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ESTIMATION OF VEGETATION CARBON STOCK IN PORTUGAL USING LAND USE / LAND COVER DATA

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ESTIMATION OF VEGETATION CARBON STOCK IN PORTUGAL USING LAND USE / LAND COVER DATA

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ESTIMATION OF VEGETATION CARBON STOCK IN PORTUGAL USING LAND USE / LAND COVER DATA

ABSTRACT

This research aimed to quantify the carbon stored over the years in vegetation throughout Continental Portugal. Carbon stock was measured for the years of 1985, 2000 and 2006. For this, the CORINE (Co-Ordination of Information on the Environment) Land Cover (CLC) database was used to estimate the spatial distribution and quantity of carbon stored by each land cover class. Carbon stock was the result of each CORINE land cover class area multiplied by its respective carbon density. Densities were derived from literature, namely Portuguese Environmental Agency tables. Results show a decrease of carbon stock for the time lapse of both 1985-2000 and 2000-2006. The year 1985 had a total carbon stock of 173.08 Mt, 2000 resulted in a total of 170.22 Mt and finally the year 2006 with 159.97 Mt. Spatial distribution of the carbon stock was also verified as well as the statistics per class. Results show that the gathering of carbon stock records is a key step in monitoring changes in carbon sequestration. By using CORINE land cover as a default database, this methodology may be used by other countries members of the CORINE program and therefore may be easily comparable in between them. In another approach, the COS LULC (*Carta de Ocupação do Solo* or land Use Cartography) was used to compare the impact and effect of scale on carbon stock estimation, represented here by different minimum mapping units (MMU). The COS land cover from the year 1990, with a 1 ha MMU was generalized into 3, 5, 10, 15, 20 and 25 ha as a way to gather information on the effects of scale differences. Results showed a small difference but with certain remarks regarding each study area.

ESTIMATIVA DE *STOCK* DE CARBONO NA VEGETAÇÃO DE PORTUGAL UTILIZANDO DADOS DE USO E OCUPAÇÃO DO SOLO

RESUMO

Esse estudo procurou quantificar o carbono estocado na vegetação de Portugal Continental sobre um período definido de tempo. O *stock* de carbono foi quantificado para os anos de 1985, 2000 e 2006. Para tanto, bases de dados de uso e ocupação de solo do programa CORINE (*co-ordination of Information on the Environment*) foram utilizadas para estimar a quantidade e distribuição espacial de carbono estocado para cada classe de ocupação do solo. O *stock* final de carbono foi o resultado da multiplicação de cada classe do CORINE por sua respectiva densidade de carbono. As densidades foram derivadas de literatura, principalmente de tabelas da Agência Portuguesa do Ambiente. Resultados mostram uma diminuição significativa no *stock* de carbono para ambos os períodos de 1985 a 2000 e de 2000 a 2006. Para o ano de 1985 obteve-se um total de 173,08 Mt, em 2000 um total de 170,22 Mt e em 2006 um total de 159,97 Mt de carbono. A distribuição espacial a longo com estatísticas para todas as classes também foram analisadas. Os resultados mostram que a obtenção de um histórico de *stock* de carbono é essencial para monitorar flutuações em relação ao sequestro de carbono. Por utilizar-se dos dados de ocupação do solo do CORINE, essa metodologia pode ser também usada por outros países membros do programa CORINE e, portanto facilmente usada para comparação entre estes. Em outra investida, a Carta de Ocupação do Solo (COS) de Portugal foi utilizada para comparar o efeito e impacto da escala sobre a estimação de *stock* de carbono, representada como unidade mínima de mapeamento (UMM). A COS90, do ano 1990, com UMM de 1 ha foi generalizada para 3, 5, 10, 15, 20 e 25 ha com o intuito de relatar os efeitos entre as diferentes escalas. Resultados mostram uma pequena diferença, mas com atenções especiais para cada área de estudo.

KEYWORDS

Carbon Stock
CORINE Land Cover
Land Use / Land Cover
Minimum Mapping Unit
Scale

PALAVRAS CHAVES

CORINE Land Cover
Escala
Stock de Carbono
Unidade Mínima Cartográfica
Uso e Ocupação do Solo

ACRONYMS

CA – Combine & Assign

CAOP – *Carta Administrativa Oficial de Portugal* (Portuguese Official Administrative Cartography)

CDM – Clean Development Mechanism

CFC – Chlorofluorocarbon

CLC – CORINE Land Cover

COS – *Carta de Ocupação do Solo de Portugal* (Portuguese Land Use Cartography)

CORINE – Coordination of Information on the Environment

DR – Direct Remote Sensing

EEA – European Environmental Agency

EIT – Economies in Transitions

EU – European Union

GHG – Green House Gases

GIS – Geographical Information System

IGP – *Instituto Geográfico Português* (Portuguese Geography Institute)

IPCC – Intergovernmental Panel on Climate Change

LIDAR – Light Detection and Ranging

LULC – Land Use / Land Cover

LULUCF – Land Use, Land Use Change and Forestry

MMU – Minimum Mapping Unit

NUTS – Nomenclature of Territorial Units for Statistics

OECD – Organization for Economic Co-operation and Development

RADAR – Radio Detection and Ranging

SAR – Synthetic Aperture RADAR

SM – Stratify & Multiply

UNFCCC – United Nations Framework Convention on Climate Change

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1. INTRODUCTION

Global climate is being affected and changed by natural and human activities. The climate change which is resulting from human activities is linked to the emission of greenhouse gases (GHG) into the atmosphere. Gases such as carbon dioxide (CO_2), methane (CH_4) and chlorofluorocarbon (CFC) contribute to global warming. A widely discussed strategy to reduce GHGs, especially $CO_{2,}$ with great potential of success is the use of forests and other vegetation to sequester carbon from the atmosphere (Watson, Zinyowera et al. 1996; Paustian, Cole et al. 1998; Holly, Martin 2007; Valsta, Lippke et al. 2008).

Vegetation, especially forests, are known for accumulating different amounts of carbon, depending on species and its geographic location. The possibility of using vegetation as carbon reservoirs has been identified as a potential measure to mitigate the GHGs effect of global warming. The accumulation of carbon by the vegetation is defined generally as a mean of "Carbon Stock". This stock is present in all living materials, from leafs, to stems, barks, roots and microbial biomass, but is also present in dead material such as litter and organic carbon in the soil (Watson, Zinyowera et al. 1996; Amézquita, Ibrahim et al. 2005; Orrego 2005).

There are currently various methods and models for accounting the carbon stock over vegetation types (Lindner, Karjalainen 2007). Remote sensing and geographic information systems (GIS) provide a link between ground measurements and the ability of spatial distributions and mapping of different features. Remote sensing gives users the ability of identifying objects from airborne and satellite sensors giving users near exact location and dimensions of user defined classes. One example of this is Land Use / Land Cover maps (LULC). GIS in the other hand gives users the tools to capture, store, analyze, manage and present information that is spatially distributed. The contributions of both technologies towards carbon stock estimation in vegetation are very useful. Together they are able to fill in gaps, generalize, estimate and calculate information on carbon stock of geographic features such as different agricultural land uses and forest types. Using this combination it is possible to assess exactly how vegetation is impacting the carbon stock of a determined area. By tracking changes in the growth or decrease of vegetated areas and its type it is possible to determine the increase or decrease of carbon stock (Ruimy, Saugier et al. 1994; Jensen 2000; Franklin 2001; Melesse, Weng et al. 2007; Mäkipää, Lehtonen et al. 2008; Maselli, Chiesi et al. 2008).

1.1 Background

1.1.1 Climate Change

Climate change can be defined as a change in the circulation of weather throughout a specific region or in a global perspective. This change occurs over a period of time that can range from decades to millions of years. In the context of environmental policies, climate change is referred to as a change in modern climate or even used as a synonym to "global warming" (Figure 1). As for the United Nations Framework Convention on Climate Change (UNFCCC), climate change means "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UN 1992).

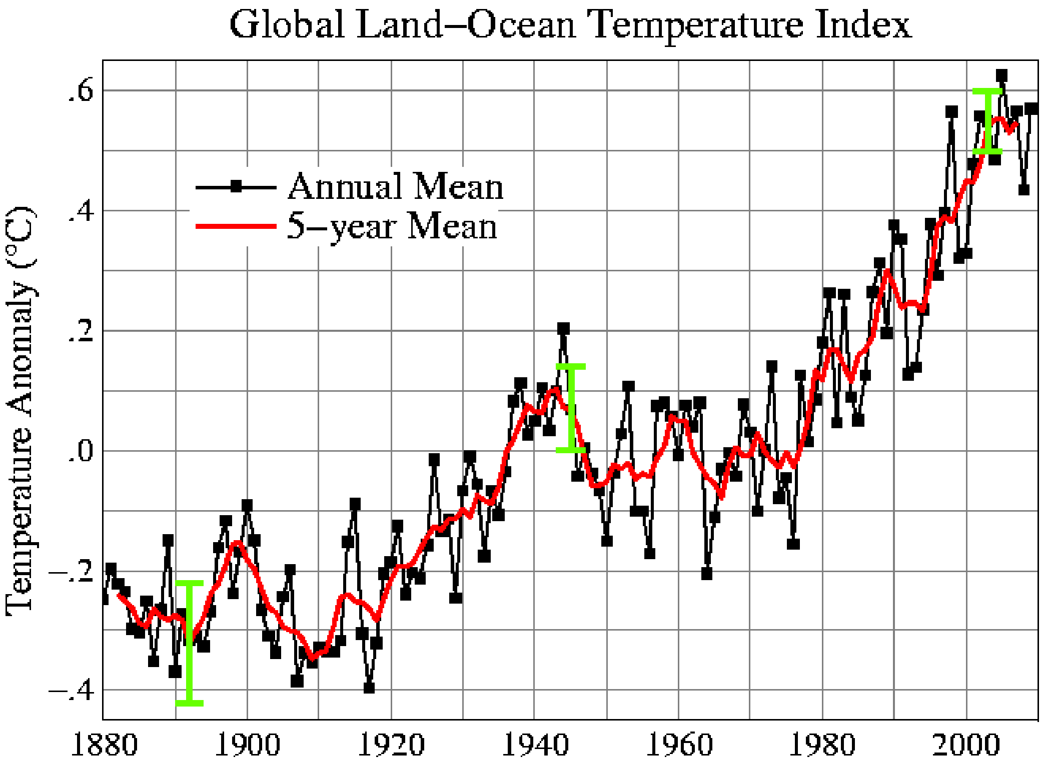


Figure 1: Plot of global annual-mean surface air temperature change derived from the meteorological station network (Source: NASA 2010b)

The factors that influence climate change are often referred to as "climate forcing", which may include solar radiations, changes in Earth's orbit, deformation of Earth’s crust, continental drift and changes in concentration of GHGs. Supposedly, the last one is the only factor where man has any influence, either in benefit or detriment of.

According to many international scientific studies, human activities resulted in substantial global warming from the 20th century onwards. Human induced emissions of GHG continued to grow generating high risks of climate change. Predictions from the Intergovernmental Panel on Climate Change (IPCC) show that an average rise in temperature in a global scale will be of between 1.4ºC and 5.8ºC for the period of 1990 and 2100 (Houghton, Ding et al. 2001).

The relation between carbon and global warming is due to the greenhouse effect that CO_2 naturally has on Earth. The temperature of Earth is the subtraction of the energy coming from the Sun from the energy that is bounced back into outer space. Carbon in the atmosphere acts as a shield to the heat energy bouncing back from Earth and is in fact a benefit because it preserves a balance in the temperature. The problems is that higher concentration of carbon in the atmosphere (Figure 2) is strongly correlated to higher average temperatures in the Earth (Petit, Jouzel et al. 1999).

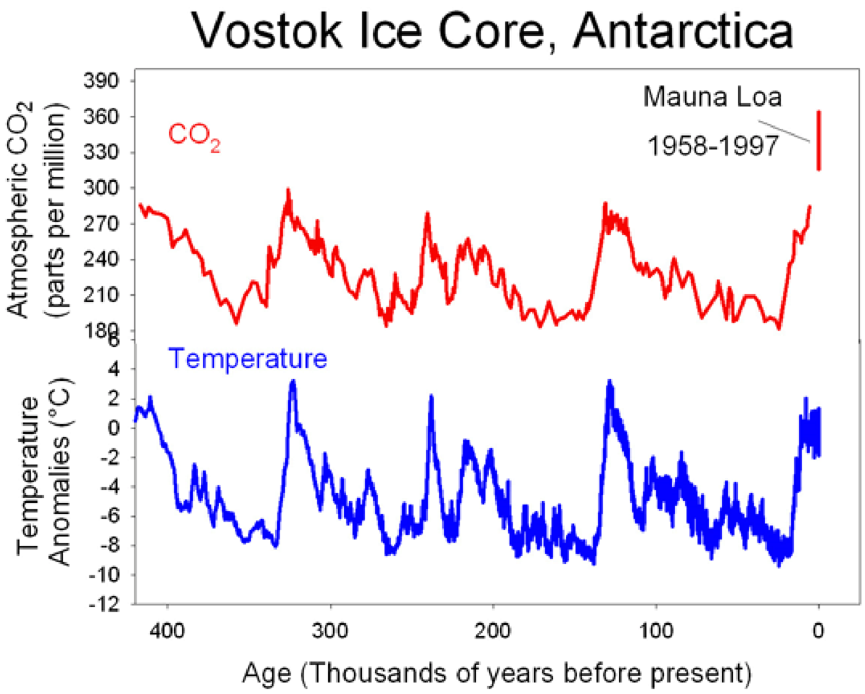


Figure 2: Vostok ice Core reading indicating correlation between temperature and atmospheric concentrations of CO2 (Source: Petit, Jouzel et al. 1999)

1.1.2 Carbon Cycle

This biogeochemical called carbon is found in four major reservoirs or pools which are interconnected in a way to form the cycle. The four major pools of carbon are the atmosphere, ocean, sediments and terrestrial biosphere. Considered as one of the most important cycles on Earth, carbon cycle is an exchange of carbon among the four pools. This cycle permits the carbon element to be recycled and reused by the biosphere (Falkowski, Scholes et al. 2000).

The annual exchange and movement of the element are related to chemical, physical, geological and biological processes. An analysis of the exchanges reveals the incomes and outflows between each pool resulting in a final global carbon budget (Figure 3). A further examination of the budget would inform whether the pool functions as a source or sink for the element. In the biosphere, carbon can be stored for hundreds of years in trees and up to thousands of years in soils making both very important and interesting long term carbon pool. The threat of deforestation and its consequences to the soil make it also one of the major hazards to climate change influenced by man (Schimel 1995).

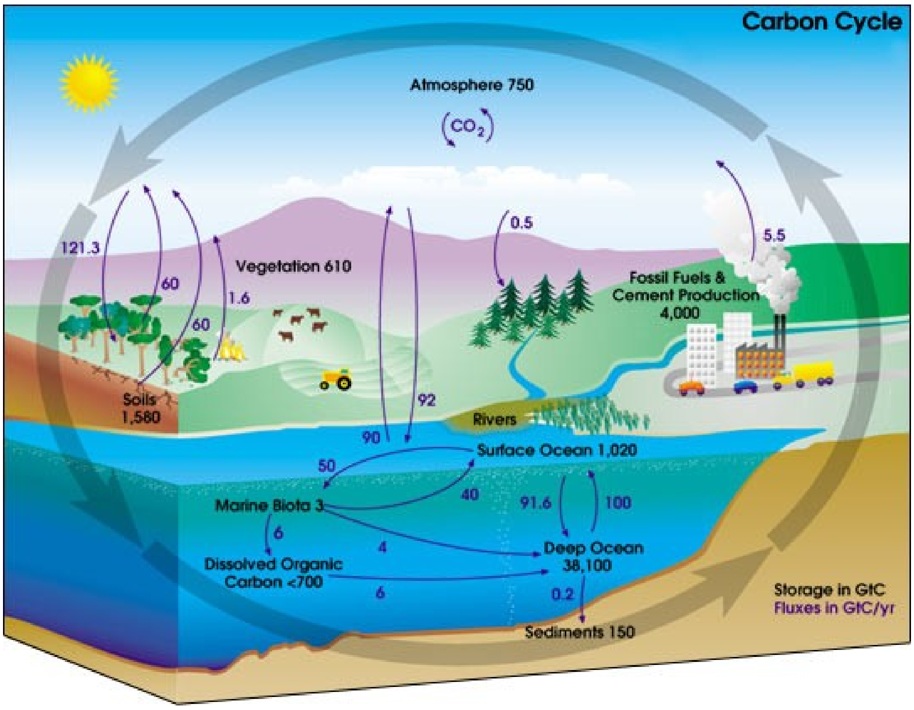


Figure 3: Carbon cycle diagram showing storage and annual exchange of carbon between atmosphere, hydrosphere and geosphere in gigatons of Carbon (Gt) (Source: NASA 2010a)

1.1.3 Kyoto Protocol

In December 11, 1997, during the UNFCCC, a Protocol was adopted aimed at combating global warming. This international treaty, which entered into force on February 16, 2005, had the objective of stabilizing GHG concentrations in the atmosphere in order to prevent hazardous interference with climate system. The Kyoto Protocol is an international agreement that has set a goal that from the year 2008 till 2012 the industrialized countries would reduce their GHG emissions by five percent compared to their 1990 rates. Failure to meet the targeted goal could compel a country to stop some of its industrial production, setting back its economies (Grubb, Vrolijk et al. 1999).

