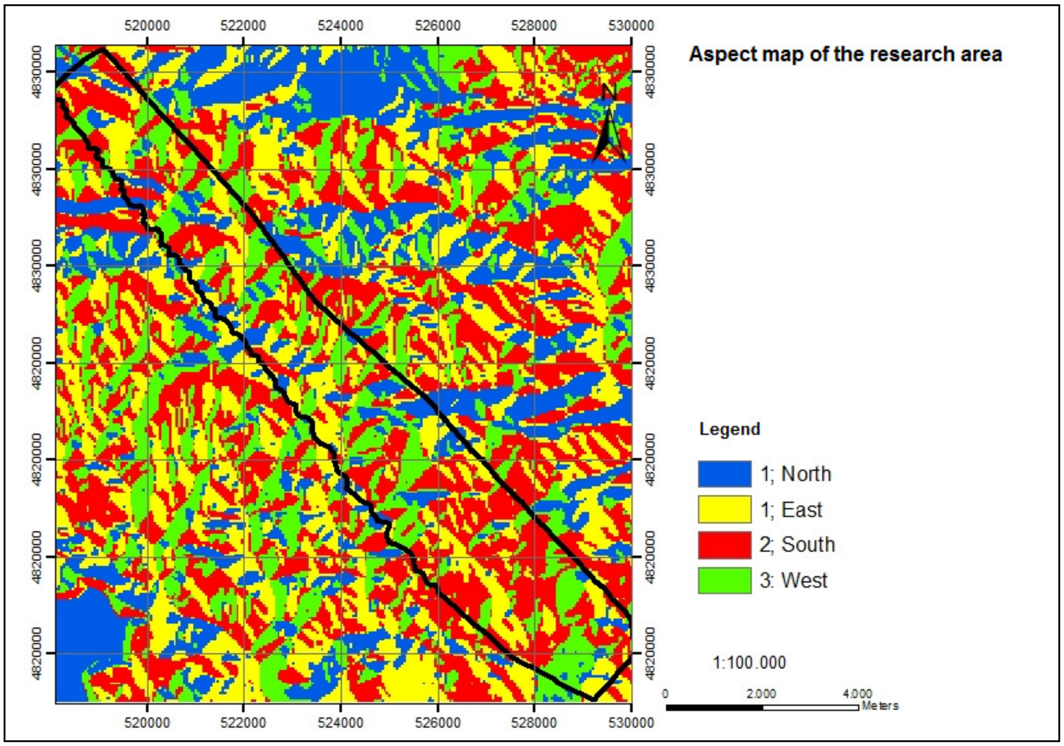


Figure 8: The aspect map of the study area.

2.6 Human influence

The study area has experienced large land cover and land use changes in the last century. The population increased between 1600 and 1850. Between 1850 and 1920 the area was extensively populated with large scale charcoal practices, the resulted extensive logging, grazing and agricultural practices. As a result of these practices, the biomass decreased rapidly. After WO II the population decreased and widespread land abandonment occurred. Land abandonment was the result of several factors, but mainly of socio-economical changes (Sluiter & De Jong, 2007). Traditional agriculture, grazing and forestry activities became in many Mediterranean regions economically non viable during the twentieth century (Debussche, 1999). Other causes are changing social expectations, tourism, forest policy and hydrological policy (Garcia-Ruiz, 1996). The wide spread abandonment since WO II and the decline of sheep grazing resulted in the expansion of scrubs, rangelands and forests (Chauchard et al., 2007; Debussche et al., 1999; Gallego et al., 2004; Cortez et al., 2007). Also tree cover and tree height increased: less then one century elapsed between the abandonment and the establishment of trees with a least a 25% cover (Debussche, 1999).

However, the population started to increase again during the last decennia's due to improved mobility. The increase in population and demand for agriculture products, such as goat's cheese, resulted in the reintroduction of grazing in small areas (Sluiter, 2005). Recreation became also more popular in the study area.

Agricultural lands are still present in the study area and are found around the Neffies village. The agricultural lands are mainly characterized by vineyards. Other agricultural management includes cultivations of corn, olives, almonts, apricots and figs. Furthermore, a pine production forest is present (north of the village of Neffies), and small scale logging occurs in the study area (Sluiter, 2005).

2.7 Relating the characteristics of the study area to biomass (hypothesis)

Some hypothesizes are made for the variation in biomass in the study area as a result of the variation in geology, soils, slope, elevation and aspect and human influence. Variation in biomass is a Mediterranean area is mainly explained by a variation in available soil moisture. Geology and soil types with a large clay content and thus a larger available moisture should have a larger biomass in comparison to types with a large sand content and thus a smaller available moisture. The same holds for the thickness lying on top of the geology. Soils with a larger soil thickness are expected to have a larger biomass than soils with a smaller soil thickness.

Low elevated areas, such as the valley at which lake Vailhan is situated (fig 6), should have a larger biomass, since all water is draining towards the lowest point. The reverse is valid for higher elevation areas, such as the area north of the study area (fig 6). Areas on large slopes should have a smaller biomass than areas on small slopes and plateaus. The study area is mainly characterized by small slopes (fig 7). However, in the centre of the study area some large slopes are present (fig 7), so smaller biomass values are expected here. Areas located on southward directed slopes are expected to receive more sunlight, are warmer and thus drier, which is unfavourable for biomass. The aspect map (fig 8) shows a large variation in aspect, but relative more southward directed slopes in the south of the study area. Smaller biomass values are expected in this area. The opposite is valid for northward directed slopes, such as some slopes around lake Vailhan (fig 8), which are cooler and wetter.

Areas with continuous human influence are expected to have smaller biomass relative to areas with no or little human influence. The reforested area near Neffies is expected to have larger biomass values. Furthermore, a variation is expected in the type of human influence: logging and large roads will have a larger negative influence on biomass, than small walking trails and hunting in the forests.

3. Methods

This chapter presents the methods and data used in this study. The aims and the study questions of the study are answered and discussed by using a combination of collected data in the field, literature and high spatial resolution images. First, the available images that are used for the study is discussed (paragraph 3.1). Second, the criteria of the chosen field plots are listed (paragraph 3.2). At these field plots the biomass (paragraph 3.3) and the causal factors (paragraph 3.4) are measured. The measured biomass in 2009 and available images are used to produce a predictive biomass model. The predictive biomass model predicts the biomass in the entire study area in 1984 and 2008 and the biomass change between 1984 and 2008 (paragraph 3.5).

3.1 Available images

Different images of the study area are available. The most recent one used in the study dates from July 23rd 2008 and is an airborne Hymap image consisting of reflectance values. The sensor has 126 bands with wavelengths between 0.45 and 2.49 µm and a pixel size of 5m. The oldest image used in this study dates back to July 5th 1984 and is a spaceborne geocorrected Landsat TM5 image, consisting of digital numbers (DN). The sensor has 6 bands with wavelengths between 0.45 and 2.35 µm (the thermal band is not available) and a pixel size of 30m. The Hymap image is more suitable to map biomass than Landsat TM image, since the Hymap sensor can collect much more detailed data.

3.2 Field plots

A total amount of 201 field plots was visited in the autumn of 2009 (September and October). The plots of the field plots were chosen based on the expected biomass change between 1984 and 2008. The expected biomass change was calculated by using the difference between the normalized differential biomass index (NDVI) of the images of 1984 and 2008. Furthermore, field plots were chosen in all nine geology classes.

Each field plot comprises an area of 25 m² (5m x 5m), in which different measurements were performed. The reason for this 5x5m plot is the fact that the surface area coincides with the pixel surface of the Hymap 2008 image.

3.3 Measuring biomass in the field

The biomass was calculated for 201 field plots using allometric equations from Ogaya et al. (2003). Different equations are used for trees (1 and 2) and scrubs (3). Equation (1) and (2) was used respectively for the evergreen oak (*Quercus ilex*) and the strawberry tree (*Arbutus unedo*) (Ogaya et al., 2003). For scrubs equation (3) is used (Pereire et al., 1994).

$$\ln AB = 4.900 + 2.277 \ln D50 \tag{1}$$

$$\ln AB = 3.830 + 2.563 \ln D50 \tag{2}$$

$$AB = 0.642\, H^{0.0075}\, Dmax^{2.4901} \tag{3}$$

with AB is the above ground biomass (gr), D50 is the stem diameter at 50 cm height (above the ground surface) (cm), Dmax is the maximal scrub diameter (cm) and H is the height (m). The stem diameter and scrub height were measured in the field by using a measurement tape.

3.4 Measuring the factors in the field

3.3.1 Geology and soils

The geology map (fig 4) and the soil map (fig 5) were used to achieve information about the different geology and soil types at each field plot. The soil map description was also used for deriving information on the carbon-nitrogen ratio for each soil.

Soil characteristics that were measured in the field are the thickness of the soil and the available soil moisture. The soil thickness was measured by entering an iron stick into the soil. In each field plot this was done twice to get a more reliable result. The available soil moisture was measured by calculating three important points of the soil moisture retention curve (pF curve): saturation ($pF \approx 0$), field capacity ($pF \approx 2.0$) and wilting point ($pF \approx 4.2$).

The soil moisture retention curve describes the relation between suction ($-\psi$) and volumetric moisture content (θ). The suction is normally presented as pF, which is the logarithm of the suction ($-\psi$) in cm (fig 9). A pF close to zero indicates that the soil is close to saturation. Field capacity is the maximum soil moisture that a soil can held against gravity. The wilting point can be defined as the soil moisture at which a plant starts to wilt and die when a soil dries out. The available soil moisture for plants is the available soil moisture between pF 2.0 and pF 4.2 (Hendriks, 2008).

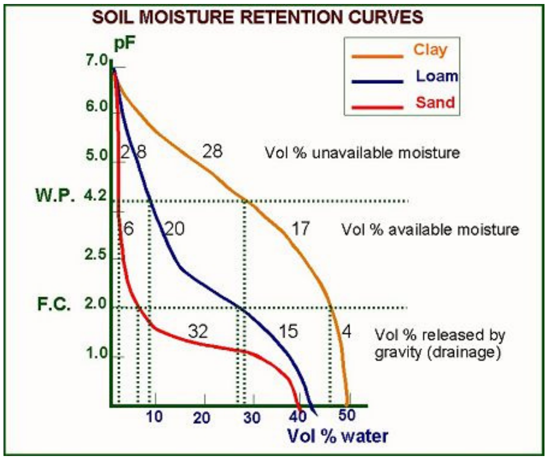


Figure 9: The soil moisture retention curve (based on Hendriks, 2008).

Soil samples were collected in the field at each field plot to determine the three points of the soil moisture retention curve. Assumed was that the collected soil samples were at field capacity; the saturated samples were at pF≈0 and the dried samples at wilting point. The soil samples were taken twice at each plot at approximately 10 cm depth. For this purpose, open rings (no bottom or top) with a height of 5 cm and a radius of 2.5 cm (kopecki-rings), were filled with soil. The volume of the rings and the weight of the soil samples was determined and the soil samples were placed in an oven at 105 degrees for 24 hours. The weight of the water was determined by the loss of weight of the sample after drying. After drying, the soil samples were weighted again. The last step involved the saturation of the soil samples, which was determined by placing the soil samples into a 2.5 cm layer of water, during 24 hours, and then weighted again. The collected weights and volumes of each sample were used in equation (4) to calculate the soil moisture at field capacity, wilting point and saturation.

$$\text{Soil moisture } (\theta) = \frac{\text{Weight water in sample}}{\text{Volume of sample}} = \frac{\text{Weight water in sample}}{h \pi r^2} \qquad (4)$$

with soil moisture (-), weight of the water (gr), volume of the sample (gr), h is the height of the sample (cm) and r is the radius of the sample (cm).

3.3.2. Elevation, slope and aspect

Elevation was measured in the field by using a global positional system (GPS). Aspect and slope were measured by a compass. Aspect (table 2) was divided into five classes: north, east, south, west and plateaus.

Orientation	**Description (degrees)**	**Classification number**
North	315 - 45	1
East	45 - 135	2
South	135 - 225	3
West	225 - 315	4
Plateau	Flat or slope less then 5 degrees	5

Table 2: The five classes of aspect.

3.3.3. Human influence

The human influence was classified based on four descriptive classes: reforestation, human influence, paths and stony walls. Each class was divided into several subclasses and weights (table 3). The four classes had been determined after some days in the field, based on the presence of differenent kind of human influences. The weights were assigned based on the age of the human influence: large weights were assigned to recent influences and vice versa. The same holds for the distance of the field plot to influences such as roads or stony walls. The sum of the weights of each subclass is seen as the rate of human influence for that subclass.

Reforestation (1) was recognized in the field by the presence of coppices and the presence of human planted vegetation in rows. Human influence (2) was recognized by trash and empty bullets from hunting, but also by the presence of small houses or remainders of houses, fences, stony walls in or near the field plot. Signs of logging (coppices) were also taken into consideration. Paths (3) were dived into three paths: a D-road (a large, regularly used, paved road), a smaller road (a rarely used and unpaved road) and small walking and biking trails. Stony walls (4) are used as terraces or as an old fence, for marking the area. The stony walls used for terraces were subdivided in old and recent terraces (fig 10).

No	***Factors***	***Classes***			***Weight***	***Maximum weight***
1	**Reforestation**	Recent reforested areas			10	**45**
		Old reforested areas			5	
		Recent deforested areas			10	
		Old deforested areas			5	
		Recent abandoned areas			10	
		Old abandoned areas			5	
2	**Human influence**	Empty bullets			1 - 2	**24**
		Trash			1 - 2	
		Human buildings (hunting tours)			4	
		Iron fences			4	
		Recent cutting influences			5	
		Signs of logging (coppices)			3	
		Stony walls			2-3	
		Remainders of stony houses			1	
3	**Paths**	Distance (m)	D-road	Unpaved	Walking	**24**
		15-20	1	0	0	
		10-15	2	1	0	
		5-10	4	3	1	
		0-5	5	4	3	
4	**Stony walls**	Old terraces			1-2	**13**
		Recent terraces			10	
		Fence (old)			1	

Table 3: Classification of human influence.

Figure 10: Large human made stony walls in a forest. Photo was taken near field plot 18 (521373; 4826546).

3.5 Biomass

The biomass in 1984, 2008 and the biomass change between 1984 and 2008 was calculated based on a predictive biomass model, which is based on reflectance values of the image of 2008 and the measured biomass data in 2009. An important assumption was that the biomass did not change between 2008 (image) and 2009 (fieldwork). Based on this assumption, the measured biomass in 2009 was considered as the (measured) biomass in 2008. The predictive biomass model was applied on the images of 2008 and 1984 in order to gain biomass data in these years. The biomass change over time consisted of the difference between the biomass of 1984 and 2008. The next paragraphs describe the procedure in order to make the predictive biomass model and the biomass change between 1984 and 2008.

3.5.1. Biomass dataset

The first step was the verification of the measured biomass data for positional and measurement errors. This was based on the NDVI image of 2008. The NDVI was calculated with band 14 (0.6482 µm) and 28 (0.8491 µm). The NDVI image of 2008 indicated relative high NDVI values for the whole area, including the visited field plots. However, 11 field plots gave conflicting results, e.g. large biomass values with low NDVI and vice versa. These 11 plots were checked in both the image of 2008, as well as the field descriptions and the photos made in the field. Two field plots (80 and 84) were not used in the spectral analysis, since these plots were located in the image of 2008 on a road, while these plots were measured in a forest, next to the road. This difficulty resulted in a low NDVI, due to the road, and a large biomass, due to the forest. The other 9 field plots were located in a relatively open area in a dense forest. These field plots were located in the image of 2008 in a dense forest, resulting in relative large NDVI values. However, since these field plots were measured in an open area, small biomass values were found. These field plots were not removed from the dataset.

3.5.2. Images

The images of 2008 and 1984 were transformed in such a way that they were comparable in terms of reflectance, number of bands and pixel size. The image of 1984 was available in digital numbers (DN), while the image of 2008 was available in reflectance, multiplied by a factor 100. Furthermore, the image of 1984 consisted of 6 bands and had a pixel size of 30m, while the image of 2008 consisted of 126 bands and had a pixel size of 5 m.

The first step was to divide the values in the image of 2008 by a factor 100. Second, the values in the image of 1984 were converted from DN into radiance into reflectance. Equation (5) and (6) give the conversion equations from Chandler et al. (2009).

$$L(\lambda) = G \cdot DN + B \qquad (5)$$

with $L(\lambda)$ is the spectral radiance (W/m^2 sr μm), G is the gain factor (W/ (m^2 sr μm) / DN) and B is the offset (W/m^2 sr μm). The gain factor (G) and the offset (B) varies per band and can be found in table 4.

$$R(\lambda) = \frac{\pi L(\lambda)}{E_0(\lambda)\,(1/r^2)\cos(\theta_0)} = \frac{\pi L(\lambda)}{E_0(\lambda)\,(1/r^2)\sin(\alpha_0)} \qquad (6)$$

with $R(\lambda)$ is the reflectance (-), $L(\lambda)$ is the spectral radiance (W/m^2 sr μm), E_0, is the solar irradiance (W/ m^2 μm), r is the earth-sun distance (astronomical units), θ_0 is the solar zenith angle (degrees) and α_0 is the solar elevation angle (degrees). The gain factor (G), the offset (B) and the solar irradiance (E_0) varies per band (table 4). The earth-sun distance (r) is taken as 1 and the solar elevation angle (α_0) is taken as 50.2 degrees.

	Wavelength *(range in μm)*		G **Gain** *(W/m^2 sr m)/ DN*	B **Offset** *(W/m^2 sr m)*	E **Solar irradiance** *(W / m^2 m)*
Band 1	0,452	0,518	0,671339	-2,19	1983
Band 2	0,528	0,609	1,322205	-4,16	1796
Band 3	0,626	0,693	1,043976	-2,21	1536
Band 4	0,776	0,904	0,876024	-2,39	1031
Band 5	1,567	1,784	0,120354	-0,49	220
Band 6	10,45	12,42	0,055376	1,18	N/A
Band 7	2,097	2,349	0,065551	-0,22	83

Table 4: Lookup table for the images of 1984 (Landsat TM5) (from: Chandler, et. al., 2009).

An adjustment was made for the difference in the amount of bands. The wavelengths and associated bands of the image of 1984 were taken as a basic. Each new band of the image of 2008 had the same wavelength as the associated band of the image of 1984, but consisted of a range of bands, which were averaged (table 5). A total amount of 57 bands of the image of 2008 were used. This resulted in a new image of 2008, consisting of 6 bands, with the same wavelengths as the bands of the image of 1984.

New band no	**Wave length**	***Landsat 1984***		***Hymap 2008***	
		Band no	*Amount of used bands*	*Band no*	*Amount of used bands*
1	0,45-0,52	1	1	1-5	5
2	0,52-0,60	2	1	6-11	6
3	0,63-0,69	3	1	13-17	5
4	0,76-0,90	4	1	22-32	11
5	1,55-1,75	5	1	75-90	16
7	2.097-2.349	7	1	103-116	14
TOTAL	-	-	**6**		**57**

Table 5: Spectral bands of the images of 1984 and 2008 used for the predictive biomass model.

3.5.3 Predictive biomass model

Two options were investigated for a predictive biomass model. First, a model based on the NDVI was made. For this purpose the NDVI was calculated (equation 7) based on the original image of 2008.

$$\mathrm{NDVI} = \frac{\lambda_{NIR} - \lambda_{red}}{\lambda_{NIR} + \lambda_{red}\}} \qquad (7)$$

with λ_{NIR} is the near-infrared reflectance and λ_{red} is the red reflectance. For the near-infrared reflectance (λ_{NIR}) band 14 (0.6482 μm) was used and for the red reflectance (λ_{red}) band 28 (0.8491 μm) as used. The predictive biomass model was based on a simple linear function between the NDVI values and the measured biomass at the field plots. The correlation between measured biomass and the NDVI was 0.01, and the correlation between logarithmic biomass and the NDVI was 0.08. The use of a range of bands did not result in a better correlation.