As of November 6, 2009, 189 countries and 1 regional economic integration organization have deposited instruments of ratification, accession, approval or acceptance to the referred Protocol. In a special composition of the Protocol there are 41 industrialized countries identified as "Annex I" countries which committed themselves to the reduction of 5.2% of GHG by the year 2012 – compared to what was produced by them in 1990.

The Annex I is composed of 41 countries that include the industrialized countries that were members of the Organization for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States (UNFCCC 2009).

Each of these countries, which includes Portugal and other European Union (EU) members, are required to submit annual reports accounting inventories of any anthropogenic GHG emission from sources or removals from sinks under the UNFCCC and Kyoto Protocol (UNFCCC 2010).

The Kyoto Protocol gave way to flexible mechanisms such as emission trading, clean development mechanism (CDM) and other implementation strategies which in return allow the Annex I countries to meet their GHG commitments. This allowed states to buy GHG emission reductions credits (also referred to as carbon credits) from other states (Grubb, Vrolijk et al. 1999).

Along the line of thoughts and concepts created by the Kyoto protocol, five principal components are brought to attention. The first as already mentioned is the commitment to reduce the GHG. The second, implementation of policies and measures to reduce the GHGs such as through carbon sequestration. Third, establish adaptation funds for climate change in developing countries through which impacts could be minimized. Fourth, compliance by establishing a committee to enforce agreements and at last the fifth which is to account, report and review to ensure the integrity of the Kyoto Protocol (Freestone, Streck 2007).

The EU has made a joint reduction goal of 8% in relation to its emissions in 1990. For Portugal, this means that it must also reduce its emissions by 8% even though it represented only 0.3% of emissions generated by the total Annex 1 parties in 1990. Under the EU burden sharing agreement Portugal is committed to limiting its emissions during the first commitment period to no more than +27% compared to the 1990 level. The Portuguese National Inventory Report on Greenhouse Gases, 1990-2007 Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol (Pereira, Seabra et al. 2009) has reported that Portugal has emitted 36% more GHG in 2007 than in 1990, without counting Land Use, Land Use Change and Forestry (LULUCF). Remembering that in the first commitment period Portugal was set to limit its emissions by +27% until 2010 and therefore emissions were in 2007 above the target path (Figure 4).

The Portuguese inventory has been continuously revised for the use of more detailed methodologies, better access to underlying data allowing the development of the comprehensiveness of the inventory and better database storage and calculation structure. This endeavor can be seen on various studies, reports, meetings and pilot studies such as the PREK, a pilot study for defining Portugal’s reporting methodology under the UNFCCC and the Kyoto Protocol, in the LULUCF sector (Caetano, Pereira 2008).

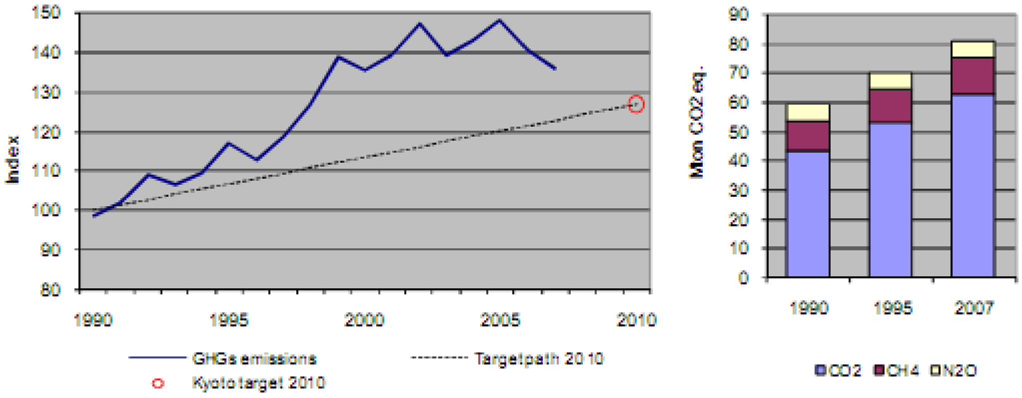


Figure 4: GHG emissions for Portugal without LULUCF (Source: Pereira, Seabra et al. 2009)

1.2 Problem Statement

This study describes an effort to estimate vegetation carbon stock in Continental Portugal using CORINE (Coordination of Information on the Environment) land cover (CLC). These LULC are maps derived from remote sensed images and are characterized by having a minimum mapping unit (MMU) of 25 ha. By means of measuring carbon stock on vegetation cover derived from CLC90 (year 1985), CLC00 (year 2000) and CLC06 (year 2006), and the addition of different vegetation carbon densities gathered in literature, it was possible to produce high-quality estimates of carbon stock for the continental part of the country as well as identify its spatial distribution and carbon change detection.

An interesting approach of this study is the possibility of encouraging the use of CLC for carbon stock estimates to verify international carbon reduction agreements not only by Portugal but also by other countries that develop and use CLC maps.

In addition, COS (*Carta de Ocupação do Solo* or Land Use Cartography) land cover maps from the year 1990 (COS90) were used to detect the effects of the MMU over the quality of carbon stock maps. The thematic COS land cover maps are characterized for having an MMU of 1 ha, which results in a greater definition of objects there represented. By means of generalization, it was possible to transform the COS90 maps into 3, 5, 10, 15, 20 and 25 ha MMU. By doing this, the study retrieved information on the effects of scale, represented here by MMU, on carbon stock estimation.

1.3 Research Questions

This research was considered and implemented in a way to answer the following questions:

1) What are the total carbon stocks of Portugal for the years 1985, 2000 and 2006?
2) What are the statistical differences in each year and to each class?
3) What is the spatial distribution of carbon throughout Portugal?
4) How does the MMU effect carbon stock estimation?

1.4 Objectives

The research undertaken intends to quantify the carbon stocks of Portugal for the years 1990, 2000 and 2006 as well as to consider the effects of MMU in its calculation.

A list of more specific objectives for this study can be listed below:

- Identify optimum carbon density values for each CLC class;
- Assess the carbon stock of Portugal for each of the CLC datasets;
- Analyze results;
- Produce maps of spatial distribution of carbon stock of Portugal; and
- Produce a diverse quantity of maps with diverse values of MMU to analyze its effects on carbon stock.

1.5 Hypotheses

The following hypotheses were formulated prior to this study:

1) Carbon stock has decreased over the years
2) Carbon stocks are concentrated mostly on forested areas and thus the spatial distribution is influenced by the presence of forests
3) Vegetation carbon stock will increase or decrease according to the predominant class in area size when MMU is increased.

1.6 Study Area

The study area for this project is composed of the entire country of Continental Portugal (Figure 5). The study area limits were made according to the *Carta Administrativa Oficial de Portugal* (CAOP – Portuguese Official

Administrative Cartography) and projections, MMUs and scales will follow the CORINE land cover 2006 defaults (Caetano, Nunes et al. 2009; IGP 2009).

For the study of scale effect on carbon stock, portions of the country were chosen across Portugal where different classes could be analyzed. Hence, Nelas, Mora and Castro Verde municipalities were selected for testing (Figure 6).

Portugal is located in the southwest region of Europe on the Iberian Peninsula. Portugal is bordered by the Atlantic Ocean to its west and south and by Spain to its north and east. Makes part of Portugal the Atlantic archipelagos of Azores and Madeira, but these will not be part of this study as it will only describe Continental Portugal.

Continental Portugal is split by its main river, the Tagus. To its North, the landscape is mountainous in the interior with plateaus indented by river valleys. To its South, Portugal features mostly rolling plains and a climate somewhat warmer and drier than in the north. The highest point can be reached in Serra da Estrela, with an altitude of 1,993 m.

Portugal has a Mediterranean climate, *Csa* in the south and *Csb* in the north, according to the Köppen climate classification. Portugal is one of the warmest European countries with the annual average temperature in the continent varying from 13 °C to over 18 °C in some areas. Average rainfall varies from more than 3,000 mm in the mountains in the north to less than 600 mm in southern parts of *Alentejo*.

Portugal has an administrative structure of 308 municipalities, 18 Districts plus two autonomous islands, and 7 regions according to the Nomenclature of Territorial Units for Statistics (NUTS II), being two of them of autonomous administration (Islands of Madeira and Azores).

The city of Nelas is located in the Centro region of Portugal according to NUTS II division. Mora and Castro Verde are located in the Alentejo region, being Castro Verde further south and Mora further north. These three municipalities were chosen because they represent the most important landscape diversity of Continental Portugal. Nelas is represented mostly by forest formations such as coniferous (22%) and mixed species (13%) forests followed by agricultural patches of non irrigated arable land (15%). Mostly all landscape is fragmented with few exceptions. In the other hand, Mora is covered by 51% of its area by broad-leaved forests followed by mixed specieis forest (17%) and non irrigated arable land (10%). The landscape is very continuous throughout most of the area. Castro Verde has 68% of its area covered by non irrigated arable land followed by 13% of broad leaved forests. Again, the landscape is not fragmented, showing much continuity especially for the agricultural and forest lands.

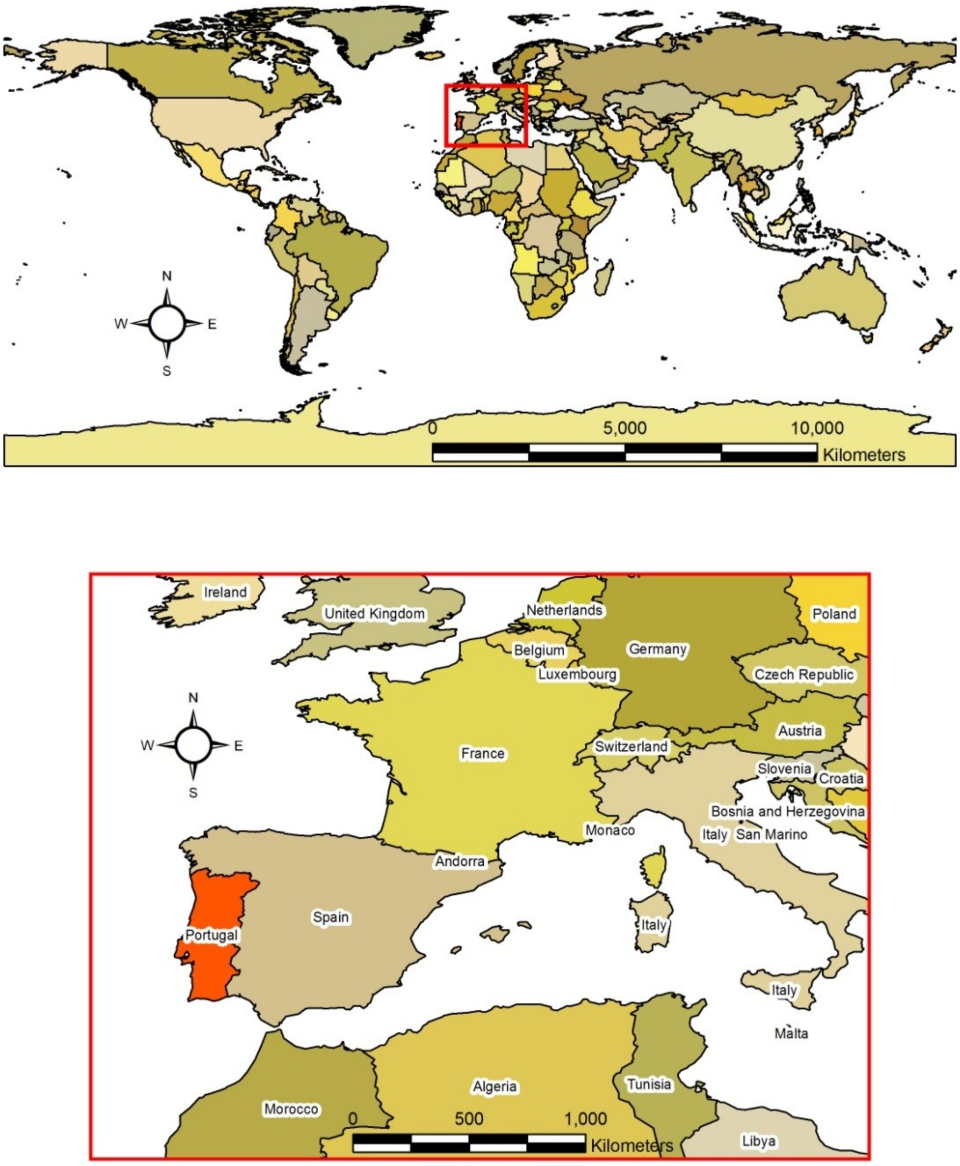


Figure 5: Location of Continental Portugal

Figure 6: Location of the three MMU study areas over Continental Portugal, represented by the CAOP 2009 limits with NUTS II division (Adapted from: IGP 2009)

1.7 Overview of Document

Part one of this thesis tries to bring the reader into the context of the objectives and background of the research undertaken. The significance and review of important facts are offered in a simple summary as a mean and tool to help acquire a general idea of the subject.

On part two a literature review on remote sensing and GIS is structured to provide information on the uses of these tools for carbon stock estimation. Further on, examples of specific studies are explained for the reason that they play a major role in the inspiration of this thesis.

From part three specific methodology and materials are overviewed, explaining details of the values chosen for the carbon stock estimation. Part four will present results and discussion of the research through the use of statistics in graphical form, tables and maps. Finally, a concluding ending will offer a summary of the study and suggest recommendations for future studies and will also address the limitations encountered.

2. REMOTE SENSING AND GIS AS TOOLS FOR CARBON STOCK MONITORING

2.1 Remote Sensing

Remote sensing can be briefly defined as the acquisition of information of an object through the use of sensors that are located away from the object, in a way where no contact is possible. In the field of Earth observation and near Earth observation the term remote sensing usually refers to the use of space or airborne imaging sensors who gather and record reflected or emitted energy for users to process, analyze and apply that information (CCRS 2005).

The sensors can be divided into two categories, passive and active. The passive sensors receive radiation that are reflected or emitted by an object. In the other hand, active sensors provide the radiation needed to reflect from the objects. In passive sensors, the source of radiation is usually the light provided by the sun while in active sensors the most common form of radiation emitted is RADAR (Radio Detection and Ranging). Passive sensors have the capability of collecting and processing radiation from different parts of the electromagnetic spectrum. What this means is that the sensor can process information from the visible part of the spectrum all the way to Infrared, a very important part where information on vegetation can be analyzed (Campbell 2002).

When talking about optical remote sensing, it is important to point out the basic characteristics that may define the best use for that particular sensor. The determining characteristics are usually related to resolution, coverage and costs (Vincent, Saatchi 1999). Resolution of a sensor can yet be broken down into four different types, being them spatial, spectral, radiometric and temporal resolutions. Spatial resolution is the smallest area identifiable in an image which commonly uses the term pixel. Spectral resolution is related to the number of bands that are incorporated in the sensor. Each band corresponds to a specific frequency in the spectrum, enabling to collect information of the visible colors (Red, Green and Blue) and on several infra-red portions, for example. Radiometric resolution is the number of intensities of radiation or energy that a sensor is capable of identifying. Finally, temporal resolution refers to the frequency in which the sensor can come back to a single point over a period of time. Coverage in the other hand refers to how much of the land surface a sensor is capable of registering. And cost refers to the actual economic cost that an operation with a specific sensor may have.

Remote sensing can help provide data and focus on measuring GHG sources and sinks by observing land transformation or, in other words, analyzing change detection (Melesse, Weng et al. 2007). It shows to be a perfect tool for environmental monitoring and therefore also for vegetation carbon stock monitoring.

Not only are satellite sensors different in resolution, coverage and cost but there are also different methods and techniques for measuring vegetation carbon stock and sequestration. These differences between them may vary in time labor, techniques, need of special software and especially in investment. Although remote sensing looks promising, some complications are naturally observed. Cloud cover for instance is sometimes presents year-round and impossible to overcome for optical remote sensing. Flooding also imposes difficulties when trying to measure vegetation carbon stock. Selective logging and forest diversity is another crucial discussion when a land classification is considered. The removal of specific species may imply differences in total carbon stored but may not imply on a distinct change in an image pixel value. As for forest diversity, methods for quantifying carbon in a forest with single species is significantly different from a mixed species forest (Vincent, Saatchi 1999).

According to Goetz et al. (2009) there are four approaches to mapping carbon stocks from satellite observations, (i) Synthetic Aperture Radar (SAR), (ii) Light Detection and Ranging (LIDAR), (iii) Optical and (iv) Multi Sensor. All of these rely on calibration of the sensored measurements with estimates from ground-field study sites. The field measurements are usually allometric relations between stem diameter, density and canopy height.

When applying sensor measurements directly to maps together with calibration from field estimates, statistical techniques, neural networks or regression trees a Direct Remote Sensing (DR) approach is achieved. It is basically an approach where a set of field measurements "train" algorithms to produce a set of rules which in the end produce maps with continuous values. A more simple approach called Stratify & Multiply (SM) derives carbon stock maps from an assigned range of carbon density values and a LULC map. The thematic maps are originally remote sensed images that are classified and placed into categories such as different kinds of forests, grasslands, bare soil and so on. The range of carbon density values is gathered in literature or in field observations for local projects. The LULC classes are multiplied by its respective carbon density to estimate total carbon stock. This approach may be limited by the number of classes and definition of each class but shows an easy and fast way of estimation.

The last approach is defined as Combine & Assign (CA) and is considered as an extension of the last one. The difference is that essentially this approach makes use of further data sets and spatial information to make better estimates. For example, with the help of GIS, data sets with meteorological and soil information may be added to weigh the original carbon density values.

2.2 Land Use /Land Cover

Although they are used sometimes with the same meaning, land cover and land use are actually different from one another. Land cover refers to the surface cover found at a specific location on the ground, being it some vegetation, soil, or urban area. Land use in the other hand refers to the function that the land serves for, being it a recreation area, park, agriculture, and so on.

It is interesting to identify and map land cover for its importance in monitoring studies in a wide field of activities. When a set of land cover maps are available in a time series, it is possible to make temporal analysis. A comparison of land cover maps is referred to as land cover change detection.

LULC change is widely considered as one of the factor concerning the cycle of carbon. It is a notable influence on concentration of CO_2 in the atmosphere and particularly on the concentration of other forms of carbon on the biosphere. IPCC estimates that LULC change can contribute up to 1.6 ± 0.8 Gt of carbon per year to the atmosphere in a global perspective. Also, from 1850 to 1998 about 136 ± 55 Gt of carbon have been emitted as a result of LULC change. One major source of this is through the conversion of forests into other land classes (IPCC 2000).

According to the Kyoto commitment, the so called Annex I parties have the need to account for changes in carbon stocks in LULUCF. It is mandatory to account for changes resulting from afforestation and reforestation but voluntary for emissions from forest management, cropland management, grazing, grazing land management and revegetation (UNFCCC 2006).

LULC maps derived from remote sensed images are of great potential for studies such as the one presented in this thesis. The fact that there are several LULC projects and programs around the world and at different levels of coverage make of this tool or data an interesting approach to diverse environmental studies. There are LULC programs that are specific to local actions but there are also programs that are nationwide or even have global coverage. A good example of a well defined and concrete program is the CORINE land cover program from the European Commission. It proves to be of great interest for this study since it embraces the country of Portugal in three distinctive years. More information on the CLC can be found on section 3.1.1.

2.3 Geographic Information Systems

GIS can be defined as a complex system or science that grips large quantity of spatial information. The "geographic" implies that the information is geographically located and therefore is georeferenced. As for the "Information System" it implies that all information is contained in a database that can be accessed by the user for needs such as to analyze, model or edit the spatial phenomena or objects there contained. Goodchild (1988) also remarks that GIS is an "integrated computer system for input, storage, analysis, and output of geographically referenced information". Its content is a system containing geographically referenced information for the purpose of spatial decision making.

GIS have applications in a variety of professional fields. It can contribute not only to specific fields such as management, science, marketing and logistics but can also link various other fields such as archaeology, environmental impact assessments, agriculture, meteorology urban planning, forestry and so on to its geographical principals. GIS can aid researcher in problem solving when geographic interpretation is needed.

The basic components in a GIS according to Chrisman (1997) are space, time and attribute, which can be interpreted in a more common knowledge as a place where a phenomena happened, when it happened and what happened or what it characterizes.

Another very important component of GIS is scale. When we represent the real world in piece of paper or on a computerized map, scale is always an important factor for visualization and storage but also a strong tradeoff between the spatial resolution and the amount of information detailed and contained as an attribute (Longley, Goodchild et al. 2005).

2.3.1 Scale

The aspect of scale is known to be central to geography. It states the ratio between a drawn object and the object in real life or a distance on a map and distance in real life. In Goodchild (2001) the author makes a fine review of the meaning of scale, especially in today’s digital world. Terms such as levels of spatial detail, representative fraction, spatial extent and ratios are also reviewed.

Scale provides one of the main characteristics of geographic data which relates to spatial attributes such as form, process, and dimension. The term scale may include different aspects including spatial, temporal and spatio-temporal. The best scale is always dependent on the study objectives, the type of environment and the kind of information desired. Operational scale is described as the spatial extent of the operation of an observable object or phenomena. This is associated, but not equivalent, to the concept of the MMU, which is the smallest size object represented in a map (Lam, Quattrochi 1992).

A MMU can be defined as the “smallest size areal entity to be mapped as a discrete entity” (Lillesand, Kiefer et al. 2003) or as the “smallest polygon which a cartographer is willing to map” (Quattrochi, Goodchild 1997). It is an important figure in studies since it allows reducing the complexity of information on a map when this information is of little or no interest for the purpose of the development of the map. MMU can reduce salt and pepper effect and increase accuracy of remote sensed data.

Effects of MMU on land cover have been widely studied due to its importance in mapping costs. In Saura (2002) it is pointed out MMU have to be considered a key issue when dealing with land cover maps. Knight and Lunetta (2003) made an experimental assessment of MMU sizes. Using a classification based on multidate mosaics of ETM+ 30m and SPOT-4 20m multispectral data (resized to 15m), the authors aimed to seek the objective of determining the effect of MMU on accuracy estimates for the classification.

Results indicated that larger MMU significantly affected accuracy estimates of the classification. When using MMU of 6.4 ha, accuracy seemed to be statistically as good as when using MMU of 1.6. The study provides “exceptional information on the flexibility to choose from a range of MMUs that can provide similar accuracy estimates”.

Carrão, Caetano (2002) approached a study with the objectives of evaluating if “metrics that capture landscape pattern are independent of variation in spatial data and if they are sensitive to changes in landscape pattern.” Their study was considered to be of enormous interest since it could show the sensitivity of landscape metrics to scale and in the case of insensitivity, different regions mapped with different resolutions could be compared. Also, remote sensing data at a smaller resolution could be used more often for the production of maps for landscape analysis. Using MapGen (Carrão, Henriques et al. 2001), the COS90 land cover of Portugal was generalized from its original 1 ha MMU to 3, 5, 10, 15, 20 and 25 ha. The landscape metrics analyzed were richness, diversity, dominance, contagion, fractal dimension, large patch index, patch density and edge density. The study results showed that richness, diversity, edge density and large patch index metrics illustrate related performance of covariance at different MMU. The first three had negative covariance meaning that an increase in MMU causes decrease in their values as for the last it is the opposite. The rest of the metrics presented low covariance values which show that the MMU does not explain the changes occurred. Statistical models pointed to a significant effect of MMU over metric values and that their computation for landscapes with different and small MMU could not be compared.

2.4 Vegetation Carbon Stock Studies

Science has come a long way on carbon stock monitoring and modeling. A diverse quantities of studies have been published around the world referring to accounting vegetation carbon stock on specific areas, projects, nations or even globally.

According to Ravindranath and Ostwald (2008) “Carbon stock inventory involves the estimation of stocks and fluxes of carbon from different land use systems in a given area over a given period and under a given management system”. For the IPCC (2006), there are two distinguishing methods for carbon inventory, the first being “Gain-Loss” and the second “Stock-

Difference". Usually, carbon inventory is expressed as metric tons of CO_2 emission or removal per hectare per year but it can also be expressed as changes in carbon stocks in metric tons of carbon per hectare over a defined period of time. Also important to define is the difference between net carbon "emission" and "removal". The first indicates the amount of CO_2 or C lost from biomass and soil to the atmosphere by means of decomposition or combustion. The second refers to the opposite where CO_2 or C is removed or sequestrated from the atmosphere and stored in biomass and soil.

There are currently several programs that require carbon inventory each one with specific methods and guidelines to follow. It is becoming common to require carbon inventory for projects that result in interventions such as land use change, extraction of biomass, afforestation, deforestation or even soil disturbance. Some of the most known programs that require carbon inventory today either at a project level or national are the National Greenhouse Gas Inventory, Climate Change Mitigation Projects or Programmes, Clean Development Mechanism Projects, Projects Under the Global Environment Facility and Carbon Inventory for Forests, Grassland and Agroforestry Development Projects (UN 1992; IPCC 2006; UNFCCC 2006; GEF 2009).

When referring to approaches to estimate carbon stocks, three methods come to mind, (i) use of default values, (ii) cross-sectional field study and (iii) modeling. Default values are values that have come from different literature reviews, databases or other studies from similar environments. When default values are not ideal or not at all available, researchers have to rely on the generation of their own data through field and laboratory analyses. This method is referred to as cross-sectional field study. Modeling is a method used usually to make projections of future carbon stocks through the use of data acquired through a defined period of time. Therefore, models require both carbon stock estimates and rates of change (Ravindranath, Ostwald 2008).

Studies such as Moraes et al. (1998), San José et al. (2009) and Chaozong et al. (2005) have used LULC maps and carbon densities with SM and CA approaches to show total carbon stock in different areas around the world. Other studies such as De Paula and Pereira Filho (2009), Garbulsky et al. (2008) and many others, relied on an DR approach where vegetation indices derived from remotely sensed imagery were used together with ground truth data to estimate carbon stock. Strategies to account for carbon stock and change detection using LULC maps and average vegetation carbon density look promising in situations where LULC maps are widely available, especially if an national inventory is the demand.

In Moraes et al. (1998) carbon densities were introduced as attributes to land cover classes. The study was based on a specific area in the Brazilian Amazon in the state of Rondonia. Total carbon stock was calculated using estimates of above ground biomass, soil carbon stocks and changes due to land exploitation.

Land cover maps were produced from Landsat thematic mapper images acquired on July 7th 1991. The classes used were forests, pastures with more than five years, pastures between three and five years of age, pastures with less than three years, rural residential, water, and road.

Values used to estimate carbon stock came from a diverse literature review on local studies. Aboveground carbon density used values of 158 t C ha^{-1}. Burning coefficient was estimated to be 46%. Belowground carbon density was estimated to be 28 t C ha^{-1}. Decay of unburnt biomass was estimated to be 20.9%. Pasture growth per year was estimated to be 6.4 t ha^{-1} while its combustion efficiency of 94%. Soil carbon was found to lose carbon derived from forest after deforestation and gain carbon after pastures establishment. From zero to three, three to five and five to twenty years after deforestation, the soil would lose 0.5, 0.3 and 0.7 kg cm^{-2} respectively. After the establishment of a pasture land the soil would gain carbon at a rate of 0.7, 0.4 and 1.2 kg cm^{-2} between the years zero and three, three and five and five to twenty, respectively. Results showed that carbon stored in untouched forests was of 220 t C ha^{-1}.

In Chaozong et al. (2005) a study was conducted in northeast China to account for carbon stock in forest regions. A CA approach was undertaken where a LULC map was made from vegetation indices and later on had landforms and climate conditions data added in a GIS environment to multiply with biomass density estimations. The final product was an effective estimate of forest biomass and carbon stock based on LULC maps, supplementary data and biomass density which resulted in identical estimates from other researches.

A special attention is given to Cruickshank et al. (2000), a study on the application of CLC and carbon stock estimation done for the country of Ireland. The main objective was to make in initial inventory of land cover carbon stock for the year of 1990 using a similar strategy to the one to be used in this current study.

The authors used an SM approach where carbon densities for each land cover type were derived from specific studies. Each density was calculated using information found on previous studies related to the land cover class and its national carbon density equivalent. All classes found In Ireland were attributed a value as long as some vegetation was present. Special attention was given to the fact that values of density were only considered for stems, branches, foliage and roots, therefore not including litter, microbial biomass and organic carbon found on the soil. Details on densities and processes undertaken to retrieve values for this study can be found in the Appendix 1 along with Table 7.

Carbon density for each of these land cover classes were multiplied by the area calculated and stored on the feature attribute table. Results showed that Ireland as a whole contains 23.08 Mt of carbon.

The authors pointed out that many improvements could be made towards the estimation of carbon densities for each class. Special attention was given to the improvement of national and local inventories, not having therefore to rely on estimate values from other countries, default values or derived values from other classes.

Not only the density values were noted to be improved but also the basis of this study which is the CORINE land cover. It is stated that the land cover may be underestimating certain classes that could make the total carbon stock even greater. This is the case of forest areas, which on CORINE land cover are only represented if greater than 25 ha.

Also mentioned is the possibility of adoption of this strategy by other European CORINE land cover participants. The approach used in this study could also be adopted by others for the demands of the UNFCCC. Although a standard approach to land cover mapping already exists, a standardized method for calculating the carbon densities is still required and should be treated soon as an important step.

2.5 Conclusions

The use of products such as LULC maps for vegetation carbon stock estimation seems to be of great value. If LULC maps already exist and are made with a defined periodicity, it is interesting to use this resource for more studies and give it more value than it already has. In the case of the CORINE land cover project, it shows to be an invaluable resource for all European Community with very organized methodologies and great potential to serve for further studies.

3. MATERIALS AND METHODS

3.1 Materials

Materials used in this study are composed of commercial software such as ArcGIS 9.3, institution developed software such as MapGen (for generalization) and thematic LULC maps from both CORINE and COS land cover projects.

3.1.1 Data

For step one in this study, the thematic LULC maps used are from the CORINE land cover project, which is part of the CORINE program "intended to provide consistent localized geographical information on the land cover for Member States of the European Community" (EC 1992).

The program was found necessary because it counts as an essential part for the management of the environment and natural resources. At a community level, the CLC is directly useful for determining and implementing environmental policies and can be used combined with other data (e.g. carbon density) to make other complex assessments (e.g. mapping carbon stock) (EC 1992).

For the period of 1985 till 1990, the European Commission put into practice the Corine Programme. Throughout this attempt an information system on the state of the environment was created along with methodologies. The CLC was born originally for the 12 participating countries but has now grown to 38, as seen on Figure 7 (EEA 2007).

The CLC maps use a scale of 1:100.000, MMU of 25 hectares and minimum width of linear elements of 100 meters (Table 1). CLC mapping represents a trade-off between production costs and level of detail of land cover information (Heymann, Steenmans et al. 1994).

The CLC nomenclature is made up of 44 land cover classes grouped in a three-level hierarchy. This nomenclature is standard in all maps, for all countries, although over the years elements have been improved.