The second option resulted in a much better correlation. This predictive biomass model was based on a regression analysis between the reflectance bands of the new image of 2008 and the measured biomass in 2009. For this purpose the six new bands were related to the measured biomass and the logarithmic biomass. Before the predictive biomass model (equation 9) could be applied to the image of 2008, another correction had to be made: the difference in pixel size of the images. The new image of 2008 was transformed into an image with a pixel size of 30 meter. This is done by resampling the data input file from 5 m to 30 m. The predictive biomass model was applied on the two new images (consisting of reflectance values, 6 bands and a pixel size of 30m). The results were two biomass images of 1984 and 2008, which were subtracted in order to get the biomass change between 1984 and 2008.

4. Results

4.1 Measured biomass in 2009

The measured biomass in 2009 at the 201 field plots is presented in appendix II. A summary of these biomass statistics can be found in figure 11. The measured biomass varies between 2 and 681 ton/ha and has an average of 250 ton/ha. The measured biomass shows a skewed distribution with a small tail to the right, and a peak around the 200 ton/ha.

Measured biomass in 2009

(at the field plots)

Basic statistics of the measured biomass in 2008 (ton/ha)	
Mean	**250**
Standard error	9,6
Median	222
Standard deviation	**137**
Skewness	0,5
Minimum	2
Maximum	681

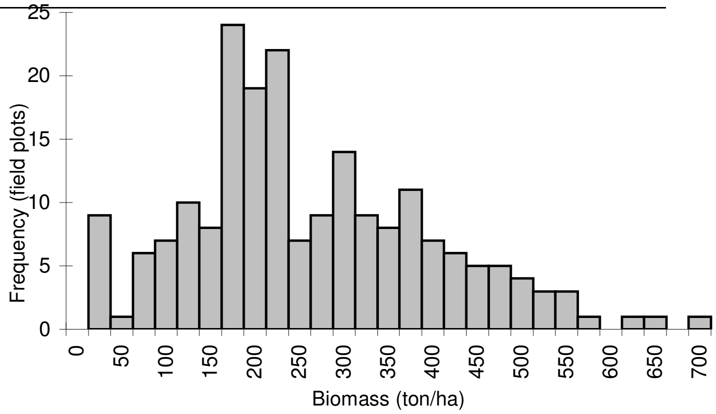


Figure 11: Overview of the biomass statistics, based on the field plots in 2009.

4.2 Predictive biomass model

The predictive biomass model is based on a regression analysis between the reflectance bands of the new image of 2008 and the measured biomass in 2009 is given below.

$$\text{Logarithmic biomass} = 1.961 + 0.191 \cdot B1 - 0.128 \cdot B2 - 0.080 \cdot B3 + 0.090 \cdot B4 - 0.242 \cdot B5 + 0.264 \cdot B7 \tag{8}$$

$$\text{Biomass} = 163.48 + 96.73 \cdot B1 + 7.21 \cdot B2 - 49.01 \cdot B3 + 19.38 \cdot B4 - 64.10 \cdot B5 + 55.59 \cdot B6 \tag{9}$$

Biomass is expressed in ton/ha and B_n is the spectral band number, specified in table 4. The correlation coefficients for the equations were 0.31 for the biomass and 0.35 for logarithmic biomass.

4.3 Calculated biomass

The predictive biomass model was applied on the two new images of 2008 and 1984 (consisting of reflectance values, 6 bands and a pixel size of 30m), which resulted in calculated biomass data in 2008 and 1984. Three negative values have been filtered out of the dataset and further interpretation uses only the other 198 field plots. Since the correlation coefficients between the logarithmic biomass and the biomass did not show a large difference (0.31 and 0.35) and since biomass was more practical to use, the predictive biomass model was therefore based on biomass data (equation 9).

4.3.1 Calculated biomass in 2008

The biomass statistics of the field plots are presented in figure 12. The mean biomass value is 245 ton/ha, with a standard deviation of 80 ton/ha. The distribution of the calculated biomass is almost normal, with two large peaks in the centre: 250 and 300 ton/ha.

Calculated biomass in 2008
(at the field plots)

Basic statistics of the calculated biomass in 2008 (ton/ha)	
Mean	**245**
Standard error	6
Median	243
Standard deviation	**80**
Skewness	0.82
Minimum	37
Maximum	653

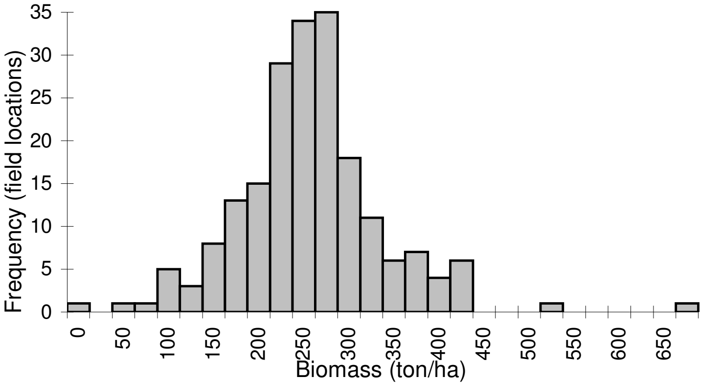


Figure 12: Overview of the calculated biomass statistics, based on the field plots in 2008.

The majority of the field plots is characterized by a biomass that varies between 50 and 450 ton/ha. Furthermore, two field plots have a relative large biomass value. Field plots 35 and 65 have a biomass value of respectively 653 and 522 ton/ha. The measured biomass at these plots are 164 and 187 ton/ha.

Clear biomass patterns are visible in the study area (fig. 13; appendix III). Lake Vailhan and the majority of the agricultural lands are masked out. One notices the agricultural lands in the southeast of the study area, near the village Neffies. However, many of these agricultural lands have negative biomass values. This can be explained by the fact that the predictive biomass model has been designed based on densely vegetated land, resulting in poorer results at less densely vegetated land. Large biomass values can be found in the centre of the study area; around the lake Vailhan. Furthermore, the reforested area north of the village Neffies is recognizable by large biomass values.

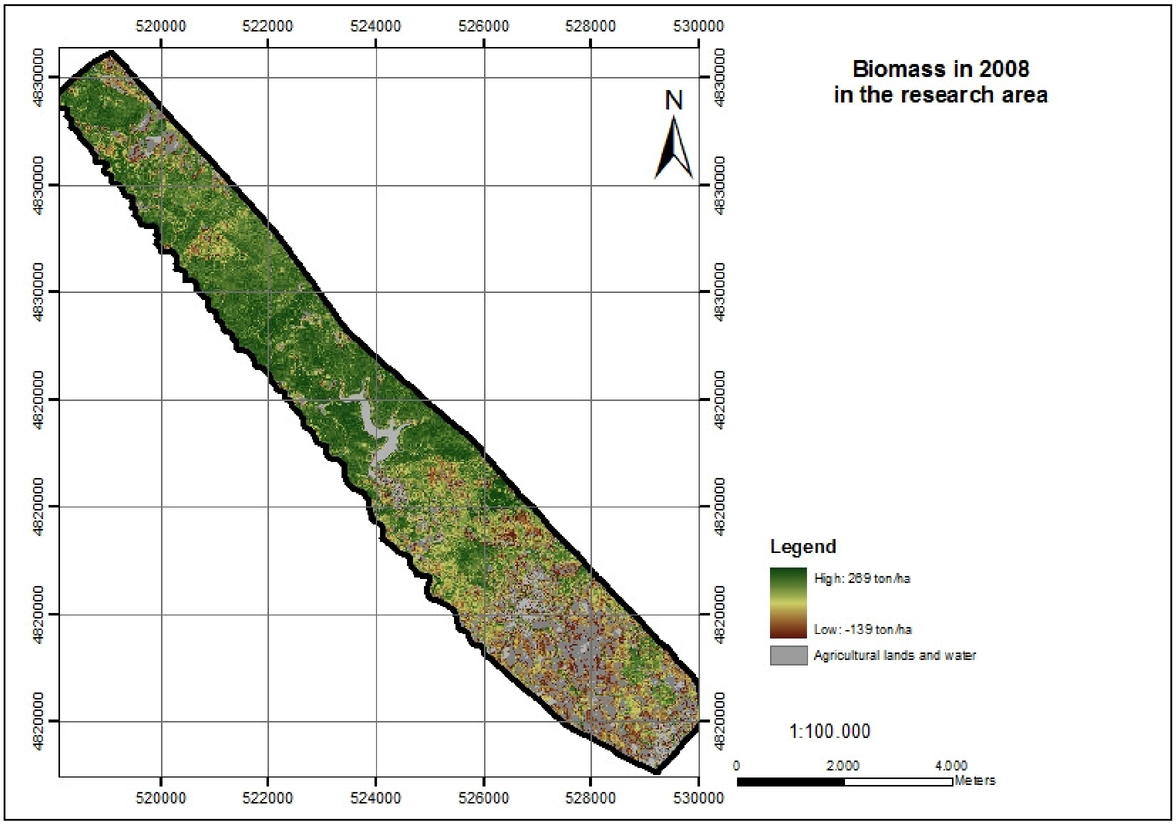


Figure 13: The calculated biomass in 2008.

4.3.1 Calculated biomass in 1984

The biomass statistics of the field plots in 1984 is presented in figure 14. The biomass image of the entire study area is presented in figure 15 and appendix IV.

Calculated biomass in 1984
(at the field plots)

Basic statistics of the calculated biomass in 1984 (ton/ha)	
Mean	**171**
Standard error	0
Median	170,7
Standard deviation	**1**
Skewness	-0,9
Minimum	168
Maximum	173

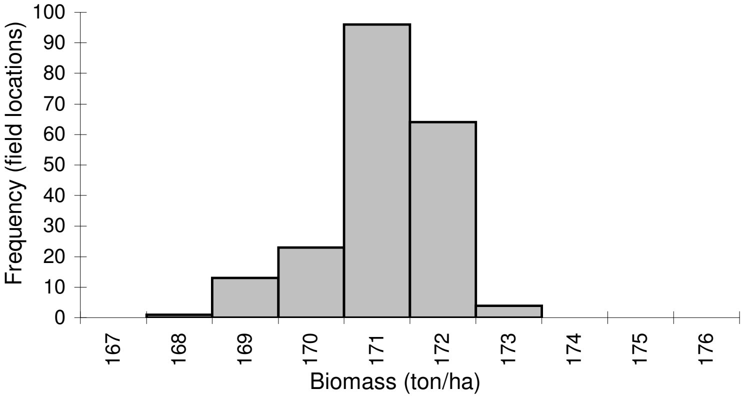


Figure 14: Overview of the biomass statistics, based on the field plots in 1984.

No variation in biomass values in present for the field plots for the year 1984 (fig. 14; fig. 15); the biomass varies between 168 and 173 ton/ha. The distribution is very skewed with a tail to the left. These results are very unexpected and unreliable, since this suggest that the area was covered by a completely homogenous biomass.

Possible explanations for the missing variation in the biomass can be explained by the original data. A possible explanation is the haze in the image. Without a correction for haze, a digital number cannot be converted into a surface reflectance (Chavez, 1989). Although only a small area was covered by haze, the haze could explain the absence in variation in reflectance values.

Another explanation is the spatial support of the pixel. The predictive biomass model is applied on the original pixel size of 30 m. However, the use of an optimally sized mapping unit instead of the original pixel, results in an improvement of the mapping accuracy of 7 to 17%. The optimal spatial support of a pixel depends on the spatial structure of the mapped parameters (biomass) and by the effects of shading patterns and gaps in the canopy (Nijland, et al., 2009). The biomass values of 1984 (as well as 2008) could be improved when an optimal spatial support of the pixel is chosen.

Furthermore, the radiometric sensitivity of the sensor plays an import role in the accuracy. Radiometric sensitivity is the number of digital levels used to express the collected data of the sensor. The number of levels is expressed as the number of binary digits, needed to store the value of the maximum level (Richards and Jia, 2006). The image of 1984 is characterized by 8 bits, while the image of 2008 is characterized by 16 bits. Since the number of levels determines the detail of information, one can conclude that the image of 1984 was less detailed then 2008.

Based on these unreliable results, the largest biomass values are found in the area north of Lake Vailhan, while the lowest biomass values are found south of lake Vailhan. The centre of the study area, around lake Vailhan has intermediate biomass values (fig. 15).

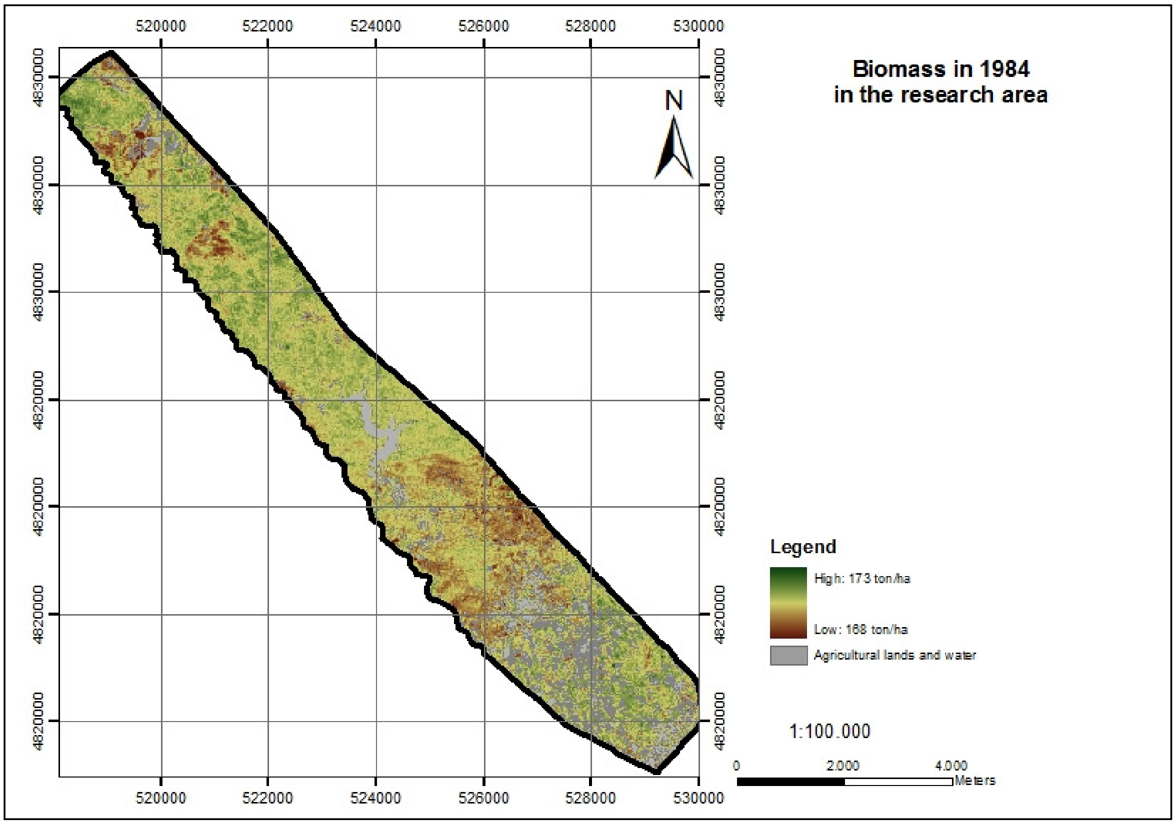


Figure 15: The calculated biomass in 1984.

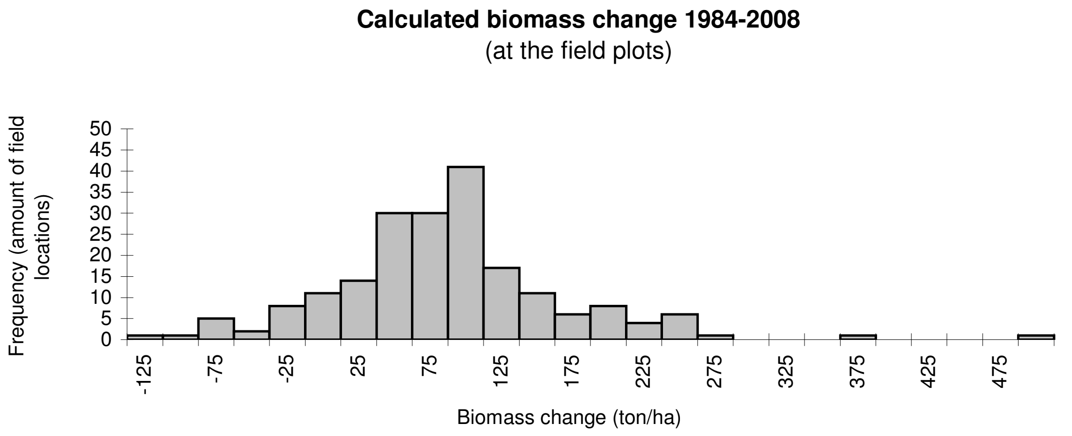
Intermezzo

Since no variation was found in the calculated biomass in 1984 (168-173 ton/ha), the calculated biomass change between 1984 and 2008 is very unreliable. The patterns of biomass change will be exactly identical to the pattern of the calculated biomass in 2008, since only a value of approximately 170 ton/ha will be subtracted.

However, since one of the main aims of the study involves the detecting of biomass change and relating the biomass change to the causal factors, the change in biomass change is discussed nevertheless. Else, one would span the main aim of the study. These biomass change results are not used for general conclusions about the relation between biomass and the causal factors; only the measured biomass in 2009 is used for this purpose.

4.3.3 Calculated biomass change between 1984 and 2008

The (unreliable) average change in biomass at the field plots is 75 ton/ha with a standard deviation of 80 ton/ha (fig. 16). This is an average increase in biomass of 30.6% relative to the year 1984, indicating that the study area in 1984 was almost non-vegetated. The majority of the field plots shows an increase of biomass between 50 and 100 ton/ha.



Biomass statistics (ton/ha)	**1984-2008** field plots
Mean	**75**
Standard error	6
Median	72
Standard deviation	**80**
Skewness	0.8
Minimum	-133
Maximum	483

Figure 16: Overview of the biomass change statistics, based on the field plots..

The biomass change of the entire study area is given in figure 17 and appendix V. Many areas are characterized by an increase in biomass between 1984 and 2008. Especially the centre of the study area, around lake Vailhan, is characterized by a large increase in biomass. The same holds for the reforested area north of the village Neffies. Furthermore, small and negative values can be found at the agricultural lands, southeast of the study area.

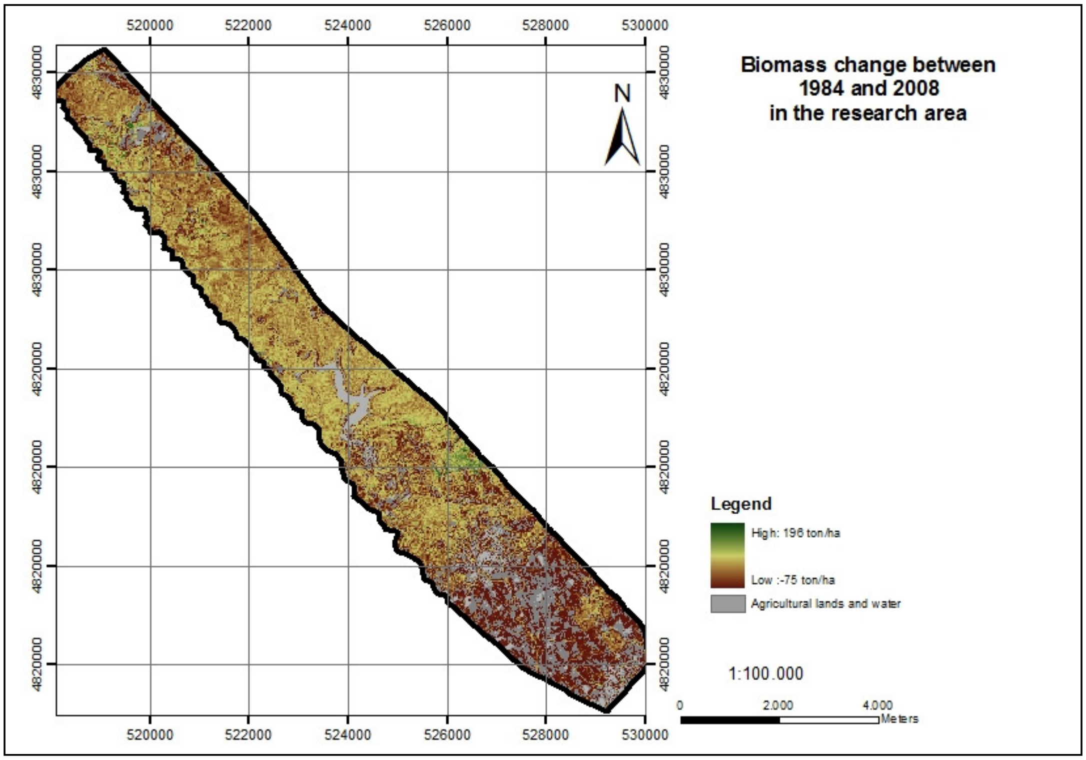


Figure 17: The calculated biomass change between 1984 and 2008.