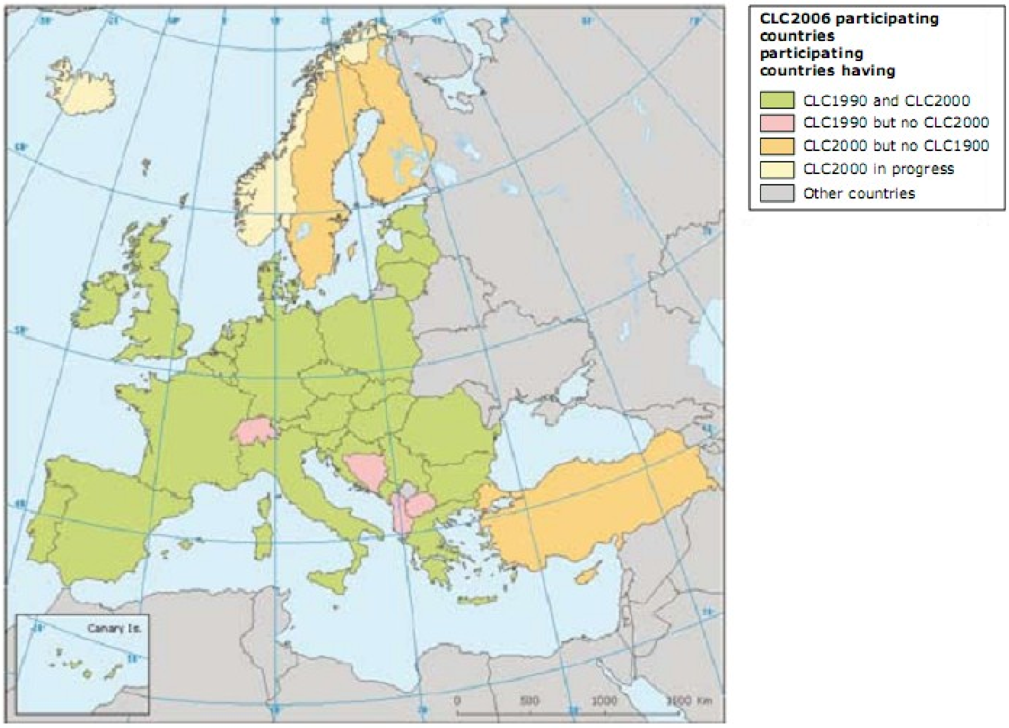
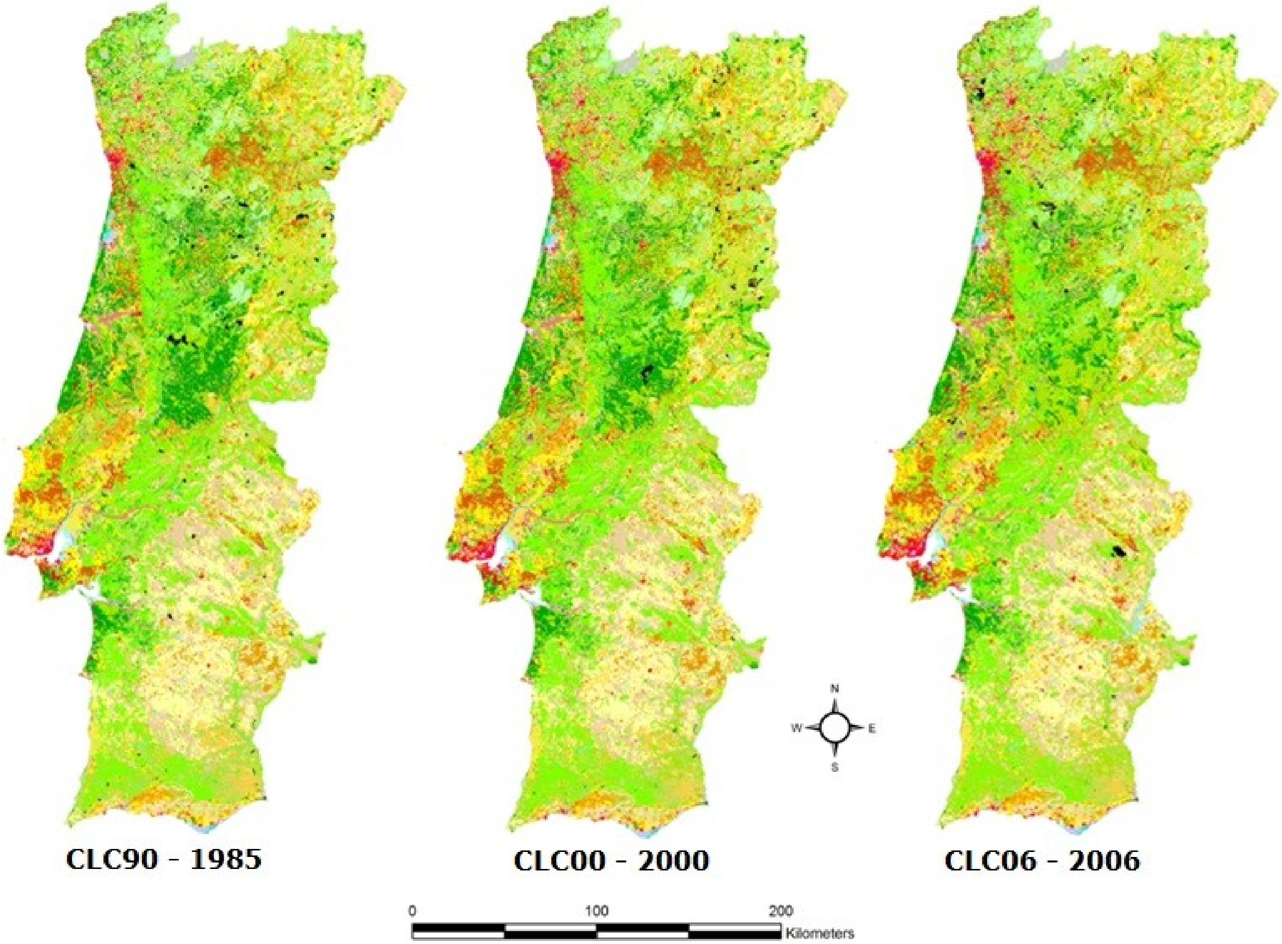


Figure 7: CLC participating countries (Source: EEA 2007)

	CLC1990 Specifications	**CLC2000 Specifications**	**CLC2006 Specifications**
Satellite data	Landsat-4/5 TM single date (in a few cases Landsat MSS, as well)	Landsat-7 ETM single date	SPOT-4 and/or IRS LISS III two dates
Time consistency	1986–1998	2000 +/− 1 year	2006+/− 1 year
Geometric accuracy satellite images	≤ 50 m	≤ 25 m	≤ 25 m
CLC minimum mapping unit	25 ha	25 ha	25 ha
Geometric accuracy of CLC data	100 m	better than 100 m	better than 100 m
Thematic accuracy	≥ 85 % (not validated)	≥ 85 % (validated, see Büttner, G., Maucha, G., 2006)	≥ 85 %
Change mapping	N.A.	boundary displacement min. 100 m; change area for existing polygons ≥ 5 ha; isolated changes ≥ 25 ha	boundary displacement min. 100 m; **all** changes > 5 ha have to be mapped
Production time	10 years	4 years	1.5 years
Documentation	incomplete metadata	standard metadata	standard metadata
Access to the data	unclear dissemination policy	free access	free access
Number of European countries involved	26	32	38

Table 1: Specifications of each CLC map (Source: EEA 2007)

For this research project, the Portuguese CLC maps from the years 1985 (CLC90), 2000 (CLC00) and 2006 (CLC06) were used (Figure 8). The land cover nomenclature applied to this land cover along with a colored legend is listed on Table 2 (Caetano, Nunes et al. 2009).

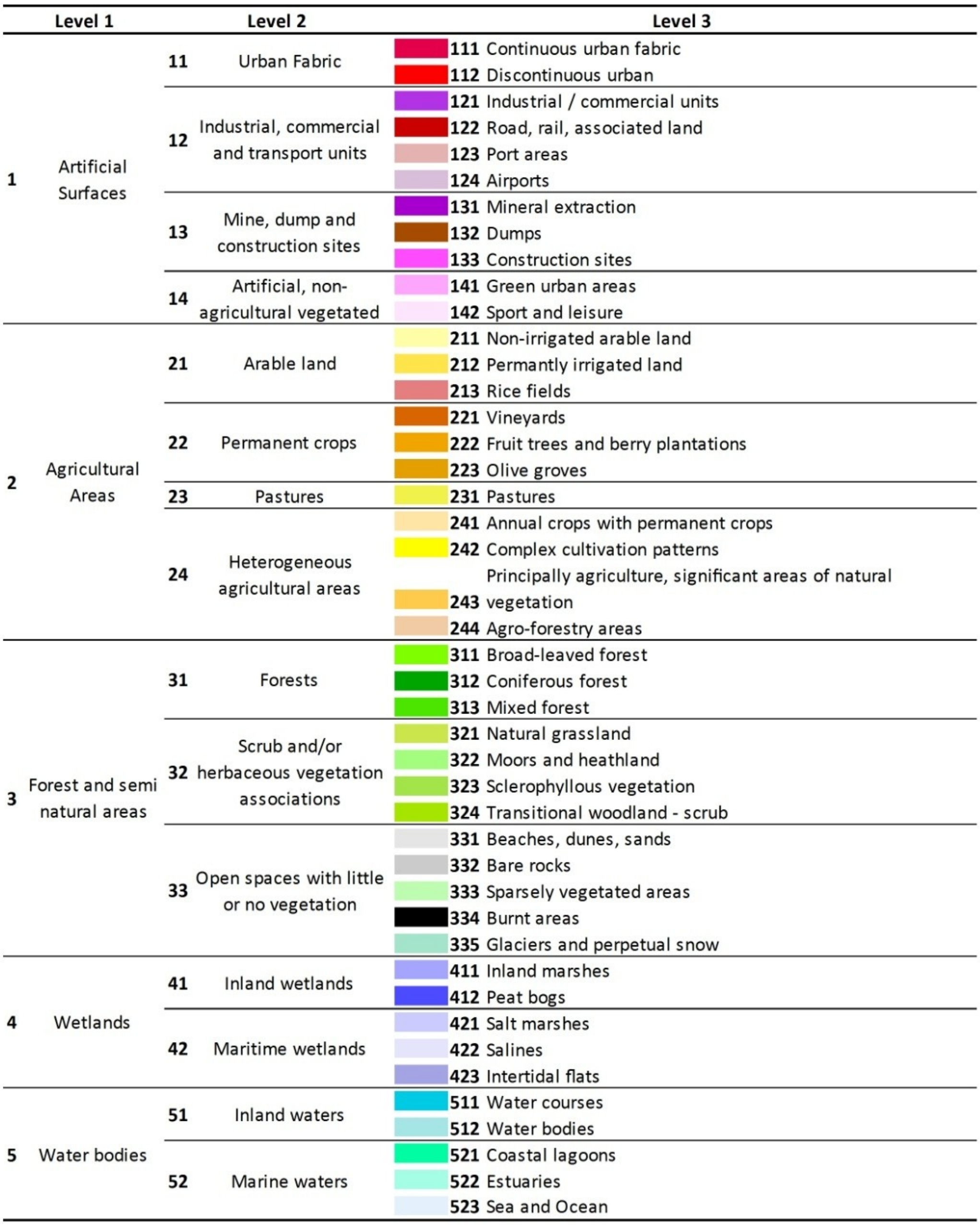


CLC90 - 1985

CLC00 - 2000

CLC06 - 2006

Figure 8: CORINE land cover of Continental Portugal for the years 1985, 2000 and 2006 (Caetano, Nunes et al. 2009)



Level 1		Level 2		Level 3		
1	Artificial Surfaces	11	Urban Fabric	■	111	Continuous urban fabric
				■	112	Discontinuous urban
		12	Industrial, commercial and transport units	■	121	Industrial / commercial units
				■	122	Road, rail, associated land
				■	123	Port areas
				■	124	Airports
		13	Mine, dump and construction sites	■	131	Mineral extraction
				■	132	Dumps
				■	133	Construction sites
		14	Artificial, non-agricultural vegetated	■	141	Green urban areas
				■	142	Sport and leisure
2	Agricultural Areas	21	Arable land	■	211	Non-irrigated arable land
				■	212	Permantly irrigated land
				■	213	Rice fields
		22	Permanent crops	■	221	Vineyards
				■	222	Fruit trees and berry plantations
				■	223	Olive groves
		23	Pastures	■	231	Pastures
		24	Heterogeneous agricultural areas	■	241	Annual crops with permanent crops
				■	242	Complex cultivation patterns
				■	243	Principally agriculture, significant areas of natural vegetation
				■	244	Agro-forestry areas
3	Forest and semi natural areas	31	Forests	■	311	Broad-leaved forest
				■	312	Coniferous forest
				■	313	Mixed forest
		32	Scrub and/or herbaceous vegetation associations	■	321	Natural grassland
				■	322	Moors and heathland
				■	323	Sclerophyllous vegetation
				■	324	Transitional woodland - scrub
		33	Open spaces with little or no vegetation	■	331	Beaches, dunes, sands
				■	332	Bare rocks
				■	333	Sparsely vegetated areas
				■	334	Burnt areas
				■	335	Glaciers and perpetual snow
4	Wetlands	41	Inland wetlands	■	411	Inland marshes
				■	412	Peat bogs
		42	Maritime wetlands	■	421	Salt marshes
				■	422	Salines
				■	423	Intertidal flats
5	Water bodies	51	Inland waters	■	511	Water courses
				■	512	Water bodies
		52	Marine waters	■	521	Coastal lagoons
				■	522	Estuaries
				■	523	Sea and Ocean

Table 2: CORINE Land Cover nomenclature and legend for all CLC maps in this study (Adapted from: EEA 2007)

For the second phase, where the scale effect will be studied, COS land cover maps from the year 1990 (COS90) were addressed. The COS90 project came as a Portuguese endeavor to obtain graphical and quantitative information on LULC for continental Portugal. The resulting product was a composition of 638 vector cartographic sheets with a MMU of 1 ha and nominal scale of 1:25000. The thematic maps in this case were derived from aerial photographs from the year

1990 with the addition of near-infrared composition (Caetano, Pereira et al. 2008).

For comparison reasons the COS90 land cover nomenclature was pre converted into the CORINE land cover nomenclature. The converted vectors were offered by the Portuguese Geography Institute (IGP) as results from a previous project which also offered all generalized shapefiles (Carrão, Caetano 2002). The COS90 land covers, original and already generalized, can be seen on Figure 9, Figure 10 and Figure 11, for Castro Verde, Nelas and Mora, respectively.

Data on vegetation carbon density was provided or adapted from tables found on The Portuguese National Inventory Report on Greenhouse Gases, 1990-2007 (and on the 1990-2004) Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol (Ferreira, Pereira et al. 2006; Pereira, Seabra et al. 2009). For some missing values, the study made in Ireland was chosen as the best source for adapting values (Cruickshank, Tomlinson et al. 2000). Values were noted to be respecting the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC 2003). Also is important to mention that these values of carbon density take into account stems, branches, foliage and roots but do not include litter, microbial biomass and organic carbon found on the soil. In Table 8 of the Appendix 2, a set of information on the description of choice for the carbon density values are presented.

Auxiliary data was used for map fabrication. Administrative divisions and borders were introduced into the study according to the CAOP 2009 official cartography and to the NUTS II divisions. For this, official shapefiles were provided and converted to this studies projection system (IGP 2009).

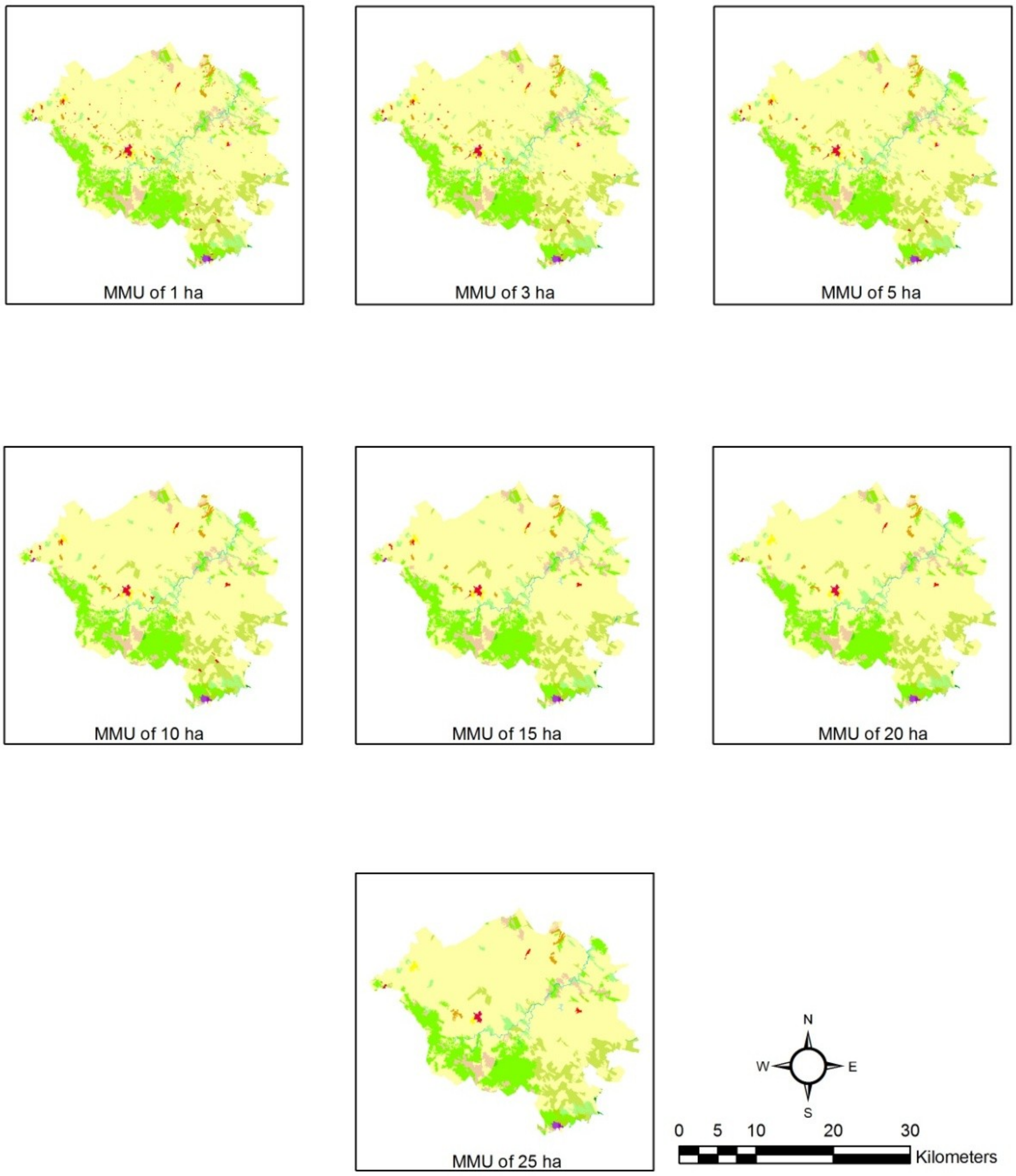


Figure 9: COS90 land cover maps of Castro Verde containing the original 1 ha MMU along with all generalizations up to 25 ha – all reclassified into CLC nomenclature (Adapted from: Carrão, Caetano 2002)

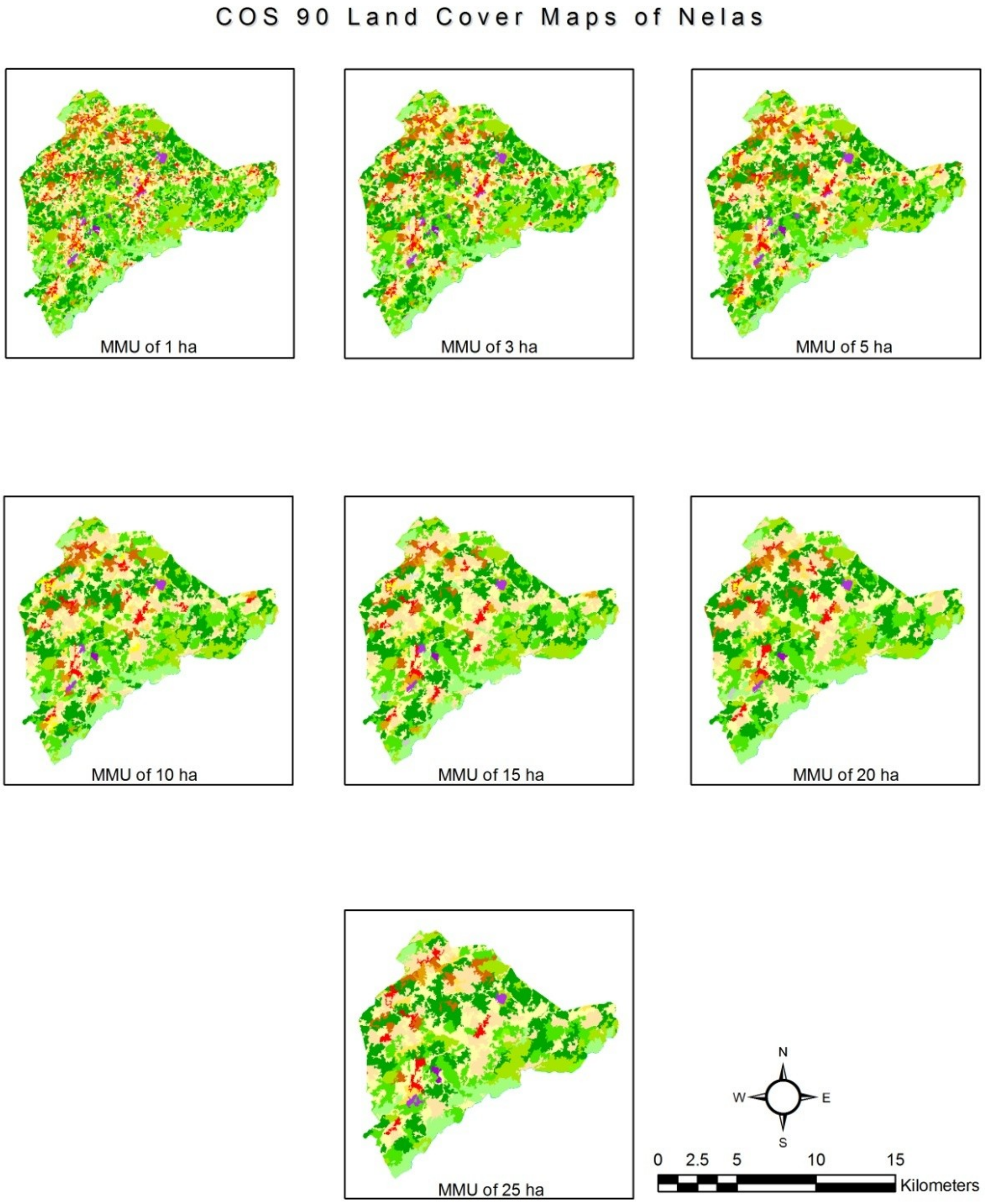


Figure 10: COS90 land cover maps of Nelas containing the original 1 ha MMU along with all generalizations up to 25 ha – all reclassified into CLC nomenclature (Adapted from: Carrão, Caetano 2002)

Figure 11: COS90 land cover maps of Mora containing the original 1 ha MMU along with all generalizations up to 25 ha – all reclassified into CLC nomenclature (Adapted from: Carrão, Caetano 2002)

3.1.2 Software

Specific software was used for visualizing, analyzing and interpreting geographical data. A major role was made by ArcGIS 9.3 but specific steps towards generalizing the COS land cover into different MMU were previously made by MapGen, an institution developed software (Carrão, Henriques et al. 2001).

3.2 Methods

3.2.1 Carbon Stock Estimation Using CORINE Land Cover

In this study, the CLC90 (1985), CLC00 (2000) and CLC06 (2006) thematic maps in vector form provided the basis for the estimation of vegetation carbon stock in Continental Portugal for each of the described years. Each dataset accounts land cover information on location, area and class for each of the respective years studied (Caetano, Nunes et al. 2009). A SM approach was used along with carbon density information (Ferreira, Pereira et al. 2006; Pereira, Seabra et al. 2009) and the auxiliary shapefiles (IGP 2009).

The first steps concerned getting data prepared for all analysis. This meant first of all, converting spatial information into the reference system to be used throughout the study. For this, the projected coordinate system established was the ETRS_1989_Portugal_TM06, same used on the original CLC06 dataset. Projection was established as Transverse Mercator with units in Meters. With all vector files converted to the specified projections and reference system, attention was given out to the carbon density review. Literature was assessed and a final table containing appropriate vegetation carbon density values was created (Table 3). This table was later to be used together with the GIS database and therefore contained an ID named CODE which contained the CLC nomenclature codes composed of three digits along with their respective carbon density values.

Level 3 CLC Nomenclature		Area (ha)			Carbon Density (t ha^{-1})
		CLC90	CLC00	CLC06	
111	Continuous urban fabric	10434	12105	12260	0.00
112	Discontinuous urban	162013	202438	215336	4.71
121	Industrial / commercial units	16727	29920	33912	0.00
122	Road, rail, associated land	568	2256	7679	0.00
123	Port areas	1685	1942	2087	0.00
124	Airports	3861	4216	4303	0.50
131	Mineral extraction	6108	12249	13662	0.00
132	Dumps	333	748	972	0.00
133	Construction sites	3061	5735	6520	0.00
141	Green urban areas	1596	1774	1774	9.42
142	Sport and leisure	5324	9098	11536	9.42
211	Non-irrigated arable land	1091750	1019420	981762	5.00
212	Permantly irrigated land	137244	203811	210529	5.00
213	Rice fields	55245	54401	52825	5.00
221	Vineyards	196575	222741	228989	21.00
222	Fruit trees and berry plantations	95493	100566	100994	21.00
223	Olive groves	271093	262925	263050	21.00
231	Pastures	54414	42104	41875	6.00
241	Annual crops with permanent crops	433479	405798	404030	13.00
242	Complex cultivation patterns	624563	609919	607114	11.52
243	Principally agriculture, significant areas of natural vegetation	736818	700130	686894	11.37
244	Agro-forestry areas	634862	628700	621494	8.22
311	Broad-leaved forest	1059381	1125182	1007057	28.24
312	Coniferous forest	786646	708637	534028	59.48
313	Mixed forest	561518	545361	475573	40.80
321	Natural grassland	185652	176184	171911	6.00
322	Moors and heathland	314570	289488	284612	17.74
323	Sclerophyllous vegetation	264975	225165	206788	17.74
324	Transitional woodland - scrub	896696	1019236	1411524	17.74
331	Beaches, dunes, sands	11865	11831	11830	0.00
332	Bare rocks	23768	23854	23881	0.00
333	Sparsely vegetated areas	99016	100528	100835	3.00
334	Burnt areas	46274	29688	32862	0.00
335	Glaciers and perpetual snow				
411	Inland marshes	1048	1119	1139	1.50
412	Peat bogs				
421	Salt marshes	18712	18509	18459	2.00
422	Salines	7117	7229	7229	0.00
423	Intertidal flats	1775	1775	1993	0.00
511	Water courses	20753	20595	19876	0.00
512	Water bodies	28855	34600	52989	0.00
521	Coastal lagoons	8475	8523	8547	0.00
522	Estuaries	45284	45113	44919	0.00
523	Sea and Ocean	2411448	2411464	2411428	0.00

Table 3: CORINE land cover third level nomenclature and respective area sizes with applied carbon density values (Adapted from: Cruickshank, Tomlinson et al. 2000; Caetano, Nunes et al. 2009; Pereira, Seabra et al. 2009)

The first step of the GIS procedures used each of the CLC maps (CLC90, CLC00 and CLC06) in conjunction with the CAOP_2009 vector file containing the official administrative borders of Portugal. Each CLC was clipped by the CAOP_2009 vector resulting in an exact perimeter for each file, renamed to CLCXX_CAOP, being "XX" the original CLC map. The density table, previously made, was joined with the attribute table of the CLCXX_CAOP so that density values would appear on the vector attributes. Geometry was calculated to find out each polygons exact area in hectares. Now, with the vector file containing density values (t ha^{-1}) and area (ha), a simple multiplication was made on the attribute table resulting in another column with the vegetation carbon stock for that specific feature (in metric tons). Statistical analysis and summaries were made with these resulting values.

A second step in the GIS procedures was accomplished to reveal the vegetation carbon stock spatial distribution. For visualization and calculation purposes, it was decided that the best method was to convert each CLCXX_CAOP map into a grid system of 2500 ha. For this, the Hawths Analysis Tools in ArcGIS environment was applied to create a grid system called CLC_GRID with specific ID for each cell. The CLCXX_CAOP and the CLC_GRID were united using the UNION function of ArcGIS, resulting in a file called CLCXX_CAOP_UNION. This file was later dissolved by the ID of each cell on the grid system with the function of summing the carbon stock attribute of each cell. This procedure resulted in the vegetation carbon stock spatial distribution map for each CLC year map, organized in cells of 2500 ha and named CLCXX_CAOP_DISSOLVE.

A final GIS procedure was undertaken to analyze vegetation carbon stock change detection. In this step each of the dissolved maps was intersected resulting in a final shapefile named CLC_CSCHANGE which contained information on vegetation carbon stock for each study year and each cell. After a field calculator procedure, three new columns were created representing the change over three periods, from 1985 to 2000 (00-85), from 2000 to 2006 (06-00) and from 1985 to 2006 (06-85). This procedure resulted in three maps representing the vegetation carbon stock change detection.

All GIS procedures, divided into the three steps are displayed on a flowchart on Figure 12.

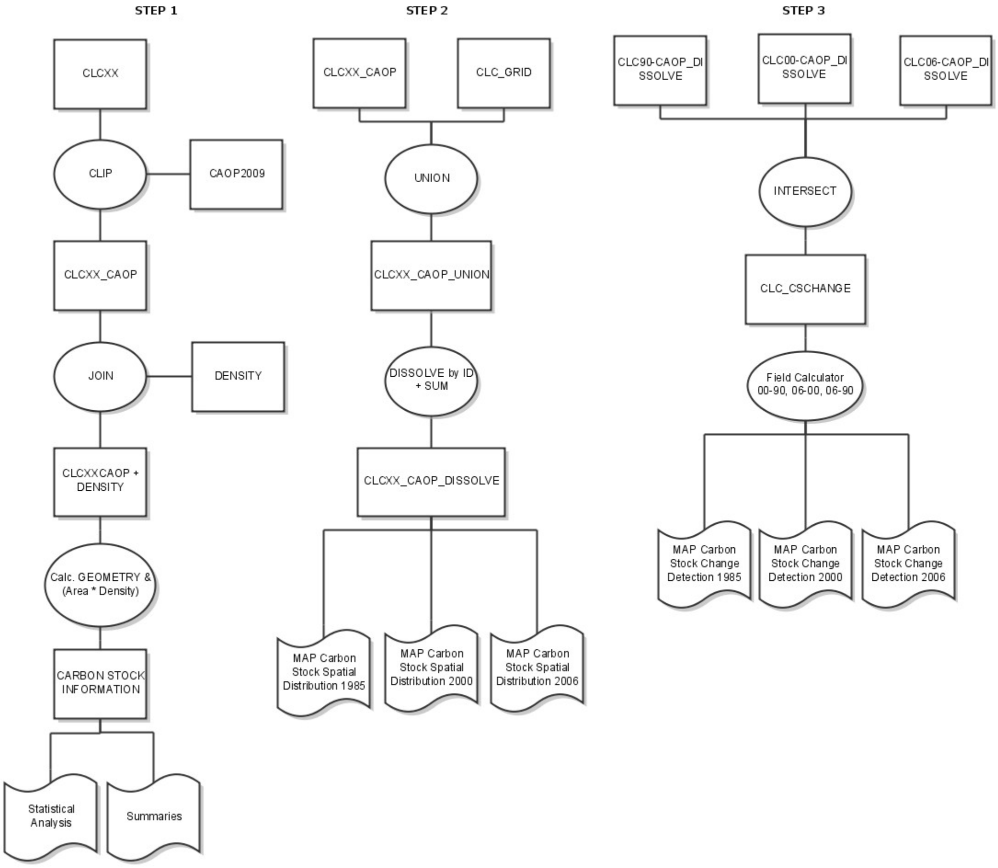


Figure 12: Flowchart of the GIS procedures undertaken

As part of the spatial distribution analysis, an adaptation of the CLC nomenclature was undertaken to help interpret results. For this, a new nomenclature was derived from the CLC third level nomenclature and named "Mega Class". In this procedure, six classes were created and called (i) Artificial Areas, (ii) Agriculture, (iii) Agriculture with Natural Areas, (iv) Forest, (v) Natural Areas and (vi) Water. The adaptation strategy can be found on Table 4. This adapted nomenclature provided a basis for more maps, tables and graphs.

ID	CLC Level 3 Nomenclature	Mega Class
111	Continuous urban fabric	Artificial Area
112	Discontinuous urban	Artificial Area
121	Industrial / commercial units	Artificial Area
122	Road, rail, associated land	Artificial Area
123	Port areas	Artificial Area
124	Airports	Artificial Area
131	Mineral extraction	Artificial Area
132	Dumps	Artificial Area
133	Construction sites	Artificial Area
141	Green urban areas	Artificial Area
142	Sport and leisure	Artificial Area
211	Non-irrigated arable land	Agriculture
212	Permantly irrigated land	Agriculture
213	Rice fields	Agriculture
221	Vineyards	Agriculture
222	Fruit trees and berry plantations	Agriculture
223	Olive groves	Agriculture
231	Pastures	Agriculture
241	Annual crops with permanent crops	Agriculture
242	Complex cultivation patterns	Agriculture
243	Principally agriculture, significant areas of natural vegetation	Agriculture with Natural Area
244	Agro-forestry areas	Agriculture with Natural Area
311	Broad-leaved forest	Forest
312	Coniferous forest	Forest
313	Mixed forest	Forest
321	Natural grassland	Natural Area
322	Moors and heathland	Natural Area
323	Sclerophyllous vegetation	Natural Area
324	Transitional woodland - scrub	Forest
331	Beaches, dunes, sands	Natural Area
332	Bare rocks	Natural Area
333	Sparsely vegetated areas	Natural Area
334	Burnt areas	Natural Area
335	Glaciers and perpetual snow	Natural Area
411	Inland marshes	Natural Area
412	Peat bogs	Natural Area
421	Salt marshes	Natural Area
422	Salines	Natural Area
423	Intertidal flats	Natural Area
511	Water courses	Water
512	Water bodies	Water
521	Coastal lagoons	Water
522	Estuaries	Water
523	Sea and Ocean	Water

Table 4: Adapted Mega Class nomenclature from the CLC third level nomenclature

3.2.2 The Effect of Scale (MMU) On Carbon Stock Estimation

In this study, the COS90 thematic map in vector form provided the basis for the estimation of carbon stock for the study sites. Study sites were chosen across Portugal where different classes could be analyzed. Hence, Nelas, Mora and Castro Verde municipalities were selected for testing. A SM approach was used along with carbon density information (Ferreira, Pereira et al. 2006; Pereira, Seabra et al. 2009).

The COS90 maps for each city were previously generalized from its original MMU of 1 ha into 3, 5, 10, 15, 20 and 25 ha maps. In all, twenty one different maps were made available, seven for each city. The comparison of each map was expected to deliver information on the effects of scale on carbon stock estimation. Generalization was made by MapGen software (Carrão, Henriques et al. 2001). The MapGen application runs on ArcView 3.2 and allows non-expert users to automatically generalize COS90 maps to the CORINE land cover classification scheme using the desired MMU values. The set of rules for the generalization procedures were based on the CORINE land cover technical guide specifications for manual generalization (Heymann, Steenmans et al. 1994). All this previous work was a result from studies undertaken by the IGP Remote Sensing Group (Carrão, Caetano 2002), who also donated this dataset.

The first steps in this study were similar to the previous study. Data was first prepared for analysis which meant converting spatial information into the reference system to be used throughout the study. For this, the projected coordinate system established was the ETRS_1989_Portugal_TM06, same used on the original CLC06 data. Projection was established as Transverse Mercator with units in Meters. Carbon density values used are exactly the same used on the first study.