4.4 Explaining the biomass variation

The (measured) biomass variation in 2009 will be discussed in terms of geology, soils, elevation, slope, aspect and human influence. Since, no large fires were observed in the study area during the last 30 years, the effect of fires will not be considered. The same holds for grazing. Only in a few field plots grazing signs were found, so grazing will not be discussed. The main focus is on the field plots, since detailed field data is available at these field plots (appendix I and II).

The biomass change in only shortly discussed, since these results were very unreliable (see intermezzo). Each paragraph describes a different causal factor, and starts with describing the associated factor in terms of measured biomass in 2009 and calculated biomass change between 1984 and 2008. Second, some site specific conclusions will be made (based on the measured biomass data in 2009). The subparagraphs end with a comparison to available literature.

4.4.1 Geology

The biomass data is evenly distributed over the 9 geology classes: each geology class covers approximately 22 plots (table 6).

Geology type	**Description**	**Average biomass in 2009 (ton/ha)** *(measured)*	**Average biomass change 1984-2008 (ton/ha)** *(calculated)*	**Frequency (plots)**
1	Dolomite	195	37	25
2	Meltflows, basalt and tuffs	262	80	19
3	Flysch with Conglomerates	174	70	22
4	Schists and quartzite	243	77	19
5	Sandy shale, schists, coals and limestone	109	25	20
6	Red slate and mudstone with conglomerates	270	68	25
7	Sandstone, sandy limestone	436	168	23
8	Limestone and limestones with chert	272	84	23
9	White limestone, sandstone and marls	269	61	25
	Average	250	75	-

Table 6: An overview of the geology types and the associated average biomass values at the field plots.

The biomass distribution per geology class indicates a clear variation of the measured biomass in 2009 (fig. 18) with the different geology types. The biomass averages in 2009 for the nine different geology types varies between 109 and 436 ton/ha. The smallest average biomass (109 ton/ha) is found on sandy shales, schists, coals and limestones (5) with biomass values varying between 25 and 325 ton/ha. The field plots are quite evenly distributed over this range, with one peak at 50-75 ton/ha.

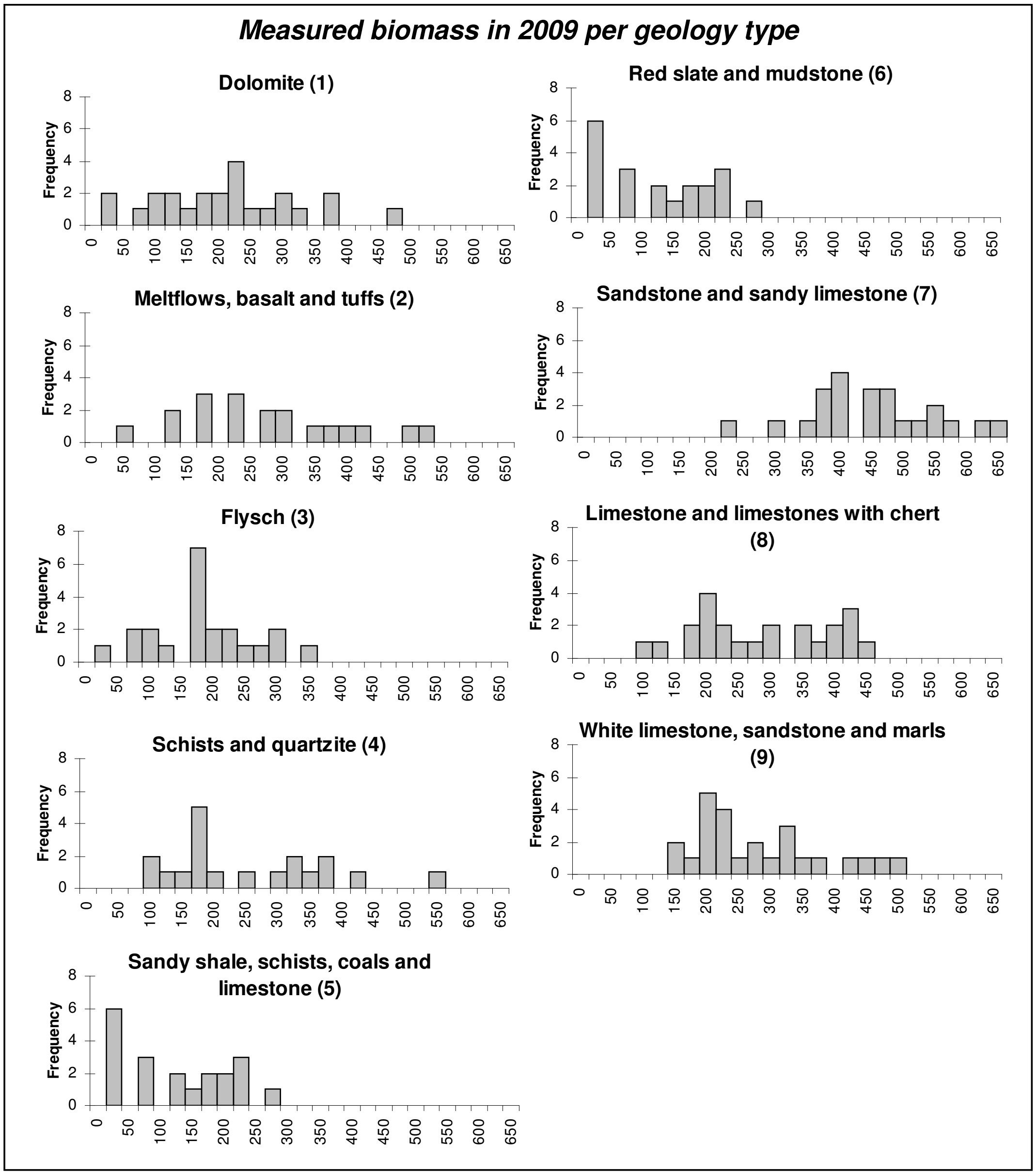


Figure 18: Biomass data in 2009 for each geology type with on the horizontal axis the biomass (ton/ha) and on the vertical axis the frequency (field plots).

Sandstones and sandy limestones (7) have the largest average biomass (436 ton/ha), with biomass values varying between 250 and 675 ton/ha. All plots are evenly distributed over this range, with no peak present (fig. 18; table 6).

Four geology types have an average biomass around the 270 ton/ha: basalt (2), slate, mudstone (6), limestones (8), limestones, sandstones and marls (9). However, the distribution of biomass of these four geology types shows some remarkable differences.

Basalt (2), slate, mudstones (6), limestones (8), sandstones and marls (9) show an almost evenly distributed biomass variation, but with a different range of biomass values. Basalt (2) shows values over almost the entire biomass range (75 – 525 ton/ha), while slate and mudstones (6) only have biomass values between 50 and 325 ton/ha. Limestones (8) have a biomass range between 150 and 475 ton/ha and the biomass values at sandstones and marls (9) vary between 175 and 550 ton/ha (fig. 18; table 6).

Dolomite (1), flysch (3), schists and quartzite (4) have a biomass distribution with one clear peak at respectively 250-275 ton/ha, 200-225 ton/ha and 200-225 ton/ha. The other field plots are evenly distributed over the other biomass classes (fig. 18; table 6).

The *biomass change* results show that that the largest biomass change occurred on sandstones and sandy limestones (7): 168 ton/ha. The biomass distribution is concentrated between 225 and 375 ton/ha. The smallest change in biomass occurred on dolomite (1) and white limestones, sandstones and marls (8) with an average change of respectively 37 and 42 ton/ha. The field plots at dolomite (1) are characterized by a change in biomass between –75 ton/ha and 325 ton/ha, and are evenly distributed over this range. The biomass change distribution at limestones (8) varies between 50 and 275 ton/ha (fig. 19; table 6).

Meltflows, basalt, tuffs (2) flysch (3), schists, quartzite (4), white limestones, sandstones and marls (9) show an almost normal biomass change distribution, with the majority of the field plots having an average biomass change of 100-150 ton/ha. The rest of the field plots are evenly distributed at plots with an increase between 125 and 175 ton/ha or a somewhat smaller decrease between 0 to 100 ton/ha (fig. 19; table 6).

A clear peak is present at sandy shale, schists, coals and limestones (5) at 25-50 ton/ha. The rest of the field plots shows an increase in biomass between 75 and 175 ton/ha or a decrease in biomass between –50 and -75 ton/ha. The same holds for red slate and mudstone (6) with a clear peak at 125-150 ton/ha, with the rest of the field plots having an increase in biomass between 150 and 200 ton/ha or a decrease in biomass between –25 and –50 ton/ha (fig. 19; table 6).

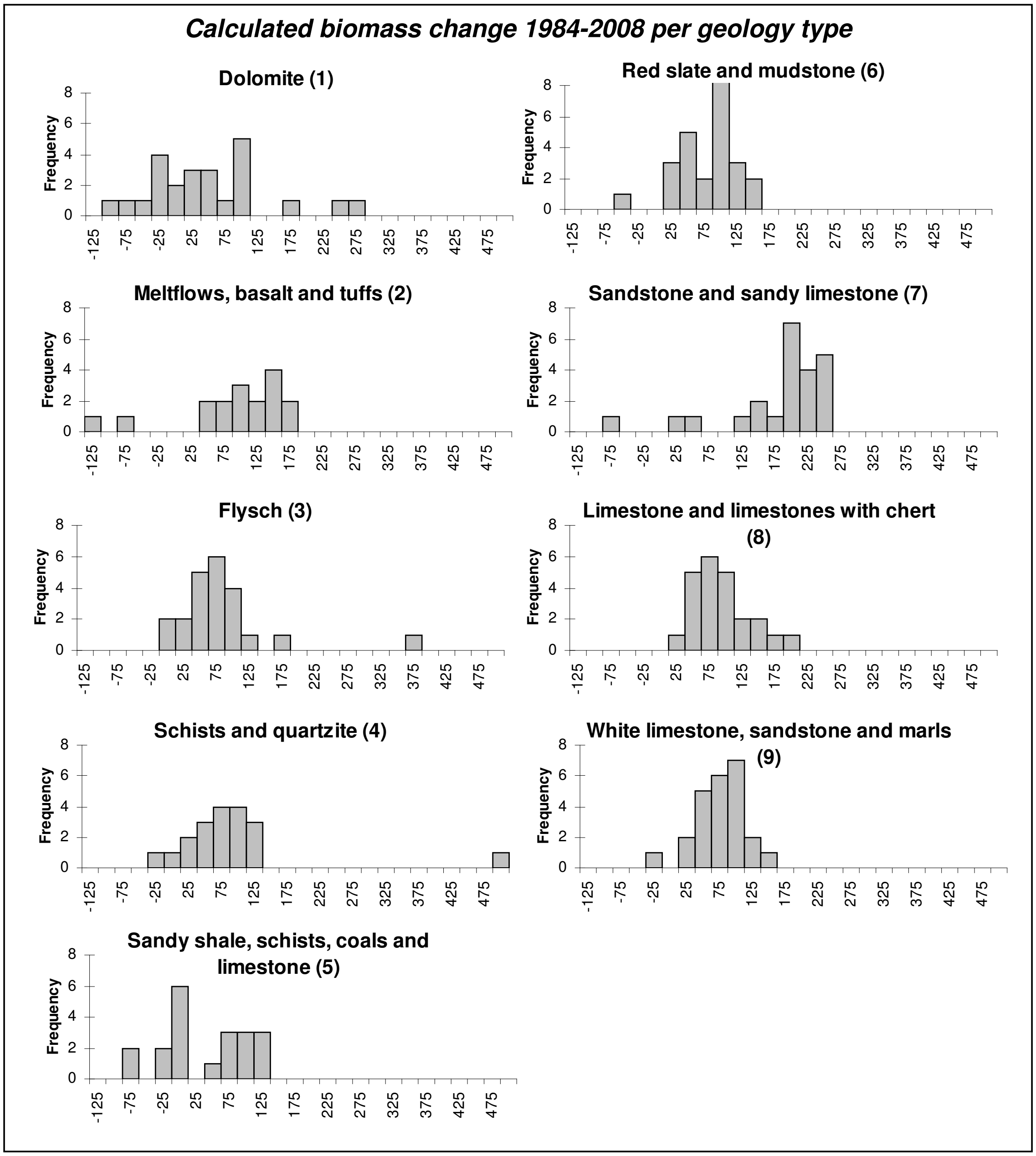


Figure 19: Biomass change for each geology type with on the horizontal axis the biomass change between 1984-2008 (ton/ha) and on the vertical axis the frequency (field plots).

Different conclusions can be made based on the measured biomass in 2009 (fig. 18 and table 6). First, geology plays an important role in determining the biomass variation. This is also confirmed based on the results of the ANOVA test (table 7). The ANOVA test was performed with a null hypothesis assuming no differences in biomass averages at the different geology types. Since the F-ratio is much larger than 1 (11.89), the null hypothesis can be rejected. One can conclude that it is very credible that the biomass averages differ at the different geology types.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	1372811	8	171601	11,89	0.00
Between groups	2886559	200	14433		
Total	4259370	208			

Table 7: ANOVA results for the biomass in 2009; the groups refer to the geology types.

The biomass variation in 2009 will be explained in terms of the characteristics of the soils, lying on top of the geology: soil thickness and available soil moisture, which are both measured in 2009 (table 8). Other characteristics are also taken into consideration.

	Geology type	**Measured biomass in 2008 (ton/ha)**	**Calculated biomass change 1984-2008 (ton/ha)**	**Measured soil thickness (cm)**	**Measured available moisture (-)**
1	Dolomite	195	37	25,2	0,10
2	Meltflows, basalt and tuffs	262	80	22,9	0,12
3	Flysch with Conglomerates	174	70	24,6	0,11
4	Schists and quartzite	243	77	23,3	0,06
5	Sandy shale, schists, coals and limestone	109	25	27,2	0,13
6	Red slate and mudstone with conglomerates	270	68	25,8	0,12
7	Sandstone, sandy limestone	436	168	42,5	0,09
8	Limestone and limestones with chert	272	84	23,5	0,11
9	White limestone, sandstone and marls	269	61	20,9	0,14
	Average	248	75	26,2	0,11

Table 8: Soil thickness and available moisture for the geology types, measured in 2009 at the field plots.

Soil thickness varies between 0 and 68 cm in the field plots in 2009 and based on this range, soil thickness could explain the variation in biomass at the different geology types (fig. 20). Furthermore, a correlation of 0.39 is found between biomass and soil thickness (fig. 20). This is also confirmed based on the results of the ANOVA test. The ANOVA test was performed with a null hypothesis assuming no differences in soil depth at the different geology types (table 9). Since the F-ratio is much larger than 1 (13.23), the null hypothesis can be rejected and one can conclude that soil depth differs per geology type.

Measured soil depth in 2009 (at the field plots)

Basic statistics of the measured soil depth in 2009 (cm)	
Mean	**26.2**
Standard error	0.7
Median	24.2
Standard deviation	**10.2**
Skewness	0.9
Minimum	0.0
Maximum	68.4

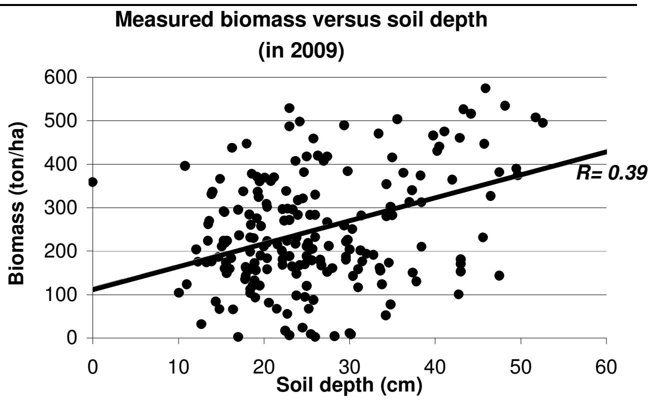


Figure 20: Statistics of the measured soil depth in 2009, and the scatterplot of the measured biomass and soil depth in 2009.

Sandstones and sandy limestones (7) illustrate this relationship very well with the largest biomass in 2009 and the thickest soil. However, soil thickness cannot explain all variation in biomass at the geology types. This can be illustrated by sandy shale, schists, coals and limestone (5) (low biomass and average soil thickness) and white limestones, sandstones and marls (9) (moderate biomass and small soil thickness). Although some exceptions are present, the variation in biomass in 2009 at the different geology types in the study area can be related to a variation in soil thickness.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	7434	8	929	13,23	0.00
Between groups	13414	191	70		
Total	20848	199			

Table 9: ANOVA results for the soil depth in 2009; the groups refer to the geology types.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	0.19	8	0.02	4,71	0.00
Between groups	1.78	361	0.005		
Total	1.97	369			

Table 10: ANOVA results for the available soil moisture in 2009; the groups refer to the geology types.

The same conclusions can be made for the relation between biomass and available soil moisture. First, the soil water retention curve reveals large differences between the different geology types (fig. 22). Furthermore, results of an ANOVA test reveal that the available soil moisture differs per geology type (table 10). Although a small correlation between available soil moisture and biomass is found (0.03), the variation in biomass in 2009 at the geology types can also be related to a variation in available soil moisture.

Measured available soil moisture in 2009 (at the field plots)

Basic statistics of the measured available soil moisture in 2009 (-)

Mean	**0,11**
Standard error	0,00
Median	**0,10**
Standard deviation	0,07
Skewness	2,42
Minimum	0,00
Maximum	0,75

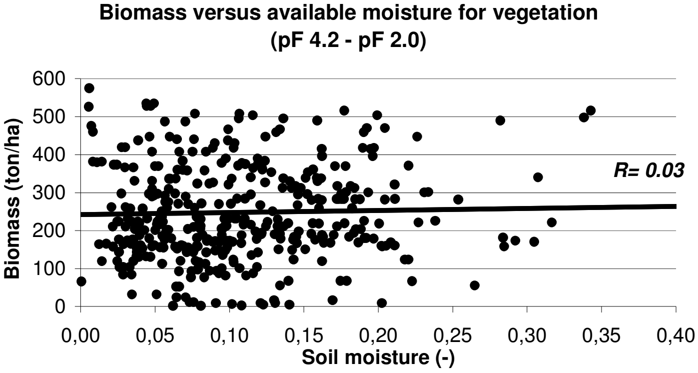


Figure 21: Statistics of the measured available soil moisture in 2009, and the scatterplot of the measured biomass and available soil moisture in 2009.

Not only soil thickness and available soil moisture are related to biomass; soil thickness and soil moisture are also related to each other. A correlation of 0.13 is found between soil moisture and soil thickness (table 16), indicating that thicker soils in the study area have a relative large available soil moisture.