Each one of the twenty one vector files were named according to its city and the MMU utilized. Therefore, files were named CITY_XX, where "CITY" is the name of the study site and "XX" is the MMU used. The density table, previously made, was joined with the attribute table of each CITY_XX so that density values would appear on the vector attributes. Geometry was calculated to find out each polygons exact area in hectares. Now, with the vector file containing density values (t ha^{-1}) and area (ha), a simple multiplication was made on the attribute table resulting in another column with the vegetation carbon stock (in metric tons) for that specific feature. Statistical analysis and summaries were made with these resulting values. A flowchart with the GIS procedures is presented on Figure 13.

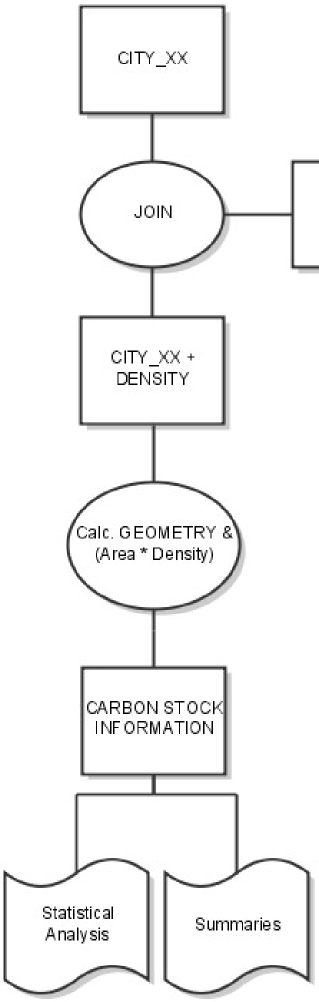


Figure 13: Flowchart of the GIS procedures undertaken

3.3 Summary

This study was designed to first estimate vegetation carbon stock for Continental Portugal using CORINE land cover datasets. Secondly, a different study was undertaken to analyze the effects of different MMUs on vegetation carbon stock estimation in three municipalities of Continental Portugal. For both studies, an SM approach was applied along with specific carbon density values for each identified class in the land cover.

4. RESULTS AND DISCUSSION

4.1 Vegetation Carbon Stock Estimation Using CORINE Land Cover

After pre-processing and preparing all spatial data for the current study projections, the CLC maps were clipped to the CAOP 2009 official administrative division. These maps guaranteed a symmetrical comparison in between maps and also guaranteed official divisions and borders for the study outputs.

The first step in the GIS procedures resulted in land cover maps of vegetation carbon stock. From these maps it was possible to retrieve information on a final summary of vegetation carbon stock in Portugal for the years 1985, 2000 and 2006. Values showed a high decrease of carbon over the years, especially from 2000 to 2006. The year 1985, derived from the CLC90, turned out with a total of 173.08 Mt of carbon. The years 2000 and 2006 resulted in 170.22 Mt and 159.97 Mt of carbon, respectively.

A simple subtraction shows us that for the period of 1985 to 2000, Portugal had a total loss of 2.86 Mt with an average of 0.19 Mt of loss per year. The following period, from 2000 until 2006, although represents less than half the time of the first period had a greater total loss of carbon with values rising up to 10.25 Mt and an average loss of 1.70 Mt per year. In a total, from 1985 up to 2006, Portugal had a total loss of 13.11 Mt of carbon with an average loss of 0.62 Mt per year. In Table 9 of the Appendix 2 it is possible to view total vegetation carbons stock for each CLC class and each year, along with other useful information. A graph with carbon density for each CLC class is presented on Figure 14 as a tool for interpretation. A graphical distribution of vegetation carbon stock and a distribution of area of each CLC class over the three years are presented in Figure 15 and Figure 16, respectively.

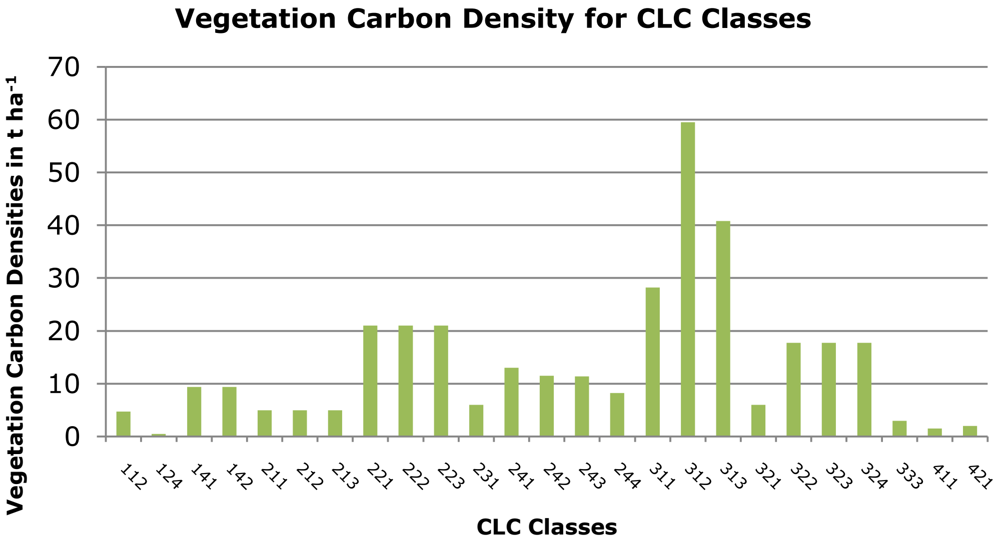


Figure 14: Vegetation carbon density values applied for each CLC class (Adapted from: Cruickshank, Tomlinson et al. 2000; Pereira, Seabra et al. 2009)

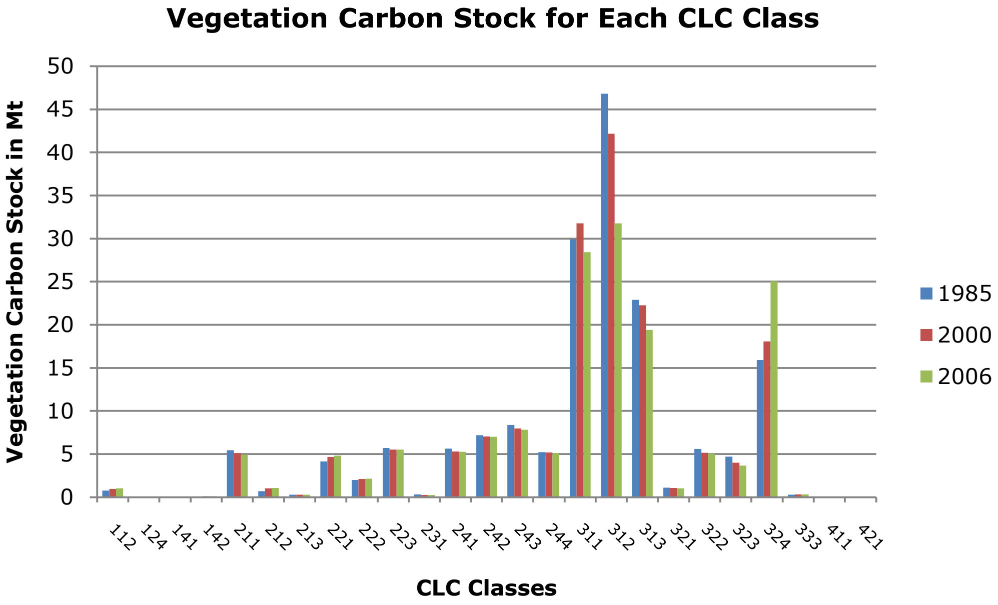


Figure 15: Vegetation carbon stock is represented for each CLC class with carbon density values ≠ 0

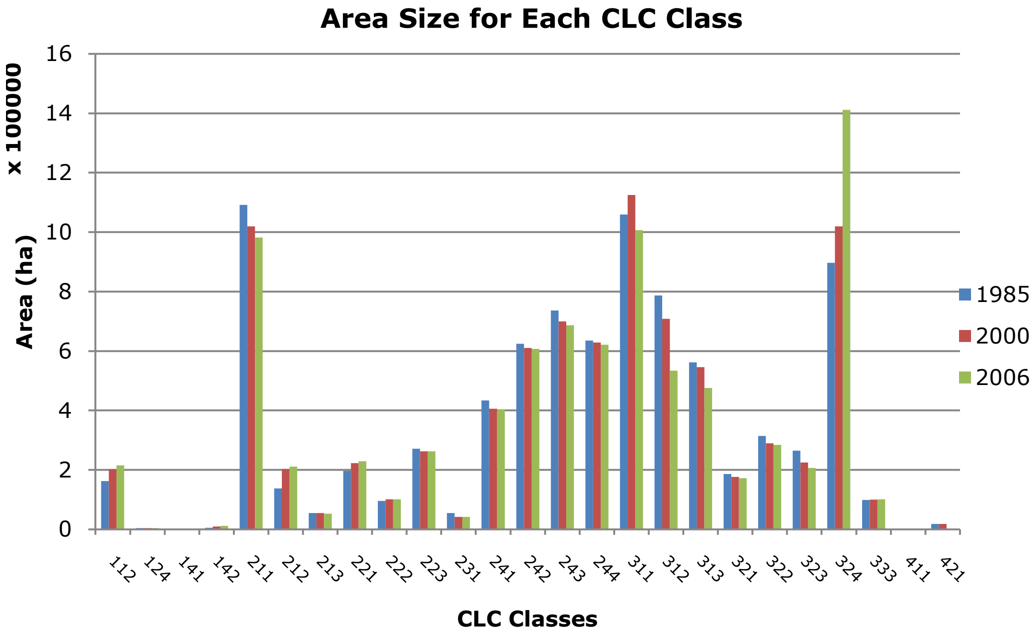


Figure 16: Corresponding area size for each CLC class with carbon density values ≠ 0

On the last two graphs, the most visible changes that have occurred over the years are noted on the classes of Coniferous Forests (312), Mixed Forests (313) and Transitional Woodlands – Scrub (324). The first has had a high decrease in both area and in carbon stock, resulting in a 32.1% change. Mixed Forests has also had a high decrease in both area and carbon stock with changes of 15.3%. In the other hand, Transitional Woodlands – Scrubs had a higher change with an increase 57.4% in both area and carbon stock.

The carbon density graph works as an auxiliary tool for interpretation of the other two distribution graphs presented. By comparing and analyzing these three sources of information it is possible to suggest that classes 312, 313 and 324 have an intimate relation to one another. These classes represent the highest values in carbon density with values of 59.48, 40.8 and 17.74 t ha^{-1}, respectively. If we take into account that the first two classes correspond to the highest concentrations of carbon stock it is also possible to say that any decrease in their area should reflect in a high decrease in total vegetation carbon stock. Following this theory, it is also possible to suggest that a decrease in forest areas may lead to an increase in transitional woodland areas.

According to the European Environmental Agency (EEA 1997), the short definition for the class 324 refers to a bushy or herbaceous vegetation with scattered trees which can represent either woodland degradation or forest regeneration/colonization but may also refer to new plantations or even recently cut plantations. If we take this into account than it is possible to state that the deforestation of classes 312 and 313 may lead to class 324. Proof of a supposition such as this one is plausible if we consider the series of forest fires that Portugal has been hit with the last few years. A forest fire could be a reasonable source for the phenomena shown by the presented graphs.

In an effort to better interpret and visualize the information gathered, a set of “mega classes” were derived from the CLC nomenclature. A table with resulting information is presented in Table 10 of the Appendix 2. Two graphical representations may be viewed in Figure 17 and Figure 18 where distribution of area size and carbon stock is represented, respectively.

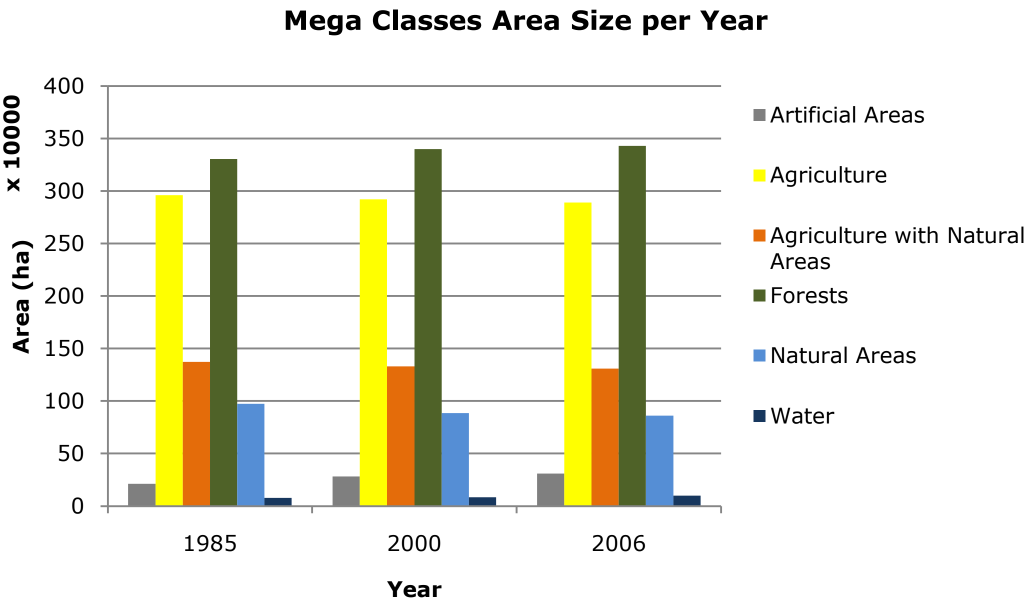


Figure 17: Distribution of area of each Mega Class per year

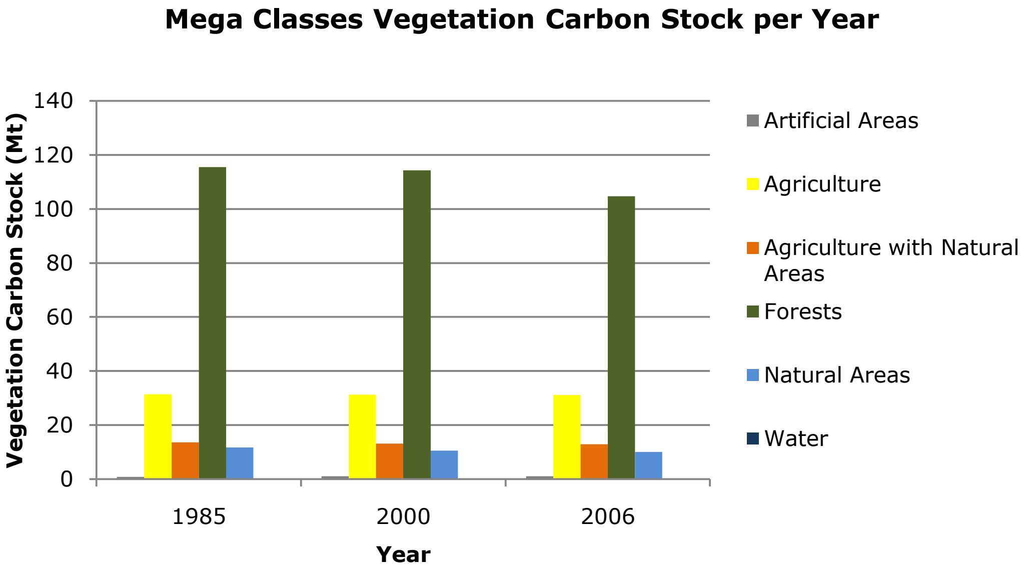
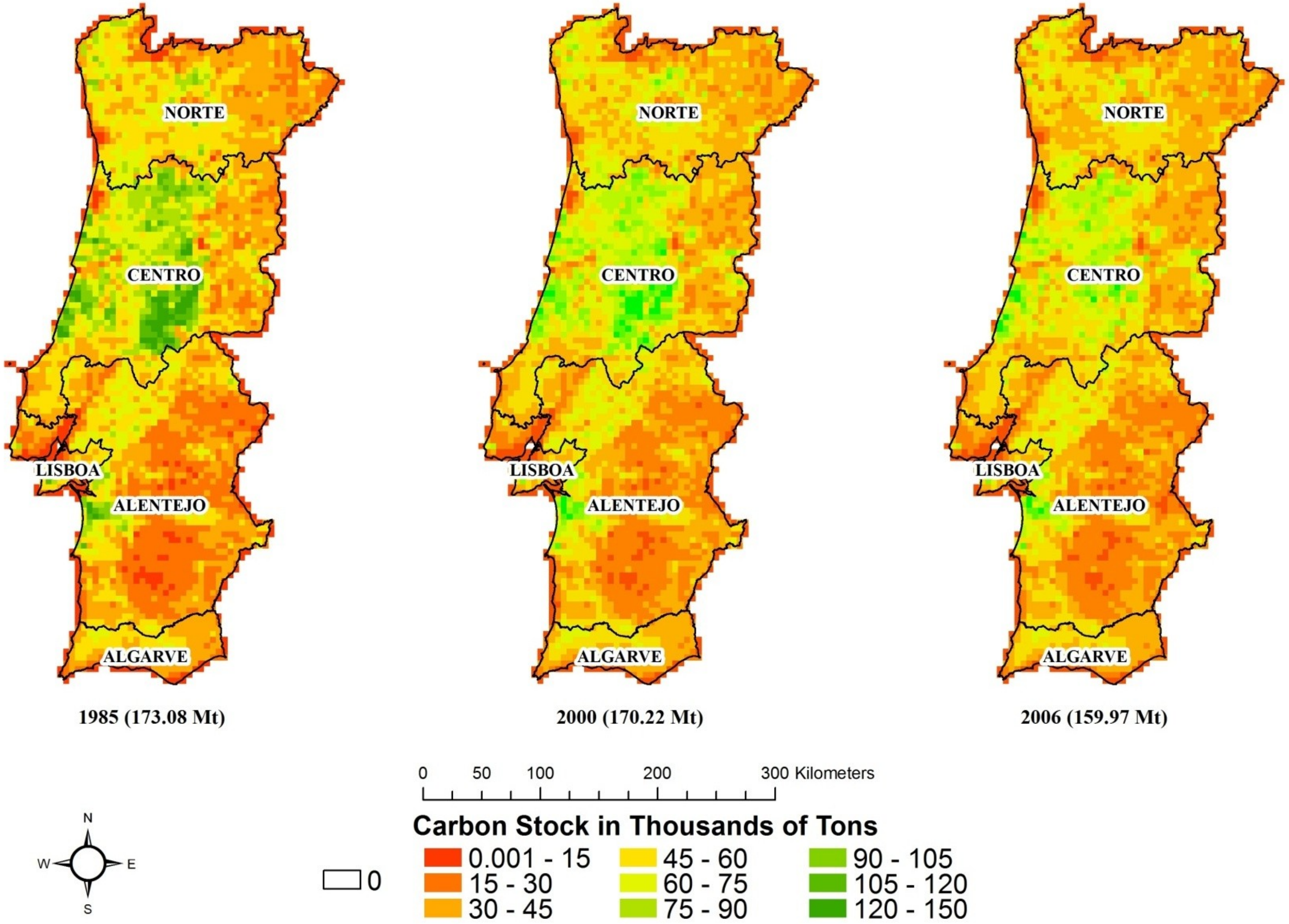