Relating these site specific conclusions to general statements, several conclusions can be made. First, Smith and Smith (2001) report that a thicker soil is favourable for the biomass. This statement is also confirmed by this study. However, Smith and Smith (2001) also report that a larger available soil moisture is related to a larger biomass, which is in contradiction with the site specific conclusions. Another resemblance with the literature is the relation between soil moisture and soil thickness. Smith and Smith (2001) found that thicker soils are related to a larger water holding capacity.

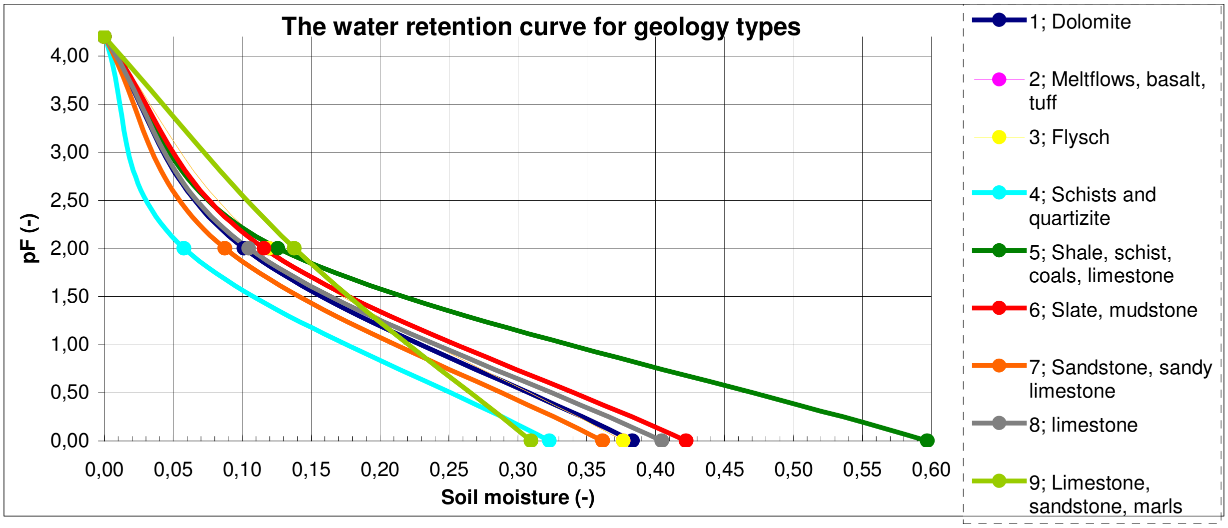


Figure 22: The water retention curve for the geology types, based on measured biomass in 2009.

Not only available soil moisture and soil thickness determine the variation in geology and thus the variation in biomass, also other factors are involved. An example of such a factor is the presence of large outcrops and boulders. The presence of large outcrops and boulders effect the erosion and infiltration rate of the soil, and tend to be a relative difficult environment for plants (Fernandez et al., 2004; Kutiel et al., 1998). White limestones, sandstones and marls (9) are characterized by large outcrops (fig. 23). However, this geology type has a moderate biomass in 2009, concluding that the general statement is not valid for the study area.

Figure 23: Large outcrops at white limestones, sandstones and marls (9).Photo taken on field plot 128 (519207; 4829407).

The variation in erodability of the different geology types is another import factor. Less resistant substrates weather more deeply, resulting in relative thicker soils and in a more favourable situation for biomass (Marshak, 2001). Quartzite (4) is very resistant to erosion and is characterized by a relative small soil layer. On the contrary, limestones (8) are a less resistant substrate and have a large biomass and a very thick soil layer. Although no clear signs of erosion were found in the study area, the erodability of a geology type seems to affect the thickness of the soil and therefore the biomass.

The variation in geology also results in a variation in different species (appendix VI). This can be attributed to the fact that different species require different soils and geological conditions (Bonet, 2004). Appendix VI shows that the *Quercus ilex* (qil) is the dominant species for almost every geology type. This can be explained by the fact that *Quercus ilex* is an evergreen oak species, which can easily survive under dry conditions (Ogaya et al., 2003).

Flysch (3) and sandy shale, schists, coals and limestones (5) are not dominated by the *Quercus ilex* (qil). These geology types are evenly vegetated by *Quercus ilex* (qil), *Arbutus unedo* (aun) and *Erica arborea* (ear). Another prominent difference, is the fact that sandstones and sandy limestones (7) are only vegetated by *Pinus sylvestris* (psy). Sandstones and sandy limestones were only found in the reforested area. This geology type is very suitable for pine trees and it is assumed that this explains why pine tree were planted at this geology type.

4.2.2 Soils

The study area is covered by 19 different soils (table 11). Only 11 soil types were considered here. Three soil types were covered by less then 3 field plots; fluvisols (5), dolomite soils and regosols (9) and calcic soils (11). These soil types are not taken into consideration, since there is not enough data to make reliable conclusions.

Soil No.	**Soil (Bonfils)**	**Description**	**Average biomass in 2008 (ton/ha)** *(measured)*	**Average biomass change 1984-2008 (ton/ha)** *(calculated)*	**Frequency (plots)**
1	13	Modal brown soils	168	71	18
2	29	Eutrophic brown soils	259	99	6
3	47	Calcareous regosols	261	40	24
4	52	Andosols	258	92	25
5	83	Fluvisols	528	107	1
6	21a	Acid lithosoils and brown soils	160	36	41
7	34b	Regosols	274	55	15
8	3d	Humified podzols	458	183	15
9	41a	Dolomite soils and regosoils	188	85	1
10	43	Lithosoils and fertilized calcaire soils	265	89	52
11	57	Calcic soils	300	17	3
		Average based on 8 soil types	263	83	-

Table 11: An overview of the soil types and the associated average biomass values. Soil types 5, 9 and 11 are not incorporated in the averages.

The largest biomass in 2009 can be found at humified podzols (8) with a biomass average of 458 ton/ha. No small biomass values are found; only values of 375 ton/ha or higher (fig. 24, table 11). Very small biomass values are found for modal brown soils (1), acid lithosols and brown soils (6) with an average biomass of 168 and 160 ton/ha (table 11). The biomass values for modal brown soils (1) are evenly distributed over a range of 75-300 ton/ha. The biomass of acid lithosols and brown soils (6) ranges between 25 and 500 ton/ha, with peaks at 25 and 175 ton/ha (fig 24; table 11).

The biomass range at lithosols and fertilized calcaire soils (10) is very large, and ranges between 25 and 625 ton/ha. One clear peak is present at 225 ton/ha (fig. 24, table 11).

Six soils have almost the same average biomass in 2009 (around 160 ton/ha): eutrophic brown soils (2), calcareous regosols (3), andosols (4), regosols (7), lithosols and fertilized calcaire soils (10). However, the distribution of these biomass values differs. The biomass of eutrophic brown soils (2) varies between 175 and 375 ton. The biomass distribution of calcareous regosols (3) varies between 100 and 450 ton/ha with one peak at 200 ton/ha. The same holds for andosols (4) but with a range between 50 and 525 ton/ha and a less pronounced peak at 175 ton/ha. The biomass distribution at regosols (7) is characterized by a range between 125 and 325 ton/ha and two outliers at 525 and 700 ton/ha (fig. 24, table 11).

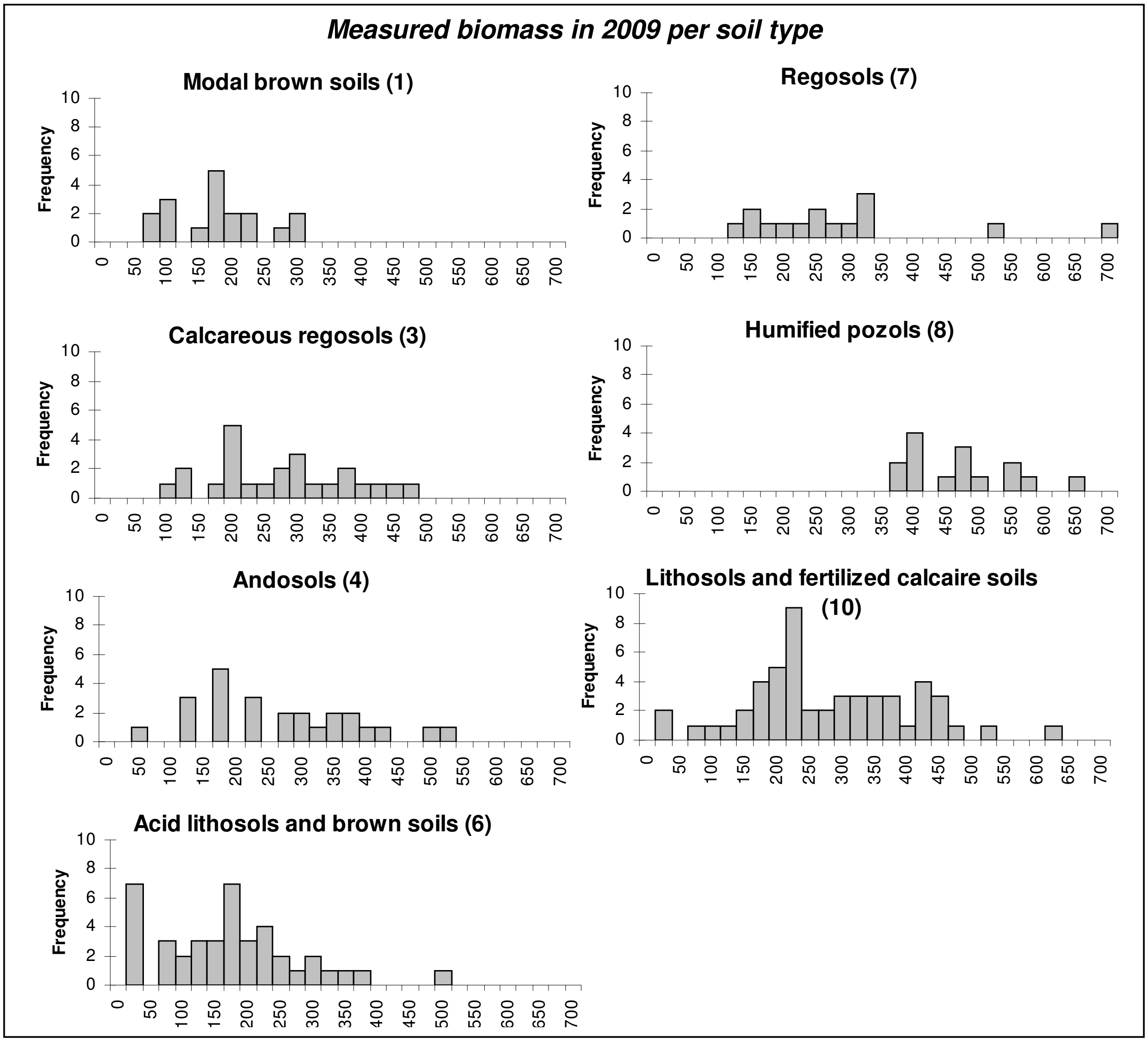


Figure 24: Biomass for each soil type with on the horizontal axis the biomass in 2009 (ton/ha) and on the vertical axis the frequency (field plots).

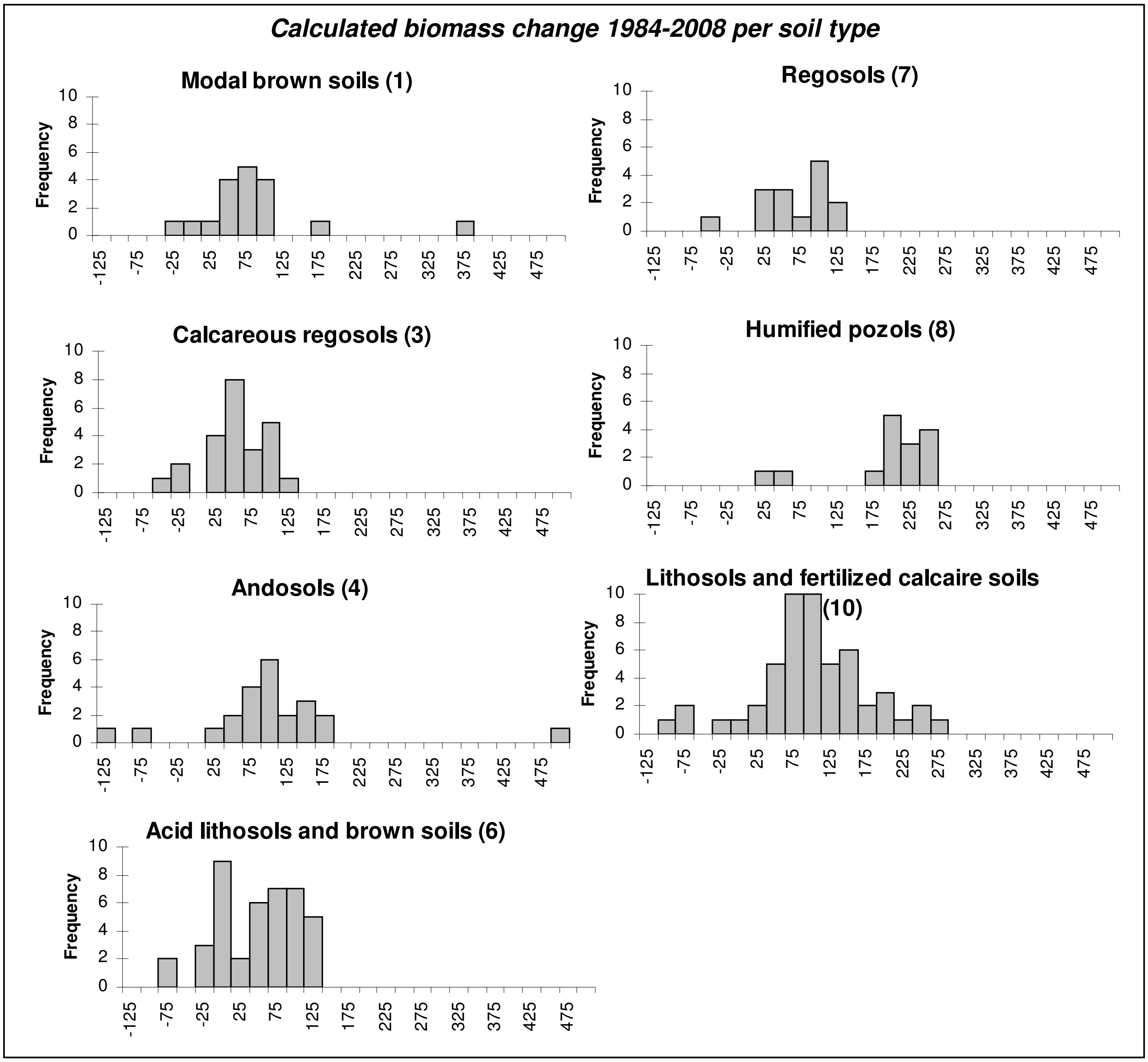


Figure 25: Biomass change for each soil type with on the horizontal axis the biomass change between 1984-2008 (ton/ha) and on the vertical axis the frequency (field plots).

The *biomass change* between 1984 and 2008 shows a variation too. Humified podzols (8) are characterized by the largest change in biomass (183 ton/ha) and a range between 175 and 275 ton/ha. The smallest change occurred on acid lithosols and brown soils (6: 36 ton/ha) and regosols (7: 56 ton/ha). The biomass change distribution of acid lithosols and brown soils (6) shows a peak of 0-25 ton/ha. Many field plots are characterized by a change in biomass between 50 and 125 ton/ha. The biomass change at calcareous regosols (7) varies between –50 and 125 ton/ha, with a small peak at the 100 ton/ha. Modal brown soils (1) and andosols (4) have a biomass change around the average biomass change of 68 ton/ha: 71 and 66 ton/ha. The biomass change distribution of modal brown soils (1) is characterized by two ranges: small peaks between –25 and 25 ton/ha and large peaks between 25 and 100 ton/ha. Two outliers are present in the range 175-200 and 375-400 ton/ha. The biomass change distribution at andosols (4) is normal distributed and shows five outliers. The majority of the field plots has a biomass change between 25 and 175 ton/ha, with a peak at 100 ton/ha change. Eutrophic brown soils (2), lithosols and fertilized calcaire soils (10) have a biomass change larger than the average change: 99 and 89 ton/ha. The biomass change varies of eutrophic brown soils varies between 50 and 150 ton/ha. The biomass change distribution at lithosols and fertilized calcaire soils (10) is normal distributed with a peak at 75-125 ton/ha. Some outliers are present between –25 and – 100 ton/ha (fig 25, table 11).

Different conclusions can be made from figure 24 and table 11. First, just like geology, soils play an important role in determining the biomass variation. This is also confirmed based on the ANOVA test (table 13), which rejects the null hypothesis that there are no differences in biomass at the different soil types.

The biomass variation in 2009 will be discussed in terms of the characteristics of the soils: soil thickness, available moisture and the C/N ratio (table 12).

Soil no.	Soil (Bonfils)	Description	Measured biomass 2008 (ton/ha)	Measured biomass change (ton/ha)	Measured soil thickness (cm)	Measured available moisture (-)	C/N (-)
1	13	Modal brown soils	168	71	25,6	0.10	11
2	29	Eutrophic brown soils	259	99	22,5	0.12	10
3	47	Calcareous regosols	261	40	23,9	0.11	12
4	52	Andosols	258	92	22,9	0.10	11
5	83	Fluvisols	528	107	23,0	0.09	-
6	21a	Acid lithosoils and brown soils	160	36	24,8	0.10	20
7	34b	Regosols	274	55	29,4	0.14	8
8	3d	Humified podzols	458	183	43,8	0.07	-
9	41a	Dolomite soils and regosoils	188	85	25,0	0.12	-
10	43	Lithosoils and fertilized calcaire soils	265	89	25,1	0.12	12,75
11	57	Calcic soils	300	17	22,0	0.14	6.7
		Average based on 8 soil types	263	83	27.3	0.11	12.1

Table 12: Soil thickness, available moisture and C/N ratio for the soil types, measured in 2009 at the field plots. C/N ratio is based on Bonfils. Soil types 5, 9 and 11 are not incorporated in the averages.

As been concluded in paragraph 4.2.1 soil thickness can be related to biomass in 2009. Based on an ANOVA test (table 14), one can conclude that the soil thickness also differs per soil type. Variation in biomass in 2009 at the different soil types seems to be related to a variation in soil thickness. The same is valid for available soil moisture, but with a less pronounced relationship. Based on the ANOVA test (table 15), the soil moisture differs per soil type.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	1222030	10	122203	9,21	0,00
Between groups	2520948	190	13268		
Total	3742978	200			

Table 13: ANOVA results for the biomass in 2009; the groups refer to the soil types. Soil types 5, 9 and 11 are not incorporated in the ANOVA test.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	5416	7	774	9,54	0,00
Between groups	15242	188	81		
Total	20657	195			

Table 14: ANOVA results for the soil depth in 2009; the groups refer to the 8 soil types. Soil types 5, 9 and 11 are not incorporated in the ANOVA test.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	0.08	7	0.011	2,29	0,02
Between groups	1.85	356	0.005		
Total	1.94	363			

Table 15: ANOVA results for the available soil moisture in 2009; the groups refer to the 8 soil types. Soil types 5, 9 and 11 are not incorporated in the ANOVA test.

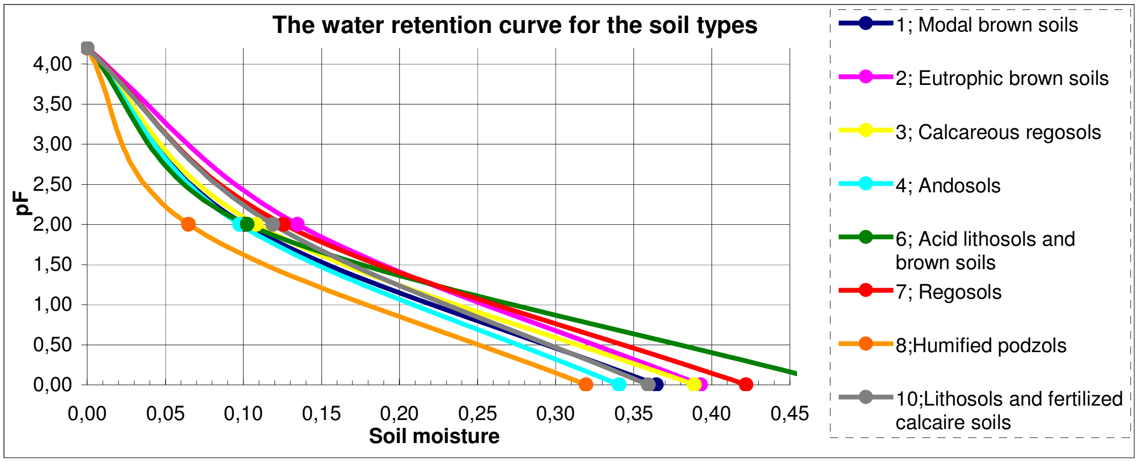


Figure 26: The water retention curve for the soil types, based on measured biomass in 2009.

The ratio between carbon (C) and nitrogen (N) also influences the biomass. The C/N indicates the presence of organic matter (humus) in the soil. Humus has a C/N ratio of approximately 7; soils with little humus have a C/N ratio larger than 18 (Smith and Smith, 2001). The C/N ratio was negatively correlated with the measured biomass in 2008 (-0.66), indicating that the variation in biomass can be related to a variation in C/N ratio.

The site specific conclusions confirm several general statements from Smith and Smith (2001) that thickness of the soils and available soil moisture are related to biomass. This is also true for the study area. Furthermore, Smith and Smith (2001) relate the C/N value to biomass: the larger the C/N ratio, the smaller the amount of humus will be, resulting in a less favorable situation for biomass. Again, the same conclusion can be made for the study area. The relation is explained by the fact that humus has the ability to hold water, and is in dry periods used as a water source. Furthermore, nutrients are available in humus.

Variation in species is also explained by the variation of the soils in the area (appendix VI). The dominant species on all soil types is the *Quercus ilex* (qil). The only exception is on modal brown soils (1), which are dominated by *Arbutus unedo* (aun). However, *Quercus ilex* and *Erica arborea* (ear) have also a prominent presence.

Pinus sylvestris (psy) is very rare in the area, except on humified podzols (8) and on calcic soils (11). Humified podzols (8) are vegetated by *Pinus sylvestris*. Humified podzols are only found in the reforested area in the study area. This soil type is very suitable for pine trees. This explains why pine tree are planted at this geology type. *Pinus sylvestris* is also very dominant on calcic soils (11), which are also dominated by *Quercus ilex*.

4.2.3 Elevation, slope and aspect

The range of the measured elevations varies between 131 and 454 m in the field plots, which is large enough to result in a variation in soil moisture between valleys and mountains. A relation of 0.28 was found between elevation and biomass in 2009 (fig. 27) indicating that biomass variation in 2009 is party explained by a variation in elevation.

The available soil moisture and soil thickness are also related to elevation. Field plots located higher in the study area have a larger available moisture (R=0.08) and a smaller soil thickness (R=–0.08) (table 16).

	Available moisture	**Soil thickness**
soil thickness	0,13	-
slope	-0,20	-0,20
elevation	0,08	-0,08

Table 16: Correlation of different factors with available moisture and soil thickness, based on the field plots.

These site specific conclusions contradict Kutiel et al (1998), who states that elevation is negatively related to biomass. Areas located in a valley receive water from all directions, since water is draining towards the lowest point. Areas in the valleys should be wetter and have a higher biomass than areas located on high elevations. However, this study concludes that areas located higher in the study area have a larger available moisture (R=0.08; table 16) and a larger biomass (R=0.28).

Measured elevation in 2009 (at the field plots)

Basic statistics of the measured elevation in 2009 (meter)	
Mean	**284.2**
Standard error	6.1
Median	283.0
Standard deviation	**86.4**
Skewness	0.2
Minimum	131.0
Maximum	454.0

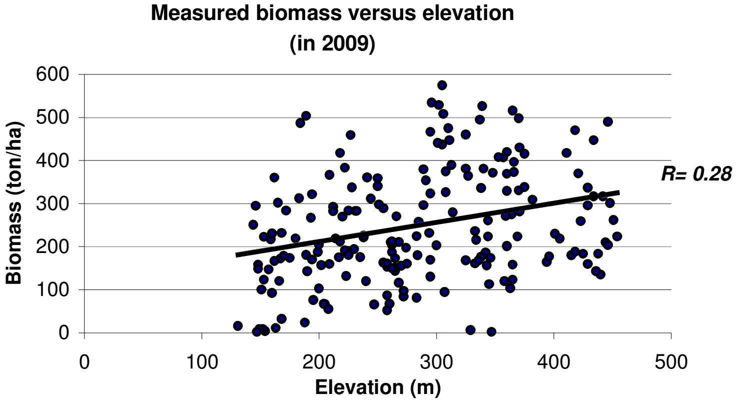


Figure 27: Statistics of the measured elevation in 2009, and the scatterplot of the measured biomass and elevation in 2009.

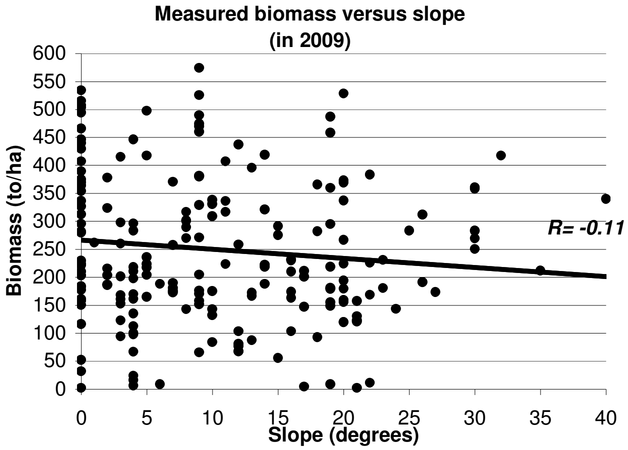
The range in measured slope varies between 0 and 40 degrees in all field plots, indicating that the range is large enough to give a reliable conclusion. A negative relation of –0.11 was found between slope and measured biomass in 2009 (fig. 28). The correlation indicate that biomass variation can partly be explained by a variation in slope.

Furthermore, thickness of the soil and the available soil moisture of the soil are, just as elevation, influenced by the slope. Soils located on a larger slope in the study area are characterized by a smaller thickness of the soil: a correlation of –0.20 was found (table 16). The same correlation of –0.20 was found for slope and available soil moisture (table 16). This also explains why the largest biomass values are found on plateaus.

These results are in agreement with general statements from Kutiel et al. (1998), Carmel and Kadmon (1999) and Marshak (2001) who showed that biomass and slope are negatively related. This can be explained by different reasons. First, water is always draining towards the lowest point and thus flowing downstream. This results in less available water for the biomass at the slope itself. Furthermore, accumulation and erosion processes play a role on slopes. A thick soil can accumulate at relative low sloping areas, while soils at steeper slopes might erode away, which results in removal of the soil or in the formation of a small soil and thus a lower biomass (Kutiel et al., 1998; Carmel and Kadmon, 1999; Marshak, 2001).

Measured slope in 2009 (at the field plots)

Basic statistics of the measured slope in 2009 (degrees)	
Mean	**10.4**
Standard error	0.6
Median	9.0
Standard deviation	**8.9**
Skewness	0.7
Minimum	0.0
Maximum	40.0



Figu re 28: Statistics of the measured slope in 2009, and the scatterplot of the measured biomass and slope in 2009.

Aspect is another factor, which influences the biomass variation. The biomass distribution per aspect class indicates a clear variation in the biomass (fig 29; table 17).

	Aspect class	Averaged biomass in 2009 (ton/ha)	Average biomass change (ton/ha)	Amount of field plots
1	North	265	67	41
2	East	217	66	39
3	South	279	97	52
4	West	201	63	45
5	Plateau	306	30	24
	Average	254	65	-

Table 17: Biomass data per aspect class.

The largest biomass average in 2009 is found on plateaus (306 ton/ha). Also, north and south orientated slopes have a relative large biomass (265 and 279 ton/ha). West orientated slopes are characterized by the lowest biomass (201 ton/ha). The biomass distributions at north, east, south and west orientated slopes are evenly distributed over the biomass classes. Plateaus are less evenly distributed over the biomass classes, which can be explained by the fact that there were too few field plots on plateaus (fig 29; table 16).

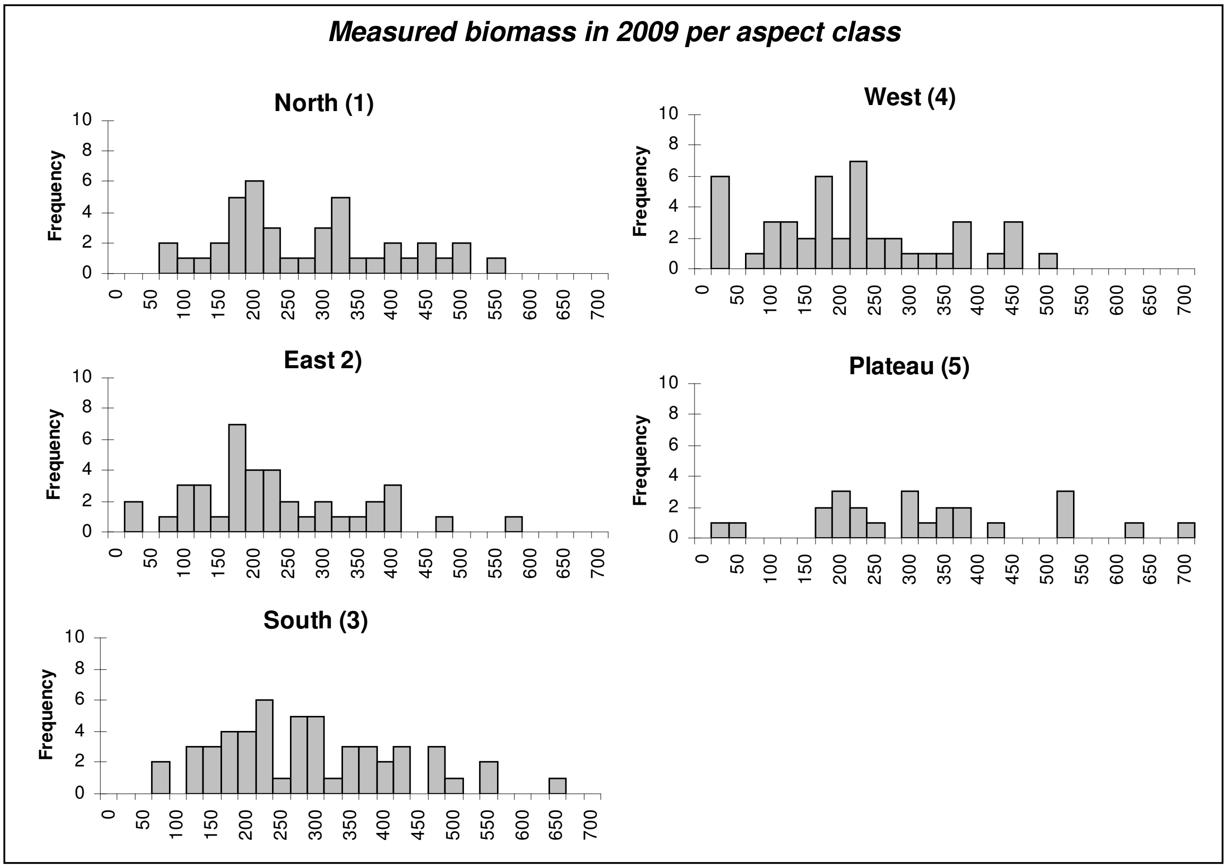


Figure 29: Biomass in 2009 (ton/ha) per aspect class.

The *biomass change* gives different results. The largest change is found on south orientated slopes. North, east and west orientated slopes have a biomass change around the average. Plateaus have the smallest biomass change (30 ton/ha). North and west orientated slopes are characterized by an almost normal biomass change distribution, with a peak around 50-75 ton/ha. South orientated slopes are characterized by a binomial biomass change distribution with two peaks around 50-75 and 100-125 ton/ha. The biomass change at plateaus is quite evenly distributed and has a small peak at 50-75 ton/ha. Plateaus are also characterized by different field plots with a decrease biomass over time (fig 30; table 16).

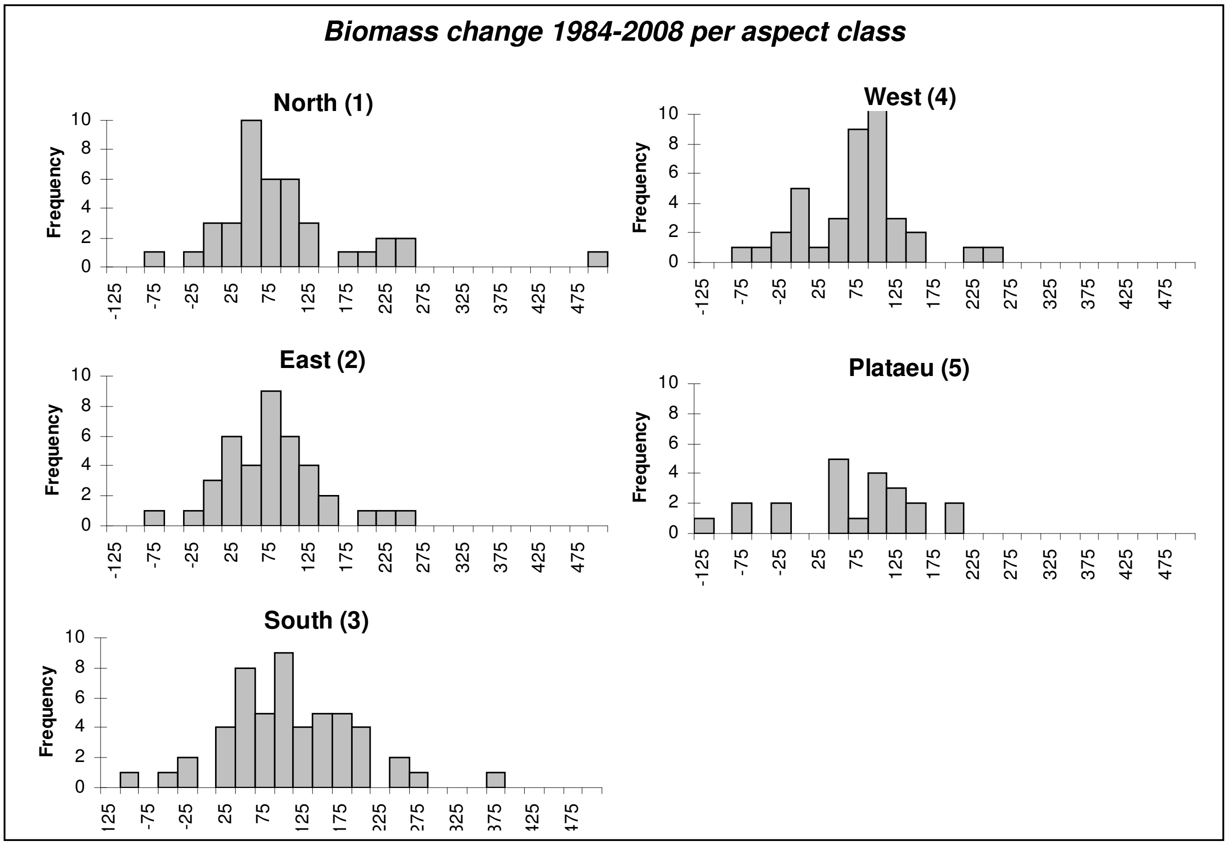


Figure 30: Biomass change between 1984 and 2008 per aspect class.

The variation in aspect classes result in a variation in biomass. This is also confirmed by the ANOVA test, with the null hypothesis indicating no differences in biomass averages at the different aspect classes (table 18). Since the F-ratio is larger than 1 (3.92), the null hypothesis can be rejected and one can conclude that it is credible that the biomass differs per aspect class.

Source	*SS*	*d.f.*	*MS*	*F-ratio*	*p-Value*
Within groups	277461	4	69365	3,92	0,00
Between groups	3465517	196	17681		
Total	3742978	200			

Table 18: ANOVA results for the biomass in 2009; the groups refer to the aspect classes.

	Aspect class	**Available soil moisture (-)** *(measured)*
1	North	0.12
2	East	0.11
3	South	0.11
4	West	0.08
5	Plateau	0.13

Table 19: The variation in available soil moisture per aspect class (measured at the field plots).

Based on the ANOVA results in table 18, it is clear that aspect influence the biomass. This relationship can be explained by a variation in available sunlight and by a variation in slope. Biomass is higher on north orientated slopes as a result a larger available soil moisture at these slopes (table 19). Figure 31 shows the variation in slope per aspect class. The biomass in 2009 is relative large on south orientated slopes. Relating the average slope to south orientated slopes, one can conclude that the majority of the south orientated slopes have a relative small slope (fig. 31) and small slopes result in a larger biomass. The same holds for plateaus. The majority of the west orientated slopes is very high, resulting in a low biomass in 2009.

The site specific conclusions match the conclusions made by Holland and Steyn (1975), Kutiel and Lavee (1999) and Carmel and Kadmon (1999). First, Holland and Steyn (1975) described the variation in biomass in terms of a variation in solar radiation. Solar radiation influences the temperature as well as water movements, which influences the biomass (Holland and Steyn, 1975). Kutiel and Lavee (1999) and Carmel and Kadmon (1999) described a difference in biomass between north and south orientated slopes: biomass is higher on north orientated slopes.

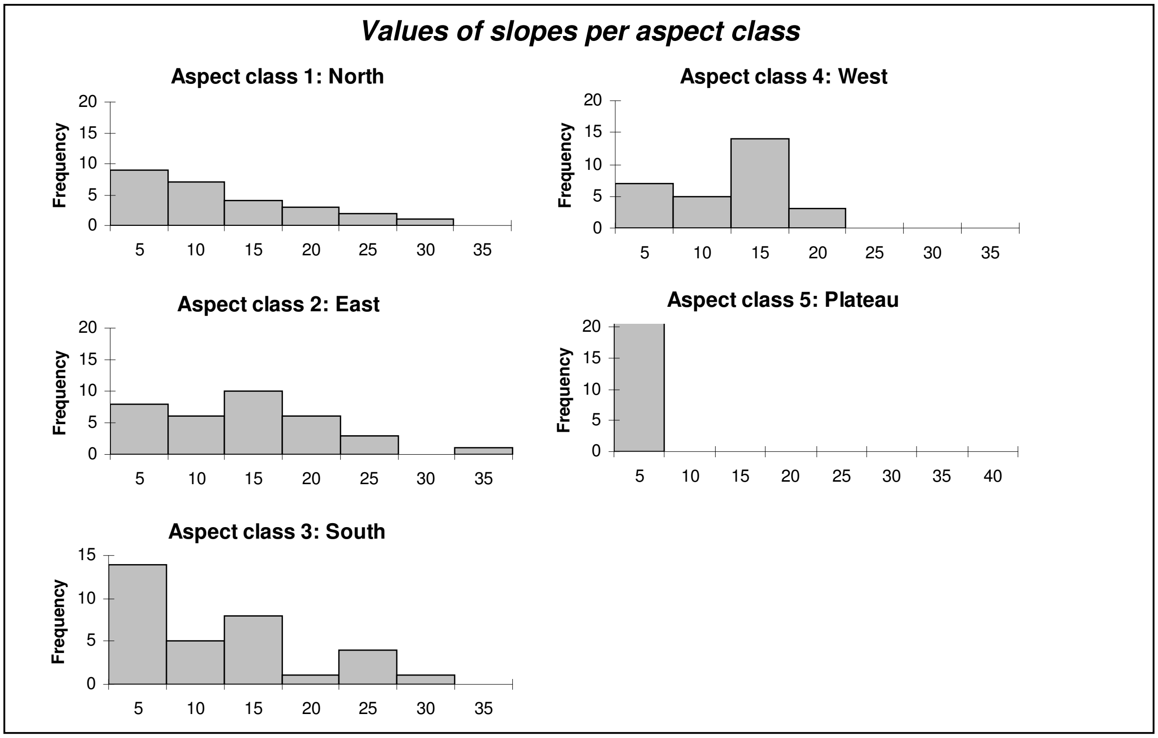


Figure 31: Values of slopes for each aspect class.