Figure 18: Distribution of vegetation carbon stock of each Mega Class per year

Results showed and confirmed the superior concentration of carbon stock on forest related classes. Numbers established a concentration of carbon stock in between 65% and 67% on forest lands with the second largest concentration in agricultural lands with values between 18% and 20%. As far as changes in carbon stock, forests also had the highest change with total loss of 10.88 Mt, followed by natural areas with 1.64 Mt. By examining the two distribution graphs it is clear to see the increase in forest area and decrease in forest carbon stock. Again, this phenomenon may be explained by the fact that high carbon density forests have been lost (classes 311, 312 and 313) while low carbon density forests have been gained (class 324). Using the same example from before, forests such as broad-leaved, coniferous or mixed could have been somehow deforested making space for low density forests such as transitional woodlands, degraded areas, regeneration land and so on.

To account for a spatial distribution of carbon throughout the country, a grid system of 2500 ha was developed. This step was crucial for better visualization of the spatial distribution and also to permit and facilitate a change detection strategy. Spatial distribution maps of 1985, 2000 and 2006 are represented in Figure 19, while change detection maps for the period of 1985-2000, 2000-2006 and 1985-2006 are represented in Figure 20.

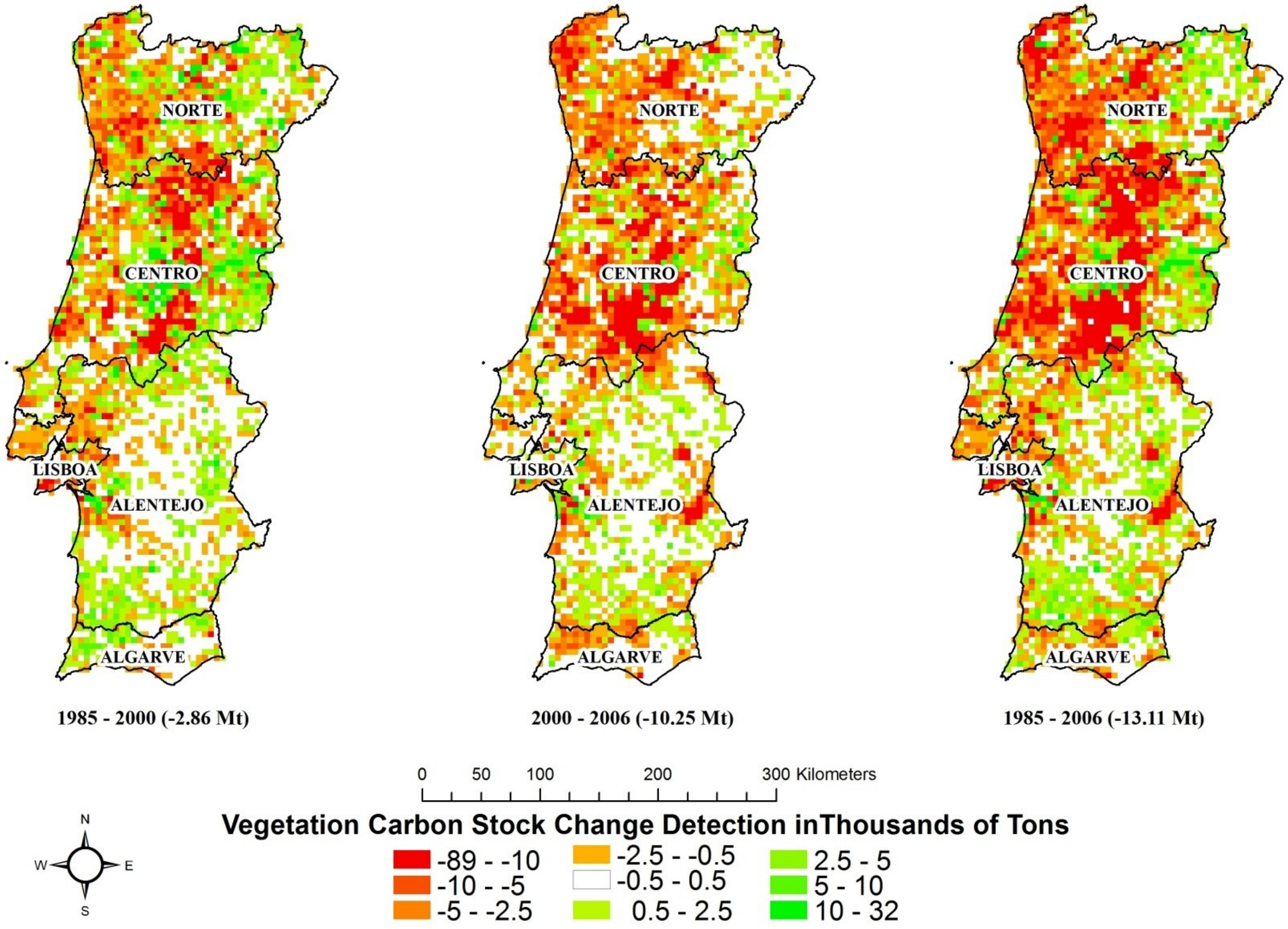


1985 (173.08 Mt)

2000 (170.22 Mt)

2006 (159.97 Mt)

Figure 19: Spatial distribution representation of the vegetation carbon stock of Continental Portugal for three years



1985 - 2000 (-2.86 Mt)

2000 - 2006 (-10.25 Mt)

1985 - 2006 (-13.11 Mt)

Figure 20: Vegetation carbon stock change detection over three periods

For identification reasons and to facilitate interpretation of the spatial distribution of carbon stock, the information was also presented with the NUTS II official administrative division. A series of information on distribution of area and carbon stock can be seen on Table 5 and in Figure 21.

			1985		2000		2006	
NUTS II	**Area (ha)**	**Area (%)**	**C Stock (Mt)**	**Density (t/ha)**	**C Stock (Mt)**	**Density (t/ha)**	**C Stock (Mt)**	**Density (t/ha)**
ALENTEJO	3155119	35.5	48.51	15.4	49.07	15.6	48.2	15.3
ALGARVE	499597	5.6	8.27	16.6	8.36	16.7	8.15	16.3
CENTRO	2820009	89.4	71.57	25.4	69.36	24.6	62.58	22.2
LISBOA	294011	3.3	4.57	15.5	4.08	13.9	4.05	13.8
NORTE	2128392	23.9	40.16	18.9	39.35	18.5	36.98	17.4

Table 5: Distribution of area and vegetation carbon stock over the NUTS II administrative division for the three years studied

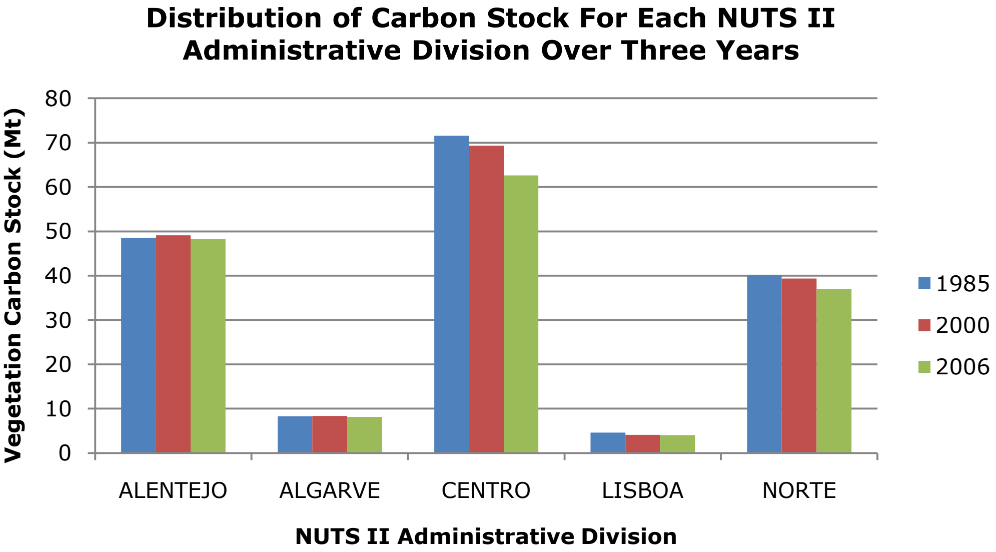


Figure 21: Distribution of vegetation carbon stock for each NUTS II administrative division over each of the three years studied

The spatial distribution maps show a clear distribution of carbon throughout Continental Portugal with focus on the high concentration of carbon stock in the *Centro* region of the country, followed by the *Norte* region, according to Table 5. This high concentration of carbon stock in Centro region can be an influence of the presence of different types of forest lands according to the original CLC maps. The same maps give an overview of lower concentration of carbon in the *Alentejo* and *Lisboa* regions.

As for the change detection maps, a high loss of carbon stock is verified especially in the *Centro* region as can be proven by values found on Table 5. In all, the *Algarve* and *Alentejo* regions suffered the least change, both in increase and decrease. It is possible to state that the regions that most lost carbon are exactly the forest regions of the central and northern part of Portugal.

4.2 The Effect of Scale (MMU) On Vegetation Carbon Stock Estimation

A final summary of carbon stock for the cities of Castro Verde, Nelas and Mora for the year 1990 (COS90) at different MMUs can be seen on Table 6. Values tended not to vary much as MMU were changed, having Castro Verde a small decline, Nelas a small increase and Mora fluctuated up and down with no correlation at all (Figure 22).

		Minimum Mapping Units							
	Study Area	**1 ha**	**3 ha**	**5 ha**	**10 ha**	**15 ha**	**20 ha**	**25 ha**	**CLC90 25 ha**
Carbon Stock (t *1000)	Castro Verde	509	507	505	502	500	500	497	419
	Nelas	342	347	347	344	342	350	348	425
	Mora	1116	1119	1122	1130	1136	1142	1143	674

Table 6: Vegetation carbon stock for each MMU

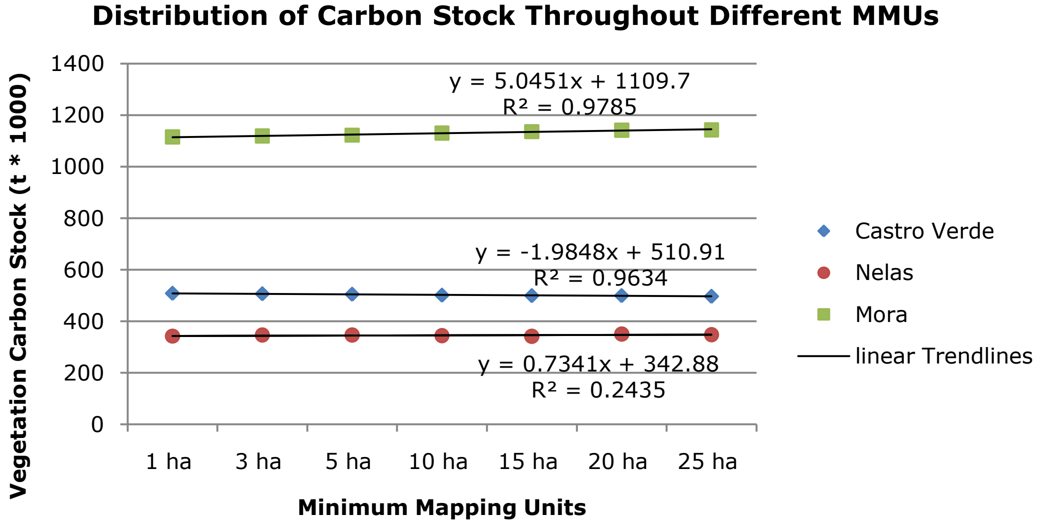


Figure 22: Distribution of carbon stock throughout different MMUs with addition of a linear trendline

Full information tables containing values per class were also created for each study site and are presented in the Appendix 3 on Table 11 for Castro Verde, Table 12 for Nelas and Table 13 for Mora.

For better visual analysis, six separate graphs were produced; one for each municipality, showing the distribution of the vegetation carbon stock and LULC area size for each one of the MMUs over the CLC adapted nomenclature. Castro Verde is presented in Figure 23 and Figure 24, Nelas in Figure 25 and Figure 26 and Mora in Figure 27 and Figure 28.