4.2.4 Human influence

The correlation between biomass in 2009 and human influence (reforestation) was 0.33 (table 19). The relative large correlation is explained by the fact that more biomass is added to the area, which results in a larger biomass. However, no direct correlation was found for the other human influences (table 20). This is explained by the fact that stony walls were past influences, which do not influence the present variation in biomass. Also paths, which had no correlation, were old and not recently used. The paths have no influence on the present biomass.

	Biomass in 2009	**Biomass change**
Regrowth	0.33	0.36
General human influence	-0.03	-0.16
Paths	0.00	0.00
Stony walls	0.05	-0.07

Table 20: Correlation coefficients for the human influence factors based on the field plots.

The positive relation between roads and change in biomass is explained by the time since abandonment. Areas located further away from roads were first abandoned, indicating that these areas had a longer time for biomass regeneration and thus have a larger biomass change (Sluiter, 2007).

Human influence has a direct and indirect influence on the biomass. The more suitable a soil, the more favorable it will be for agricultural practices. Agricultural practices has a positive or negative influence on the biomass on these soils. Every soil is influenced by humans in the past (logging and remainders of stony walls and houses) and in the present (logging, trash, empty bullets and fences). Assuming the presence of stony walls as an indication for former agricultural use, the majority of the soils have been used as agricultural land. Soils where no signs of former agricultural practices were found are eutrophic brown soils (2) and andosols (4) (fig. 33). These soils have a somewhat lower biomass than averaged. García (2007) reports that past agricultural practices, such as tillage and soil compaction, influence the soil in a negative way. The changing soil characteristics has a negative influence on the biomass (Garcia, 2007). Based on Garcia (2007) the soils which were not used as agricultural land should have higher biomass values. This is not true for the study area.

Figure 32: Large, human made, stony walls in a forest. Photo taken near field plot 18 (521373; 4826546).

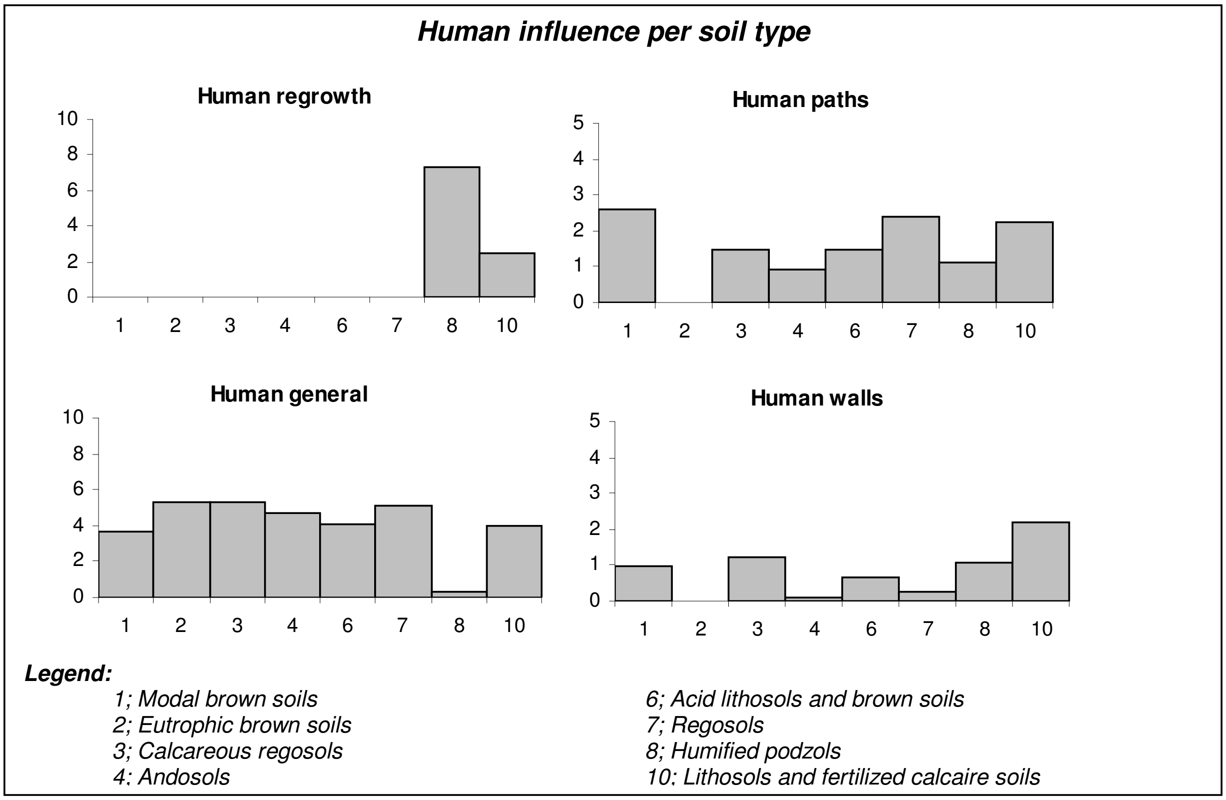


Figure 33: Human influence per soil type, with on the horizontal axis the different soil types and on the vertical axis the rate of human influence.

Available soil moisture and soil thickness are also influenced by humans. Field plots which are characterized by reforestation, have a large available soils moisture and a thicker soil. However, this could also be attributed to the soil type of the reforested areas. The reforested areas are located on sandy limestones and limestones (8), which are very less compacted. The soil thickness of very less compacted soils were easy the measure, resulting in a larger soil thickness. The same holds for the available soil moisture. Sandy limestones and limestones (8) have a large ability to store water. The available soil moisture is thus not influenced by humans directly, but by the soils on which the influence took place.

4.2.5 Interaction of factors

Biomass is not influenced by a single factor, but by the interaction of multiple factors. This interaction is mainly the result of factors that influence the available soil moisture and soil thickness. This paragraph describes the interactions of these factors. Different interactions are already mentioned: the relation between available soil moisture and soil thickness (paragraph 4.4.1), the relation between elevation, slope and aspect versus available soil moisture (paragraph 4.2.3) and the relation between aspect and slope (paragraph 4.2.3).

A final relation has to be mentioned. The study describes how the variation in the different factors influence the biomass. Another important factor has to be mentioned: the biomass itself. Different species extract or add different nutrients and organic matter to the soil. This results in a change in soil characteristics and a possible change in biomass. Furthermore, some species has deeper root systems, that prevent the soil to wash away (Marshak, 2001). However, in this study the most prominent species is the *Quercus ilex.* Other species are far in the minority, so no reliable conclusion can be made for the influence of different species on the biomass.

5. Discussion

This chapter gives an overview of several discussion points in terms of field data, image analysis and results. The found results are shortly compared to other literature and are discussed in terms of credibility and uncertainties.

5.1. Field data

5.1.1 Biomass

The biomass in 2009 was measured based on the biomass equation from Ogaya et al. (2003). The biomass at the field plots ranged between 2 and 681 ton/ha and have an average of 250 ton/ha. The measured biomass values match reasonable well with reported literature values. Mooney (1981) gives values of 270 ton/ha for a dense French evergreen oak forest. Rapp and Loissant (1981) found 43.6 ton/ha for maquis. Furthermore, De Jong et al. (2003) reports biomass values of 168.9 ton/ha for Mediterranean French forests and Addink et al. (2007) found biomass values of 167 ton/ha. Finally, Nijland, et al. (2009) reports biomass values for 143 ton/ha for Mediterranean French forests.

However, some critics have to be mentioned concerning the measured biomass. Ogaya et al. (2003) reported that allometric relations are highly significant and effective: a correlation of 0.99 for *Arbutus unedo* was found; and a correlation of 0.98 for *Quercus ilex.* However, the equation was also applied on other species in the study area. Another uncertainty, related to measuring the biomass in 2009, is the fact that the plots were not evenly distributed over the study area. The field plots were chosen based on their expected biomass change. Therefore, the predictive model is only based on areas with a large expected biomass change, resulting in poor results for agricultural land, which often shows no biomass change. In order to make a more reliable predictive biomass model for the entire study area, the field plots have to be evenly distributed over the study area.

Furthermore, there is an uncertainty concerning the position in the field. Most of the time, the global positioning system (GPS) was not able to give the exact plot in the field; the GPS deviations ranged between 0 and 10 meters, so the exact position of the field plot was difficult to find back in the image.

5.1.2. Factors

Information about the different factors (geology, soils, elevation, slope, aspect and human influence) was measured in the field. Although the field data showed a large range in variation, some uncertainties are present in the data. One of these uncertainties deals with measuring the soil thickness and available moisture. The thickness of the soil was measured by an iron bar which was pushed into the soil. However, when a large stone was present in the soil, the bar could not enter the soil. As this was not always noticed in the field, it resulted in a relative smaller soil thickness than the real soil thickness. Furthermore, the compaction of the soil had an influence on the soil thickness. Some soil were very compact, resulting in a difficult situation to insert the bar into the soil. Again, this resulted in a smaller soil thickness than the real one.

The measured available moisture contains also some uncertainties. First, not all soil samples were completely filled. As a result, the height of the soil sample in the kopecki ring had to be estimated to get the volume of the sample. The uncertainty in height is approximately 0.5 cm, resulting in an uncertainty of approximately 10 cm^2 in volume of the sample. Furthermore, the weight of the soil samples was measured three times. It could not have been prevented to loose some of the sample during the procedure. Another uncertainty concerning the available moisture is related to precipitation. During the last weeks of the study, precipitation occurred several times. The soil samples were taken in the upper 10 cm of the soil, so it is likable that the infiltrated precipitation had influence on these soil samples. The measured available soil moisture is therefore higher at samples taken at rainy days.

The factors, aspect, slope and elevation contained also some uncertainties. It was often difficult to determine the aspect in the field, especially on low sloping areas. Furthermore, uncertainties are present in the measured elevation as a result of the used GPS. Slope is measured by a compass, but most of the plots were not equalized, resulting in a variation of measured slope values within the same plot.

Human influence is another factor, which should be mentioned. There were many unknowns concerning the human influence. First of all, the exact time of the influence was not known. If the rate of influence occurred at two different moments in time, the most recent influence would have a larger effect on the biomass than the influence in the past. Furthermore, the intensity of influence was not known. Many stony walls were present in the study area, which were assumed to be related to agricultural lands. However, the presence of stony walls did not indicate the intensity of agricultural practices.

5.2 Image analysis

Different uncertainties are present concerning the image analysis and the making of the predictive biomass model. First of all, the predictive biomass model has an correlation of 0.31; which is not very large. Second, the uncertainty concerning the measured biomass values in 2009 is propagated in the predictive biomass model. Third, an important assumption that was made, was that no biomass changes occurred between 2008 and 2009. However, it is not likely that absolutely no changes occurred.

Another uncertainty related to the image analysis is the conversion in pixel size. The field plots, at which the biomass in 2009 was measured, and the pixel size of the Hymap image had a surface area of 25 m^2 (5x5m), while the pixel size of the Landsat TM 1984 image comprised a surface area of 900m^2 (30mx30m). The biomass images of 1984, 2008 and the biomass change image, had also a surface area of 900m^2 (30mx30m). Before the predictive biomass model was applied to the image of 2008, the pixels were converted from 5x5m pixels into 30x30 m pixels. The new pixels of 30x30m are an average of 36 pixels.

5.3 Biomass values

5.3.1. Calculated biomass results

The calculated biomass in 2008 varies between 0 and 653 ton/ha, after removing the three negative values out of the image. The mean biomass is 245 ton/ha, with a standard deviation of 80 ton/ha. No uncertainties are present in this step, except the uncertainties in earlier steps, such as uncertainties in measurements of the biomass in 2009 and uncertainties that arise during the making of the predictive biomass model.

The calculated biomass in 1984 were very unexpected. No variation in biomass was found (168-173 ton/ha), indicating an almost homogenous area in 1984. The biomass change was in term unreliable as well, since this incorporated the unreliable biomass values of 1984. The poor biomass results for 1984 (and the biomass change) can be attributed to a very small variation in the original image. Explanations for the missing variation are haze in the image, spatial support of the pixel and radiometric sensitivity of the sensor.

5.3.2. Explaining the biomass variation

The variation in geology and soils has a large influence on the biomass variation. This is mainly caused by a variation in available soil moisture and soil thickness. Also other factors, such as elevation, slope, aspect and human influence, have proved to influence the biomass.

Several site specific conclusions were made during the study. The conclusions that contradict other reports (such as Smith and Smith, 2001; Fernandez et al., 2004; Kutiel et al., 1998; Roche et al., 1998; Garcia, 2007) will further be discussed. Smith and Smith (2001) reported that a large soil moisture is related to a larger biomass, which is in contradiction with the site specific conclusions in this study. This contradiction can be explained by the method of measuring the available soil moisture. The soil samples were taken in the upper 10 cm of the soil. Soil water in a thicker soil can infiltrate to deeper parts, resulting in a less available soil moisture in the upper parts. When taking soil samples in thicker soils, less available soil moisture seems to be present.

The general statement that thicker soils is related to more biomass is also valid in this study area. However, this is not valid for all geology and soil types. Some geology or soil types, such as sandy shale, schists, coals and limestones (5), are characterized by a very low biomass in 2009, a moderate soil thickness and a high soil moisture. Other examples are white limestones, sandstones and marls (9) with a moderate biomass in 2009, a small soil thickness and a high soil moisture. Based on these exceptions one has to conclude that a interaction of several factors is more important than the direct relation between biomass and soil thickness and available soil moisture.

Another general statement is that the presence of large stones effect the erosion and infiltration rate of the soil, resulting in a smaller biomass (Fernandez et al., 2004; Kutiel et al., 1998). However, large outcrops and boulders do not effect the biomass in this study area. This can be explained by species. The measured biomass in this area mainly consists of trees, which can easily avoid these large outcrops.

It was found that the erodability of a geology type seems to affect the thickness of the soil and therefore the biomass. However, no clear signs of erosion were found. The absence of erosion patterns could be explained by the dense canopy which prevents splash erosion. Furthermore, erosion could easily have occurred in the past when the canopy was less developed as a result of agricultural practices and the land abandonment (Roche et al., 1998).

A last discussion point is the human influence on the biomass. Garcia (2007) reported that agricultural practices influence the soils and biomass in a negative way. However, this was not true for the study area. This contradiction could be attributed to the time since abandonment. Sluiter (2007) studied the same study area and concluded that 90% of the abandoned areas were abandoned before 1940. This was far beyond the time of the study, which could diminish the negative effects of agricultural practices.

6. Conclusions

The first aim was detecting the amount of the biomass variation in 2009 and biomass change between 1984 and 2008. This aim was answered by measuring the biomass at the field plots in 2009, by finding an predictive biomass model based on high spatial resolution image and by calculating the biomass change based on this model.

The measured biomass at the field plots ranged between 2 and 681 ton/ha and had an average of 250 ton/ha. Based on the measured biomass of 2009 and the available image of the study area in 2008, a predictive biomass model was made. The predictive biomass model is a linear regression model, based on the spectral bands of the image of 2008 and the measured biomass in 2009. The predictive biomass model was next used to predict the biomass in the entire study area in 2008 and 1984 and the biomass change between 1984 and 2008. The calculated biomass in 2008 gave very decent results. However, the biomass for 1984 was very unreliable, due to missing variation in reflectance the initial image. The biomass change between 1984 and 2008 was therefore also very unreliable.

The biomass variation in 2009 and biomass change are discussed in terms of different factors (aim 2). The environmental factors for each plot were geology, soils, elevation, slope, aspect and human influence. A large range was found in the measured data. It was found that the large variation in biomass was attributed to variation in geology and soils. This variation was mainly caused by a variation in available soil moisture and soil thickness. Elevation was found to positive related to biomass, while slope was negative correlated to biomass. Biomass varied also per aspect class. Human had an influence on the biomass too: in areas under the influence of reforestation had a larger biomass in 2009 than areas without this influence. Furthermore, other human influences, such as paths, walls and other kind of influences, was proven to have no large influence on the biomass variation in 2009.

Recommendations

Based on this study, the following recommendations can be made for future studies, concerning biomass changes. First of all, one should do the study on field plots which are evenly distributed over the study are as well as evenly distributed over dense and less vegetated areas. Such an approach (stratified random sampling) will yield larger variation in the dataset and will give more reliable results. Second, more information about allometric biomass equations should be gathered: a biomass equation including different species should be used.

Furthermore, more information should be gathered about soil characteristics. The chemical composition of the soil is very important, and deals with litter depth, organic soil carbon, nitrogen accumulation and soil moisture (Garnier et al., 2004). This study is mainly focussed on available soil moisture and soil thickness. It is recommended that more detailed information should be gathered about C/N values, organic content of the soil, and the soil structure, such as the presence of aggregates.

Another recommendation concerns the initial situation of the area. Some areas were already abandoned at the initial situation, while some areas were abandoned during the time span of the study. This results in a biomass variation that is not contributed by the factors only, but also by the process of succession. So future studies should taken the initial situation of the study area into account.

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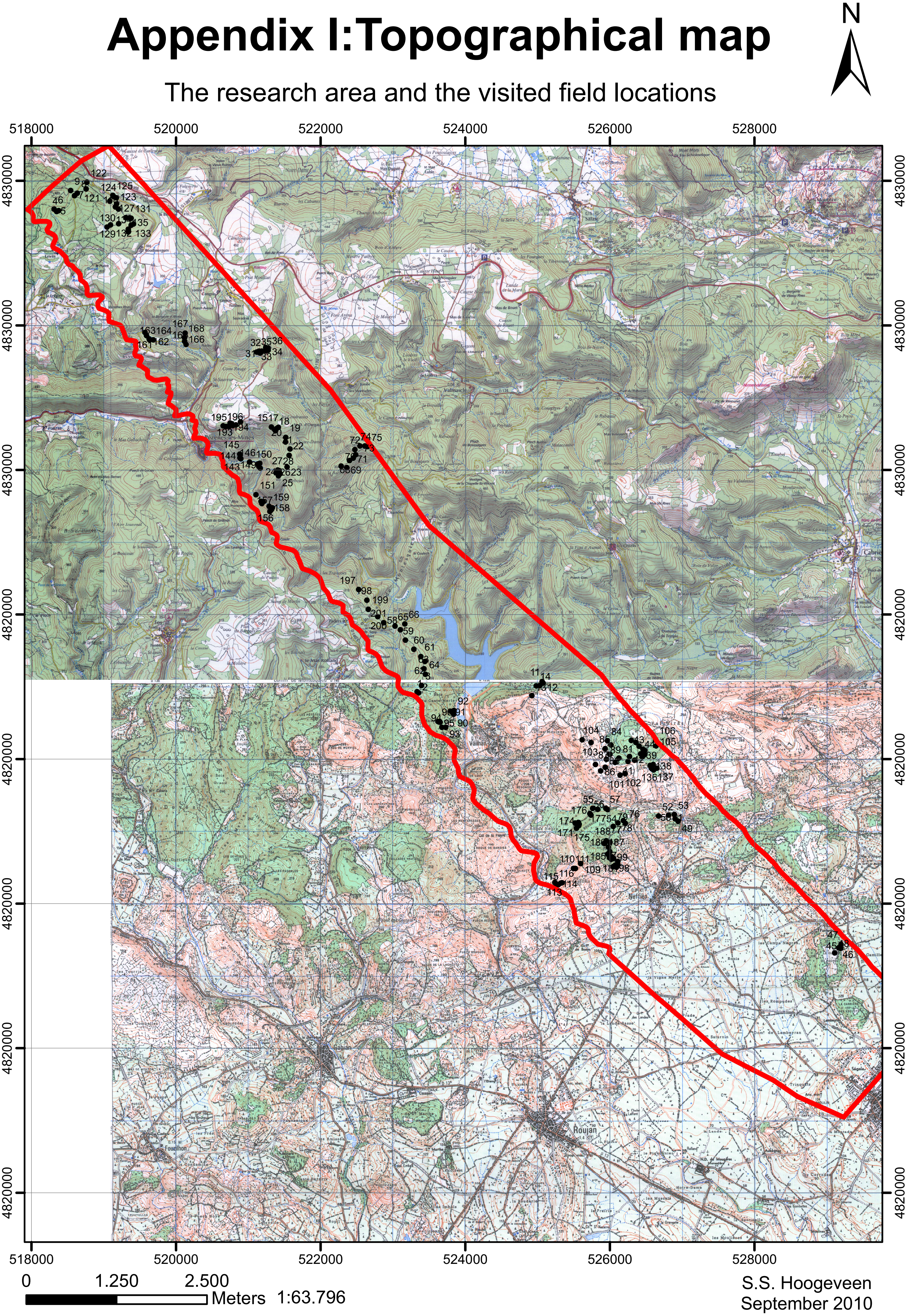
Appendix I:Topographical map

The research area and the visited field locations



S.S. Hoogeveen
September 2010

Appendix II: Overview of all measured data

No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
1	0523334	4822935	251	3	3	3	22,8	0,28	13	1	11	298	113	0	3	3	1
2	523355	4822917	247	9	3	3	16,4	0,27	13	1	11	66	226	0	3	3	1
3	523394	4823019	255	16	4	3	17,9	0,25	13	1	11	163	-3	0	5	0	0
4	518377	4829589	444	16	3	9	15,1	0,22	43a	10	13	210	68	0	3	3	3
5	518348	4829578	440	4	3	9	17,8	0,41	43a	10	13	135	51	0	3	3	3
6	518314	4829608	436	8	3	9	17,9	0,43	43a	10	13	143	100	0	3	3	0
7	518597	4829798	446	2	3	9	12,1	0,29	43a	10	13	204	112	0	3	3	1
8	518635	4829831	451	1	3	9	13,5	0,26	43a	10	13	262	128	0	8	0	0
9	518543	4829865	454	0	5	9	13,5	0,29	57d	13	20	224	0	0	3	3	3
10	525030	4823019	272	10	4	1	14,4	0,36	13	1	11	84	137	0	5	3	1
11	525063	4823073	283	20	2	1	22,7	0,49	13	1	11	224	29	0	5	0	0
12	525078	4823054	265	24	4	1	47,5	0,51	13	1	11	143	121	0	11	3	0
13	524921	4822879	285	7	3	1	19,7	0,42	47	3	12	257	85	0	3	3	1
14	524982	4823014	262	5	4	3	25,5	0,41	13	1	11	204	296	0	3	3	1
15	521319	4826596	343	20	3	2	19,1	0,30	52	4	11	156	192	0	6	3	0
16	521392	4826574	360	3	2	2	31,3	0,38	52	4	11	201	214	0	6	3	0
17	521415	4826592	363	16	4	2	10,1	0,35	52	4	11	104	-29	0	3	0	0
18	521373	4826546	360	17	4	2	22,1	0,38	52	4	11	201	145	0	3	3	0
19	521518	4826452	344	3	4	2	18,5	0,44	52	4	11	260	246	0	6	3	0
20	521513	4826389	342	2	4	1	14,7	0,39	47	3	12	186	111	0	5	3	0
21	521577	4826289	338	9	3	1	13,9	0,28	43b	11	12,5	176	138	0	6	3	1
22	521564	4826202	344	11	1	2	15,7	0,32	43b	11	12,5	224	294	0	3	3	1
23	521536	4826041	357	0	5	2	23,7	0,40	43b	11	12,5	407	340	0	6	3	1
24	521440	4825948	333	5	4	8	17,1	0,41	43b	11	12,5	236	228	0	5	0	0
25	521416	4825921	369	5	4	8	15,3	0,39	43b	11	12,5	223	199	0	7	0	0
26	521383	4825960	338	11	4	8	19,3	0,33	47	3	12	336	123	0	6	0	0
27	521406	4825998	305	12	4	8	16,3	0,31	47	3	12	437	5	0	6	0	0
28	521425	4825993	333	4	4	8	17,9	0,25	47	3	12	161	199	0	6	0	0
29	521187	4827644	366	20	4	4	38,3	0,26	52	4	11	373	-5	0	6	4	2
30	521148	4827646	360	14	4	4	26,3	0,28	52	4	11	419	-13	0	5	0	0
31	521163	4827619	346	16	4	4	13,3	0,28	52	4	11	174	96	0	5	0	0
32	521117	4827631	358	20	4	4	18,7	0,28	52	4	11	120	-14	0	6	0	0
33	521241	4827696	360	20	4	2	20,1	0,15	52	4	11	369	171	0	7	1	0
34	521275	4827686	370	10	1	4	13,9	0,19	52	4	11	330	18	0	7	0	0
35	521245	4827648	394	5	1	4	23,3	0,26	52	4	11	165	120	0	7	1	1
36	521274	4827659	382	10	1	4	20,3	0,17	52	4	11	309	157	0	3	0	0
37	526483	4822122	340	9	2	7	24,7	0,17	3d	8	0	381	316	5	0	1	0
38	526483	4822065	339	9	3	7	43,3	0,21	3d	8	0	526	326	5	0	1	1

No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
39	526449	4822029	310	9	3	7	41,1	0,30	3d	8	0	475	379	5	0	1	1
40	526341	4821987	325	9	3	7	42,9	0,31	3d	8	0	460	207	5	0	1	1
41	526250	4821968	305	9	2	7	45,9	0,30	3d	8	0	574	246	5	0	1	1
42	526272	4822034	289	9	2	7	36,3	0,29	3d	8	0	380	195	5	0	1	1
43	526458	4822138	325	9	1	7	47,5	0,30	3d	8	0	381	293	5	0	1	1
44	526427	4822075	320	4	3	7	47,5	0,21	3d	8	0	628	185	5	0	1	1
45	529193	4819384	172	4	2	2	18,3	0,38	52	4	11	284	33	0	5	1	0
46	529166	4819391	167	13	2	2	18,9	0,49	52	4	11	172	116	0	10	3	0
47	529197	4819439	159	5	1	0	23,7	0,39	52	4	11	217	-9	0	5	0	0
48	529108	4819320	168	0	5	2	12,7	0,47	52	4	11	32	-47	0	5	0	0
49	526943	4821140	202	21	2	6	18,3	0,45	29	2	10	157	130	0	3	0	0
50	526903	4821177	209	18	2	6	14,9	0,31	29	2	10	366	84	0	5	0	0
51	526813	4821225	217	10	2	6	12,3	0,43	21a	6	20	175	151	0	6	0	0
52	526673	4821213	223	10	4	6	18,9	0,07	21a	6	20	132	94	0	3	0	3
53	526892	4821232	212	15	1	6	15,3	0,45	21a	6	20	292	140	0	3	0	1
54	525970	4821303	205	4	1	5	14,8	0,40	21a	6	20	67	-4	0	3	1	1
55	525761	4821317	189	19	1	5	43,0	0,23	21a	6	20	181	75	0	11	0	0
56	525723	4821248	200	12	1	5	18,4	0,28	21a	6	20	103	-20	0	5	1	0
57	525945	4821317	194	9	4	5	43,0	0,34	21a	6	20	170	88	0	3	1	0
58	523103	4823789	255	8	4	3	15,4	0,53	13	1	11	289	115	0	8	3	0
59	523172	4823646	258	13	4	3	25,8	0,47	13	1	11	87	76	0	3	3	1
60	523289	4823518	266	8	3	3	22,4	0,36	13	1	11	270	36	0	5	1	1
61	523385	4823418	258	3	4	3	43,0	0,22	13	1	11	153	20	0	3	3	1
62	523442	4823351	265	9	1	3	27,4	0,35	13	1	11	152	109	0	3	3	3
63	523429	4823252	272	4	4	3	23,8	0,30	13	1	11	97	120	0	3	3	3
64	523448	4823176	274	4	4	3	18,4	0,41	13	1	11	198	37	0	3	0	0
65	523030	4823840	262	2	3	3	29,6	0,36	13	1	11	187	165	0	3	4	4
66	0523164	4823871		23	1	3	18,4	0,46	21a	6	20	231	202	0	0	0	0
67	522484	4826212	353	11	3	8	27,0	0,40	43b	11	12,5	407	147	0	8	0	0
68	522400	4826130	334	2	4	8	21,6	0,41	43b	11	12,5	215	72	0	8	3	3
69	522361	4826035	325	22	2	8	22,2	0,51	43b	11	12,5	168	94	0	8	3	3
70	522284	4826055	345	4	3	8	18,4	0,39	47	3	12	112	186	0	3	3	3
71	522451	4826165	348	7	3	8	19,2	0,52	43b	11	12,5	371	135	0	8	3	3
72	522473	4826285	364	15	3	8	19,2	0,25	43b	11	12,5	275	189	0	4	0	0
73	522543	4826334	375	10	3	8	22,6	0,44	43b	11	12,5	338	301	0	3	0	0
74	0522612	4826335		2	3	8	18,6	0,52	43b	11	12,5	378	340	0	3	1	0
75	522649	4826324	375	3	3	8	35,0	0,44	43b	11	12,5	415	113	0	3	1	3
76	526215	4821113	212	18	3	6	35,0	0,31	29	2	10	282	74	0	6	0	0

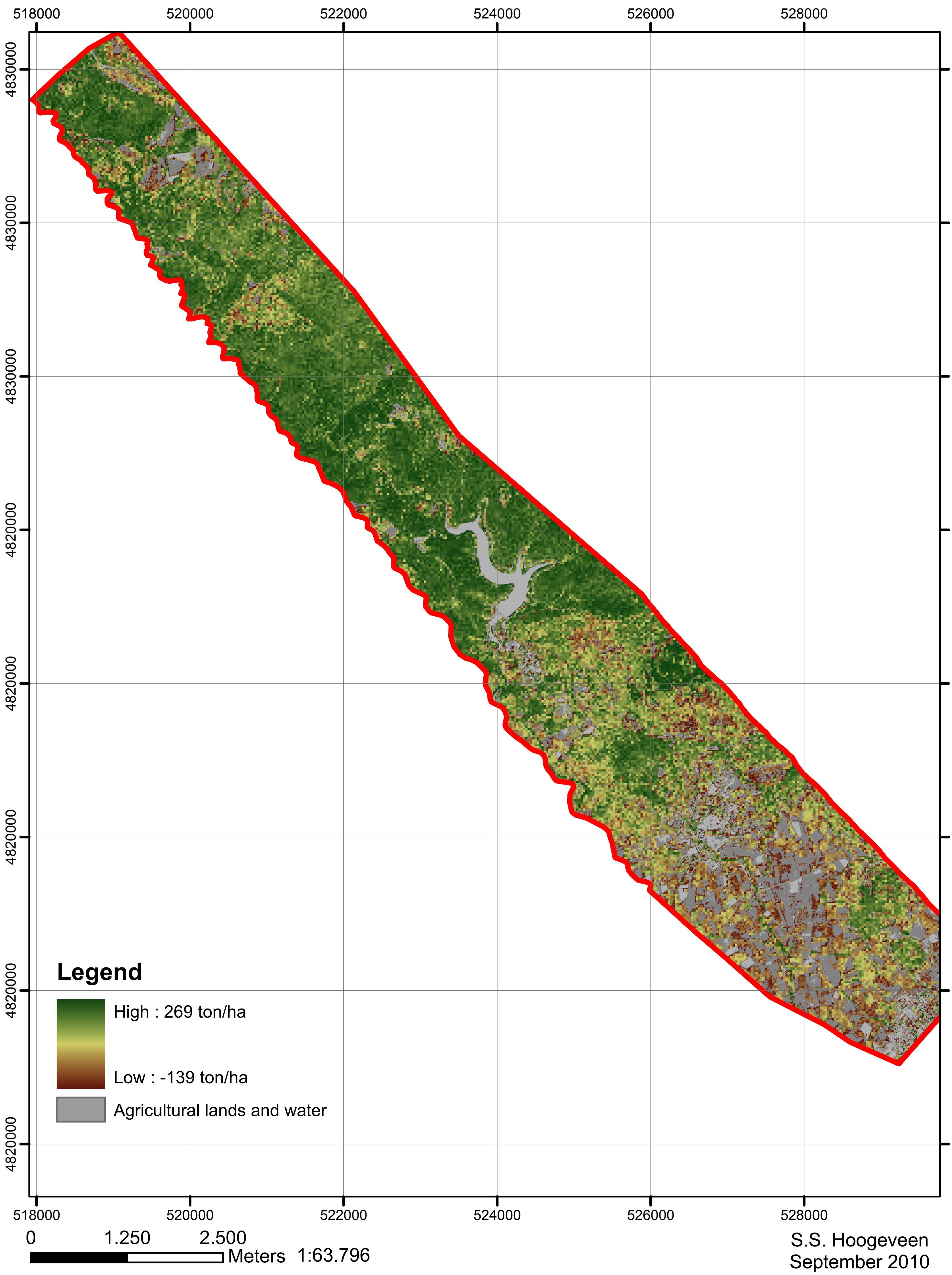
No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
77	526186	4821150	238	0	3	6	29,6	0,45	29	2	10	222	115	0	6	0	0
78	526112	4821117	228	20	3	6	17,6	0,39	29	2	10	337	20	0	6	0	0
79	526048	4821071	225	7	3	6	19,6	0,44	29	2	10	189	112	0	6	0	0
80	526075	4821956	308	0	5	7	49,7	0,39	3d	8	0	375	-73	10	0	3	3
81	526125	4822013	313	0	1	7	49,5	0,38	3d	8	0	389	82	10	5	0	0
82	526000	4822065	371	0	4	7	40,3	0,29	43b	11	12,5	430	221	10	5	0	0
83	526015	4822195	301	0	4	7	40,5	0,42	43b	11	12,5	440	350	10	0	3	
84	525966	4822253	311	0	5	7	42,3	0,43	43b	11	12,5	607	225	10	5	3	4
85	525934	4822145	291	0	4	7	34,3	0,49	43b	11	12,5	354	229	10	5	3	4
86	525873	4821835	314	0	5	7	34,3	0,46	43b	11	12,5	280	111	10	5	3	3
87	525801	4821926	300	0	5	7	30,0	0,41	43b	11	12,5	203	109	10	5	4	4
88	525936	4821890	308	0	5	7	46,5	0,42	43b	11	12,5	326	294	10	5	1	1
89	525952	4821997	306	0	5	7	51,8	0,45	43b	11	12,5	507	310	10	5	3	4
90	523839	4822624	148	9	2	4	20,4	0,31	21a	6	20	158	55	0	6	0	3
91	523806	4822660	160	18	2	4	19,0	0,44	21a	6	20	93	62	0	12	0	1
92	523845	4822673	162	19	2	4	19,5	0,37	21a	6	20	360	132	0	11	4	3
93	523729	4822438	166	21	2	3	19,5	0,39	21a	6	20	120	-4	0	0	3	3
94	523678	4822442	180	14	2	3	15,5	0,51	21a	6	20	219	24	0	5	3	3
95	523652	4822514	175	27	2	3	15,6	0,35	21a	6	20	173	50	0	3	0	0
96	523623	4822520	188	4	2	3	24,5	0,29	21a	6	20	24	16	0	5	0	0
97	526108	4820539	157	17	1	6	23,8	0,42	34b	7	8	147	31	0	5	0	0
98	526071	4820531	160	16	2	6	23,8	0,37	34b	7	8	230	100	0	5	0	0
99	526046	4820512	170	19	2	6	25,6	0,47	34b	7	8	179	96	0	5	0	0
100	526092	4820504	153	14	2	6	20,4	0,45	34b	7	8	223	36	0	7	0	0
101	526141	4821779	283	12	2	1	20,6	0,46	43b	11	12,5	81	1	0	0	0	0
102	526211	4821801	268	4	4	1	20,0	0,45	43b	11	12,5	211	16	0	6	0	0
103	525740	4822227	329	4	2	1	23,0	0,40	43b	11	12,5	6	-15	0	1	3	4
104	525618	4822266	347	0		1	17,0	0,42	43b	11	12,5	2	-44	0	0	0	1
105	526639	4822185	311	0	1	7	45,8	0,32	3d	8	0	447	302	10	0	0	0
106	526631	4822263	296	0	1	7	48,2	0,43	3d	8	0	534	169	10	0	3	3
107	526556	4821914	258	0	3	1	34,3	0,28	43b	11	12,5	52	-10	10	0	3	3
108	526599	4821924	258	0	3	1	33,5	0,43	43b	11	12,5	161	218	10	1	4	4
109	525596	4820556	184	19	4	6	23,0	0,36	21a	6	20	487	229	0	10	3	1
110	525523	4820488	163	22	4	5	30,0	0,43	21a	6	20	11	-45	0	0	0	0
111	525496	4820490	151	4	4	5	42,8	0,42	21a	6	20	100	58	0	3	0	0
112	525338	4820289	154	17	4	5	28,3	0,43	21a	6	20	4	-18	0	0	0	0
113	525322	4820285	152	19	4	5	25,5	0,37	21a	6	20	9	-9	0	0	0	0
114	525288	4820265	149	6	4	5	30,2	0,42	21a	6	20	8	-35	0	0	0	0
115	525258	4820250	147	21	4	5	26,0	0,29	21a	6	20	2	-39	0	5	0	0
116	525239	4820293	131	4	4	5	22,5	0,42	21a	6	20	16	-4	0	5	3	3

No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
117	519161	4829640	442	8	2	9	24,0	0,24	43a	10	13	317	87	0	3	4	4
118	519203	4829608	438	0	5	9	20,4	0,38	43a	10	13	184	87	0	3	1	0
119	519178	4829682	434	11	1	9	24,0	0,28	43a	10	13	317	55	0	3	0	0
120	519085	4829722	434	4	1	9	18,0	0,37	43a	10	13	447	88	0	3	0	1
121	518757	4829888	448	8	1	9	20,4	0,34	43a	10	13	301	72	0	5	4	4
122	518766	4829981	446	9	1	9	29,4	0,35	57b	12	0	489	76	0	4	4	4
123	519175	4829767	415	7	2	9	29,6	0,36	43a	10	13	180	117	0	3	4	5
124	519142	4829782	423	12	2	9	29,4	0,29	43a	10	13	259	64	0	3	4	5
125	519125	4829800	418	6	1	9	23,0	0,29	57b	12	0	188	70	0	3	4	5
126	519358	4829488	429	0	5	9	15,4	0,31	43a	10	13	160	47	0	8	4	1
127	519305	4829492	429	0	5	9	23,4	0,30	43a	10	13	296	36	0	8	4	4
128	519207	4829407	421	0	5	9	21,2	0,26	43a	10	13	369	15	0	3	4	4
129	519094	4829391	401	0	5	9	18,8	0,24	43a	10	13	230	131	0	3	4	4
130	519046	4829360	411	5	3	9	25,0	0,36	43a	10	13	417	198	0	3	4	4
131	519379	4829485	429	0	5	9	14,0	0,13	43a	10	13	337	31	0	3	0	0
132	519411	4829403	425	0	5	9	16,2	0,28	43a	10	13	183	21	0	3	0	1
133	519380	4829387	396	0	5	9	26,6	0,24	43a	10	13	177	17	0	3	3	4
134	519340	4829333	405	4	3	9	20,4	0,31	43a	10	13	218	70	0	3	0	3
135	519339	4829294	418	9	3	9	33,4	0,52	43a	10	13	470	60	0	4	3	4
136	526650	4821874	261	0	3	1	38,4	0,32	43b	11	12,5	210	186	10	2	4	4
137	526606	4821851	262	0	3	1	37,4	0,32	43b	11	12,5	150	14	10	5	4	4
138	526576	4821872	268	0	3	1	31,0	0,27	43b	11	12,5	116	95	10	0	4	4
139	526404	4822177	295	0	1	7	39,8	0,18	3d	8	0	466	325	10	0	3	3
140	526361	4822231	327	0	1	7	42,0	0,41	3d	8	0	364	251	10	0	0	
141	526296	4822261	337	0	1	7	52,6	0,36	3d	8	0	494	272	10	0	0	0
142	520897	4826157	241	30	3	1	20,8	0,33	47	3	12	361	100	0	6	0	0
143	520884	4826170	231	30	3	1	25,4	0,43	47	3	12	283	178	0	6	0	0
144	520886	4826175	250	30	3	1	0,0	0,34	47	3	12	358	76	0	6	0	0
145	520881	4826221	262	35	3	1	27,6	0,29	47	3	12	212	84	0	6	0	0
146	521018	4826111	244	26	1	1	38,4	0,43	47	3	12	312	185	0	6	3	3
147	521135	4826086	232	25	1	1	24,0	0,46	47	3	12	283	34	0	11	4	4
148	521144	4826052	238	22	2	1	29,8	0,43	47	3	12	226	30	0	11	1	1
149	521164	4826027	240	20	2	1	25,0	0,41	47	3	12	120	70	0	6	3	3
150	521157	4826092	227	19	2	1	25,8	0,36	47	3	12	459	2	0	10	4	4
151	521106	4825659	235	7	1	8	31,5	0,44	47	3	12	176	217	0	3	4	4
152	521204	4825560	222	22	2	8	29,8	0,45	47	3	12	383	103	0	3	3	3
153	521176	4825564	225	30	2	8	26,0	0,47	47	3	12	283	110	0	6	0	0
154	521187	4825538	222	26	2	8	32,8	0,52	47	3	12	191	45	0	3	0	0
155	521332	4825477	195	12	1	8	34,8	0,35	47	3	12	77	81	0	3	4	4
156	521316	4825463	218	32	1	8	27,4	0,38	47	3	12	417	127	0	3	0	0

No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
157	521320	4825453	225	23	1	8	22,2	0,41	47	3	12	181	142	0	3	0	0
158	521298	4825428	230	20	1	8	32,0	0,39	47	3	12	194	149	0	3	0	0
159	521288	4825497	220	30	1	8	13,6	0,34	47	3	12	270	157	0	3	0	0
160	519572	4827902	295	4	1	4	24,8	0,34	21a	6	20	170	6	0	3	5	0
161	519591	4827861	307	3	2	4	24,8	0,40	21a	6	20	94	43	0	10	1	1
162	519628	4827812	336	3	1	4	24,2	0,45	21a	6	20	168	66	0	5	1	1
163	519633	4827800	289	4	1	4	22,2	0,33	21a	6	20	296	134	0	5	0	1
164	519683	4827799	295	2	1	4	19,4	0,42	21a	6	20	324	63	0	3	1	0
165	520139	4827739	294	16	3	4	26,0	0,39	21a	6	20	232	282	0	3	5	0
166	520119	4827781	284	20	3	4	26,6	0,35	21a	6	20	180	111	0	3	2	0
167	520127	4827895	295	21	3	4	37,8	0,27	21a	6	20	130	191	0	3	0	0
168	520118	4827831	302	20	3	4	23,0	0,32	83	5	0	528	150	0	3	0	0
169	525565	4821127	199	14	1	5	25,0	0,48	41a	9	0	188	4	0	4	3	0
170	525520	4821116	193	20	4	5	27,4	0,45	21a	6	20	267	45	0	5	1	1
171	525534	4821107	200	9	4	5	25,7	0,45	21a	6	20	205	6	0	5	3	1
172	525561	4821110	204	12	4	5	21,5	0,44	21a	6	20	67	-47	0	3	0	0
173	525576	4821100	208	15	1	5	22,8	0,48	21a	6	20	55	-39	0	3	3	0
174	525568	4821079	214	19	4	5	25,2	0,41	21a	6	20	219	90	0	3	3	0
175	525538	4821044	218	17	1	5	25,0	0,39	21a	6	20	211	116	0	5	3	1
176	525740	4821226	209	20	4	5	16,0	0,45	21a	6	20	160	-2	0	3	3	0
177	525831	4821306	190	10	1	5	30,4	0,32	21a	6	20	143	190	0	5	3	0
178	526110	4820586	146	19	3	6	17,0	0,42	34b	7	8	295	91	0	3	3	0
179	526051	4820627	162	13	3	6	26,8	0,64	34b	7	8	167	143	0	5	4	1
180	526026	4820646	144	30	3	6	30,3	0,35	34b	7	8	251	-7	0	5	4	1
181	526018	4820613	148	19	2	6	15,7	0,36	34b	7	8	149	112	0	7	3	0
182	525993	4820640	153	21	2	6	11,0	0,65	34b	7	8	123	11	0	7	1	0
183	525969	4820687	165	8	4	6	34,8	0,47	34b	7	8	302	219	0	5	3	1
184	525998	4820721	168	16	4	6	45,6	0,32	34b	7	8	231	57	0	3	3	0
185	525980	4820783	174	0	5	6	68,4	0,15	34b	7	8	681	174	0	3	4	0
186	526003	4820850	183	0	5	6	37,0	0,36	34b	7	8	313	155	0	5	3	1
187	525926	4820832	189	0	5	6	35,6	0,48	34b	7	8	503	102	0	7	4	0
188	525948	4820872	194	14	3	6	24,6	0,42	34b	7	8	321	214	0	4	4	0
189	520892	4826667	365	0	5	2	44,2	0,45	52	4	11	515	84	0	6	1	0
190	520829	4826623	365	0	5	2	31,0	0,38	52	4	11	158	6	0	6	0	0
191	520787	4826617	365	3	3	2	33,8	0,35	52	4	11	123	112	0	2	0	0
192	520768	4826643	366	13	3	2	10,8	0,36	52	4	11	396	-45	0	2	0	0
193	520747	4826649	371	0	5	2	31,4	0,40	52	4	11	281	219	0	2	0	0
194	520733	4826603	360	9	3	2	26,0	0,36	52	4	11	329	156	0	2	0	0
195	520691	4826601	370	5	3	2	24,2	0,50	52	4	11	497	284	0	0	0	0
196	520652	4826610	359	9	3	2	23,0	0,35	52	4	11	271	151	0	2	0	0

No	X (m)	Y (m)	Z (m)	Slope (degrees)	Aspect class (-)	Geology (-)	Soil thickness (cm)	Available moisture (-)	Soil type (Bonfils)	Soil no (-)	C/N (-)	Biomass 2009 (ton/ha)	Biomass change 1984-2008 (ton/ha)	Human_regrowth (-)	Human_general (-)	Human_paths (-)	Human_walls (-)
197	522525	4824346	250	40	2	3	37,3	0,46	21a	6	20	340	86	0	0	4	0
198	522639	4824201	270	19	2	3	33,6	0,24	21a	6	20	155	175	0	0	4	0
199	522659	4824071	275	3	1	3	28,0	0,29	13	1	11	160	88	0	1	4	0
200	522790	4823970	265	7	2	3	34,6	0,33	13	1	11	173	136	0	0	4	0
201	522871	4823887	260	12	2	3	25,3	0,42	13	1	11	67	62	0	0	4	0

Appendix III:
Calculated biomass in 2008



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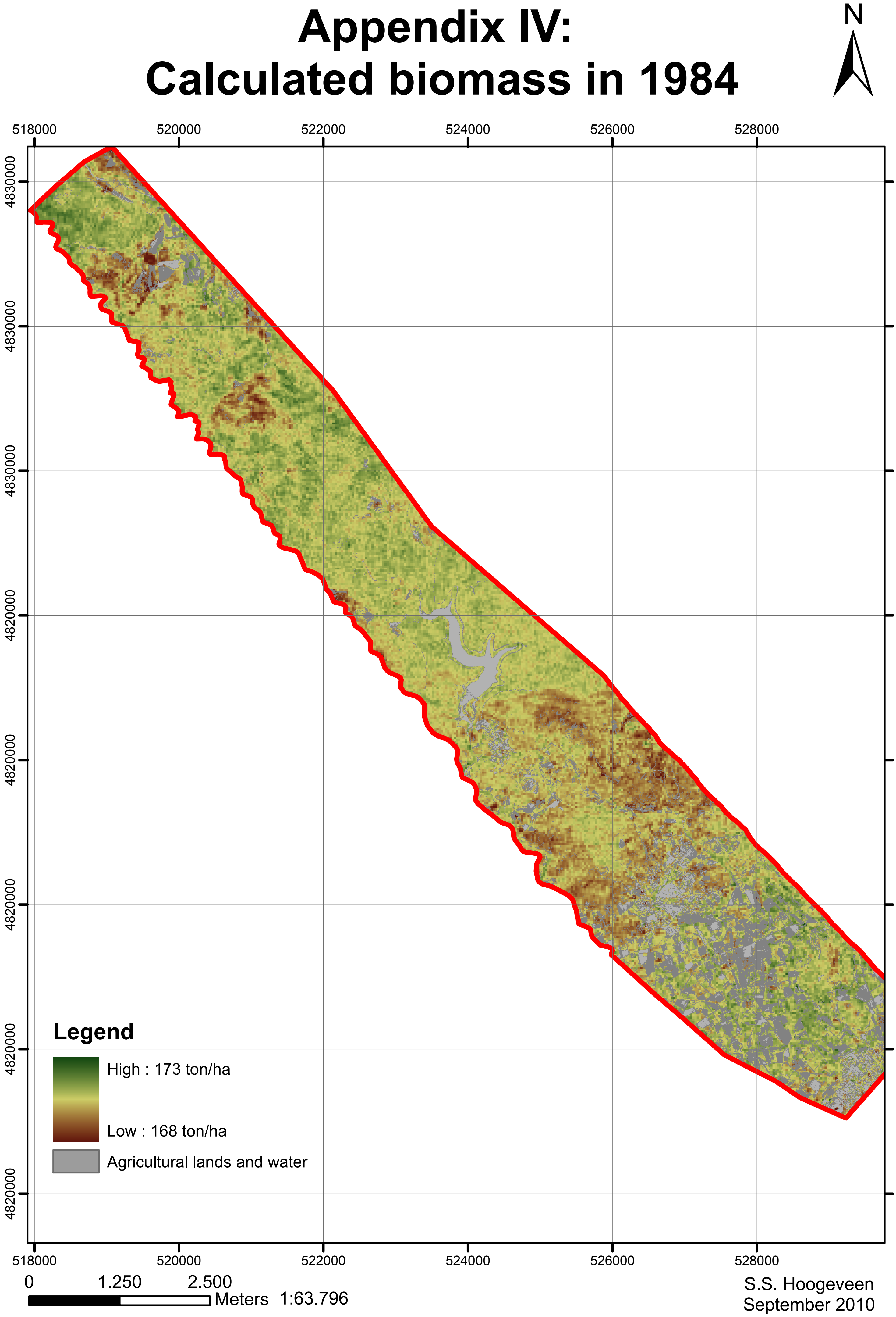
Appendix IV:
Calculated biomass in 1984



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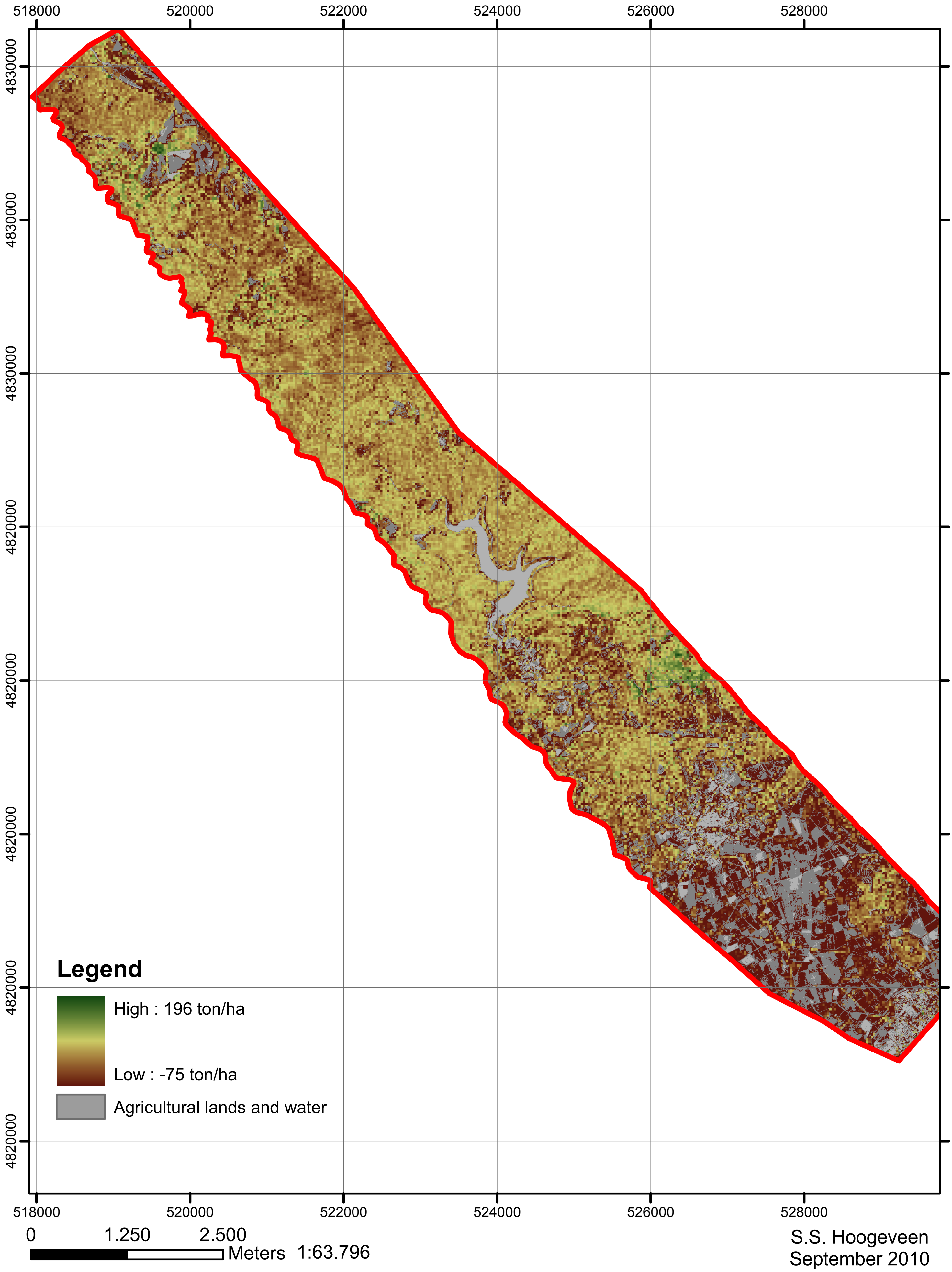
Appendix V:
Calculated biomass change between 1984 and 2008



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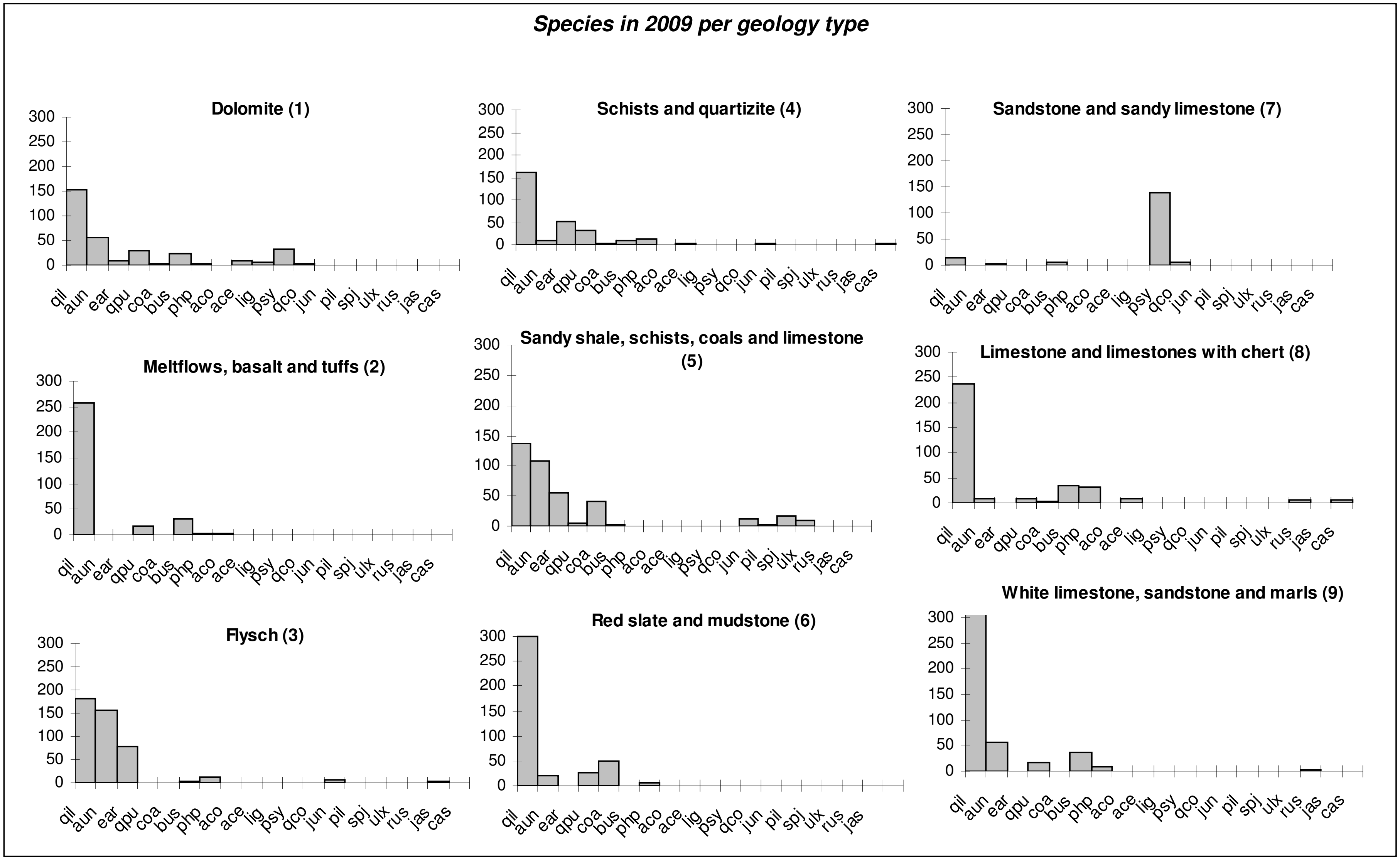
Appendix VI: Species

- **Abbreviation species**

  An overview of the abbreviation of all species are:

Biomass code	Latin name	Common name
Ace	*Acer Monspessulanum*	Montpellier Maple
Aun	*Arbutus unedo*	Strawberry tree
Bus	*Buxus Sempervirens*	Box
Cas	*Castanea sativa*	Sweet chestnut
Coa	*Colutea Arborescens*	Bladder senna
Ear	*Erica arborea*	Tree heath
Jas	*Jasminum fruticans*	Bush jasmine
Jun	*Juniperus communis*	Juniper
Lig	*Ligustrum vulgare*	Privet
Pil	*Pistacia Lentiscus*	Mastic tree
Prp	*Prunus padus*	Bird cherry
Psy	*Pinus sylvestris*	Pine tree
Qco	*Quercus coccifera*	Kermes oak
Qil	*Quercus ilex*	Holm oak
Qpu	*Quercus pubescens*	Downy oak
Rus	*Ruscus aculeatus*	Butcher’s broom
Spj	*Spartium junceum*	Spanish broom
Ulx	*Ulex parviflorus*	Gorse



Species in 2009 per geology type

Species in 2009 per soil type