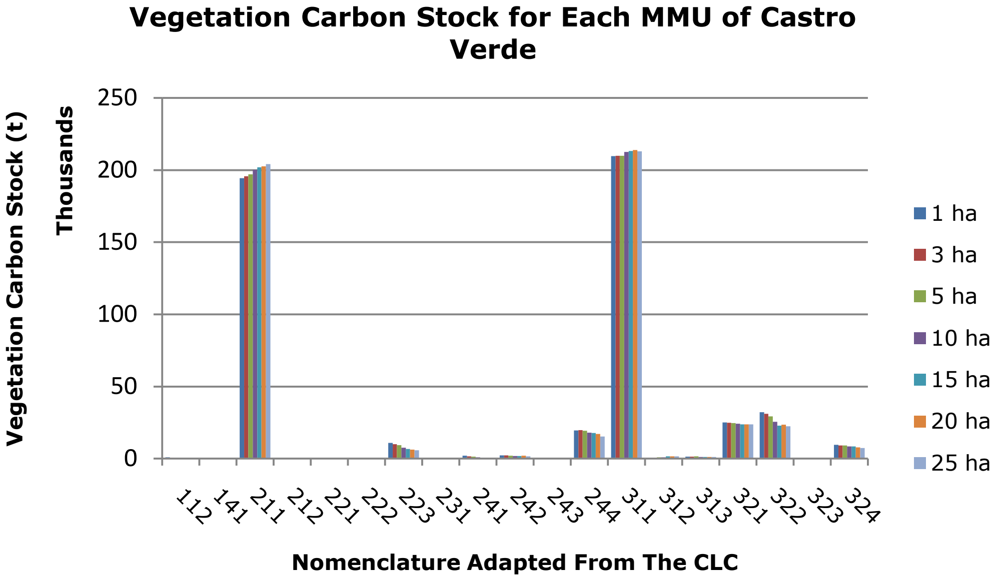


Figure 23: Vegetation carbon stock for each MMU of Castro Verde study area

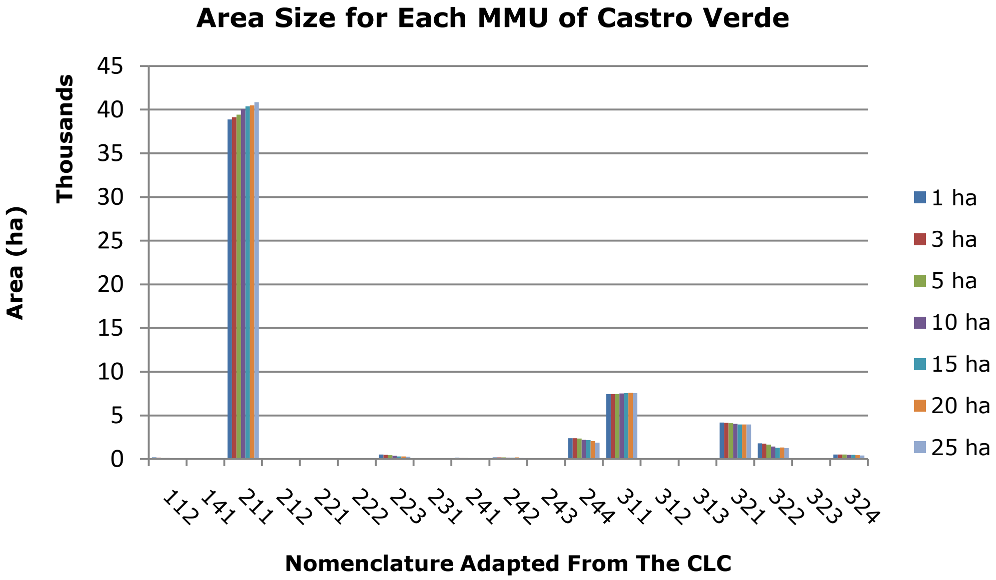


Figure 24: Area size for each MMU of Castro Verde study site

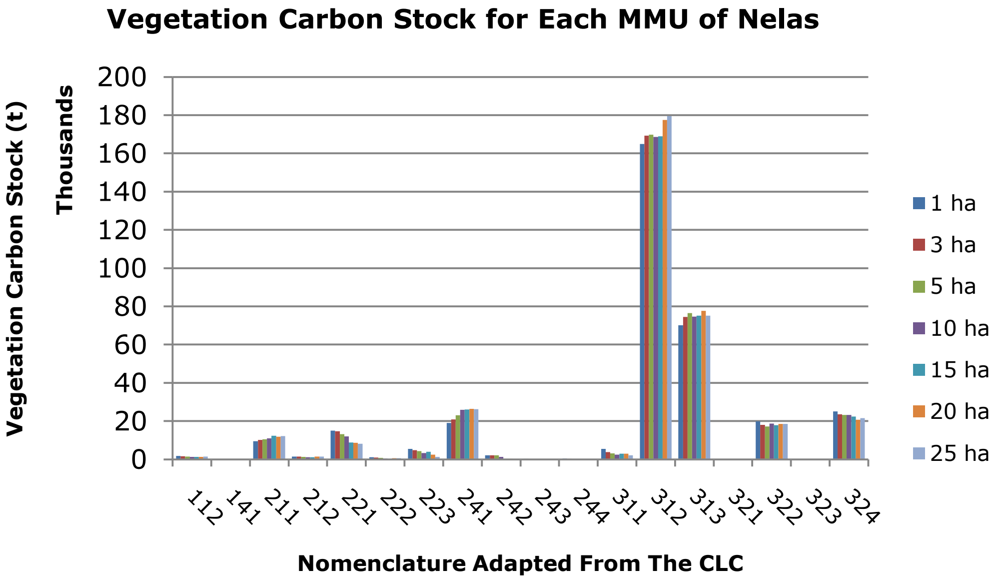


Figure 25: Vegetation carbon stock for each MMU of Nelas study site

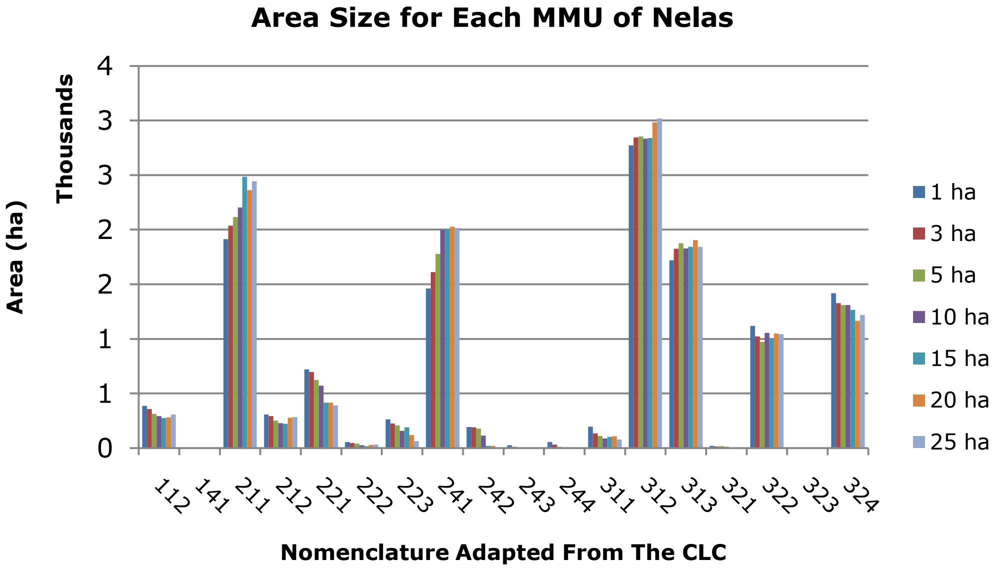


Figure 26: Area size for each MMU of Nelas study site

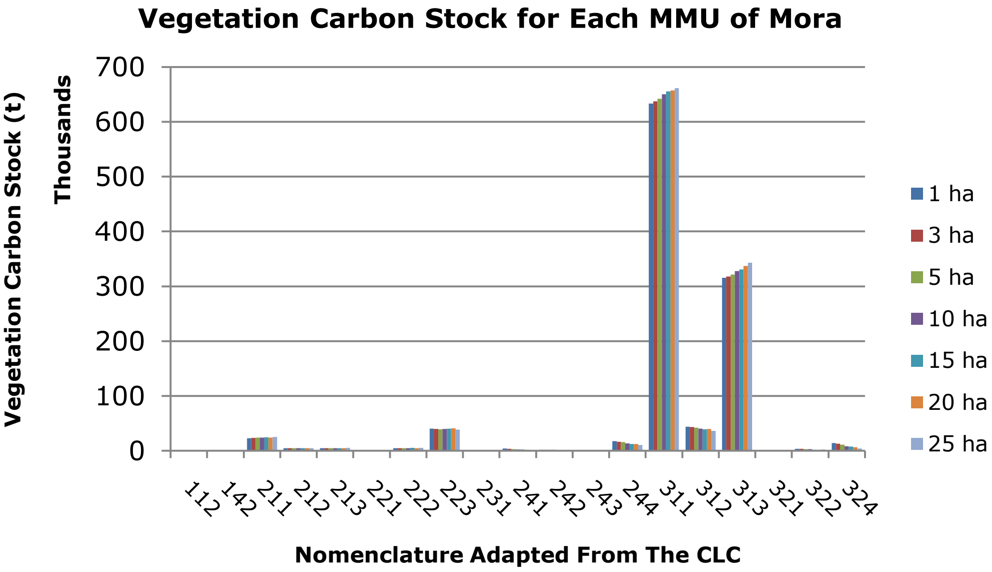


Figure 27: Vegetation carbon stock for each MMU of Mora study site

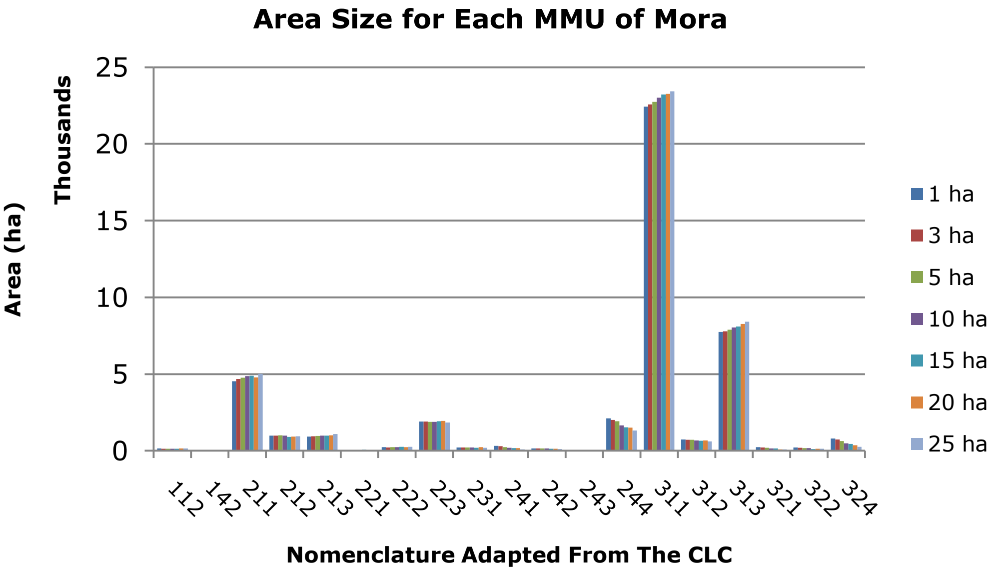


Figure 28: Area size for each MMU of Mora study site

The city of Castro Verde presented a high concentration of vegetation carbon stock in Broad Leaved Forests (311) and in Non-Irrigated Arable land (211). Both of these had an increase in carbon stock when MMU was increased. The class Coniferous Forest (312) also presented an increase in carbon stock although it is almost insignificant compared to the other two presented. All other classes have decreased carbon stock, some of them even vanishing.

Nelas presented a high concentration of vegetation carbon stock in Coniferous Forests (312) and Mixed Forests (313). Again, both have increased carbon stock values as MMU was increased. Along with the two classes already presented, Non-Irrigated Arable land (211) and Annual Crops with Permanent Crops (241) have also obtained an increase in carbon stock after MMU increase. All other classes have again decreased carbon stock, some to a point where they no longer existed.

The city of Mora had a high concentration of vegetation carbon stock in Broad-Leaved forests (311) and Mixed forests (313). One more time these classes have increased their carbon stock once MMU was increased. A few other classes such as Non-Irrigated Arable Land (211), Rice Fields (213) and Olive Groves (223) also showed a small increase in carbon stock, although these changes were very subtle. All the remaining classes have either decreased or fluctuated in their carbon stock values.

Information gathered from this study does not show enough potential to extrapolate conclusions to all Continental Portugal. It is only possible to suggest that more study areas are needed to be able to address on the effects that MMU makes for a country level analysis. For now, what is achievable is to comment on the effect that MMU had on the three separate study sites.

4.3 Summary

Results have shown that Portugal has had a decrease in vegetation carbon stock over the years 1985 and 2006. Data calculated suggested an estimation of 173.08 Mt of carbon stock for 1985, 170.22 Mt for 2000 and 159.97 Mt for 2006.

Considerable amounts of carbon have been lost to the atmosphere due mostly to forest loss. In the first period studied (1985-2000), Portugal lost 2.86 Mt of carbon, with an overall average of 0.19 Mt per year. The second period, from the year 200 to 2006, a total loss of 10.25 Mt was calculated, with an average of 1.70 Mt per year. In all, from 1985 until 2006, Portugal lost 13.11 Mt of carbon with an average of 0.62 Mt.

The highest variations observed for the CLC classes during this period were for Coniferous Forests (312) and Transitional Woodland – Scrub (324). The first was observed to have a significant decrease over the years and the second an increase, suggesting a connection between them. This is plausible once that deforestation may lead to “transitional woodland”.

Spatial distribution of this loss shows that the regions denominated *Centro* and *Norte* have suffered the most losses. Interesting though is that these regions are also the regions with the highest concentration of forests and carbon.

As for the MMU study, values tended to differ from one study area to another as MMU was increased. Castro Verde presented a small decline, Nelas a small increase and Mora fluctuated up and down with no correlation. Therefore it is not possible to confirm any possibility of extrapolation of information to other sites in Continental Portugal.

Results from this last study showed that the classes with largest concentration of area and carbon stock influenced directly the outcomes of MMU increase. When MMU was increased, the classes with superior concentration of land area had a tendency to increase even more and therefore also increase in total carbon stock.

5. CONCLUSIONS

The methodology applied was a success as it resulted in good representative estimates. Although numbers may not be considered excellent estimates, the spatial distribution and the change detection maps give a good idea of the reality. Final vegetation carbon stock values unfortunately cannot be tested for confidence since they are considered to be indicative values originated from literature sources which already contain errors.

In all, continental Portugal was found to have been losing vegetation carbon over the studied years. The rate of loss was also identified to be increasing. Concentration of carbon stock was recognized to be mostly in the *Centro* and *Norte* regions. Forests were once again noted to be of great importance on a carbon stock study. The high density of carbon in forest areas makes it as ideal strategy for carbon sequestration but also proves to be of great concern if it is lost.

In Cruickshank, et al. (2000) the authors pointed out that many improvements could be made towards the estimation of carbon densities for each class. Special attention was given to the improvement of national and local inventories, not having therefore to rely on estimate values from other countries, default values or derived values from other classes. The same was found to be necessary in this Portuguese attempt. Density values could be better worked on to achieve better estimation results.

It is important to point out in this study that carbon density values are all average values applied throughout an extensive region. Some CLC classes may have a composition of smaller classes that in reality do not fit perfectly to the assigned density value. This can be seen for example on the class transitional woodland – scrub (324) of the CLC. In this class a wide range of land covers may be referred to such as new forests, recently cut forests or even scrub land where trees are only present in between 10% and 30% of the area.

Not only the density values were noted to be improved but also the basis of this study which is the CORINE land cover. It is possible that the land cover may be underestimating certain classes that could make the total carbon stock bias. This is the case of forest areas, which on CORINE land cover are only represented if greater than 25 ha and could make a big difference if accounted for in smaller MMUs.

Also, the possibility of adoption of this strategy by other European CORINE land cover participants may be of great interest. The approach used in this study could also be adopted by others for the demands of the UNFCCC. Although a standard approach to land cover mapping already exists, a standardized method for calculating the carbon densities is still required and should be treated soon as an important step.

As for the MMU study, little difference was found for each MMU tested. When MMU was increased, the largest land cover classes in area size tended to increase even more. If this class was of high carbon density, than carbon stock tended to increase also. Although it is not possible to extrapolate the output to all Portugal, it is possible to say that for the cities studied, a MMU of 1 ha or an MMU of 25 ha is statistically indifferent from one another. This suggests that the use of a cheaper land cover with a 25 ha MMU would be as good as a more expensive land cover map with a 1 ha MMU.

5.1 Discussion on Research Questions

The research questions were:

1) **What are the total carbon stocks of Portugal for the years 1985, 2000 and 2006?**
    - The year 1985 has an estimated 173.9 Mt of carbon.
    - The year 2000 has an estimated 170.22 Mt of carbon.
    - The year 2006 has an estimated 159.97 Mt of carbon.
2) **What are the statistical differences in each year and to each class?**
    - The period of 1985 to 2000 showed a decrease of 2.86 Mt of carbon or 0.19 Mt per year.
    - The period of 2000 to 2006 showed a decrease of 10.25 Mt of carbon or 1.70 Mt per year.
    - The total period of 1985 to 2006 showed a decrease of 13.11 Mt of carbon or 0.62 Mt per year.
    - The CLC class of Coniferous Forests (312) was observed to have the highest decrease in total carbon loss over the periods.
    - The CLC class of Transitional Woodland – Scrub (324) was observed to have the highest increase in total carbon gain over the period.

3) **What is the spatial distribution of carbon throughout Portugal?**
    - Vegetation carbon was observed to be mostly located in the *Centro* and *Norte* regions, according to NUTS II administrative division.
    - *Centro* and *Norte* regions were also observed to have the highest losses in carbon stock over the studied period.
    - *Algarve* and *Alentejo* were observed to have the most untouched land.

4) **How does the MMU effect carbon stock estimation?**
    - Only small increases or decreases were observed in the three study sites.
    - Change in MMU in these study sites is statistically insignificant.

5.2 Discussion on Hypothesis

Following the results achieved and discussion presented, it is possible to say that the following hypotheses have been accepted:

1) Carbon stock has decreased over the years
2) Carbon stocks are concentrated mostly on forested areas and thus the spatial distribution is influenced by the presence of forests

As for the third hypothesis; "Vegetation carbon stock will increase or decrease according to the predominant class in area size when MMU is increased" – it is not possible to state that it has been achieved. Information gathered on carbon stock change according to increase of MMU has not been significant and therefore cannot imply that there were any increase or decrease according to MMU change.

5.3 Recommendations

These initial estimates show the possibility and opportunity of using LULC maps as a tool for national carbon estimations. It is highly recommended that information on carbon densities for different LULC classes be studied extensively, collected and published. Calculations of vegetation carbon stock and vegetation carbon densities may point toward potential directions for land cover policies, with implications on increasing possible sequestration of atmospheric CO_2. There is also a need to extend this study into soil carbon stock since this study site does not quantify this pool. It is believed that with better carbon density estimates and potentially with more secondary datasets such as soil and meteorological information, better estimates could be made.

As for recommendations following the results from this study, it is important to mention the sensitivity of these calculations towards the presence of forests. Forests play a major role in the sequestration and storage of carbon from the atmosphere and therefore represent that major role on calculations. To prevent further loss of carbon to the atmosphere, forest should be given priority in adequate management and reforestation programs. The increase in forest area will surely lead to increase in carbon stock.

It is highly recommended that more study sites be chosen for MMU comparisons. Results have shown that the final carbon stock values for the studied cities have no statistical difference. Since this shows that there is a possibility that larger MMU LULC maps make no difference in relation to smaller MMU LULC maps, there could be no reason to use smaller MMU maps for carbon stock estimation in the future.

5.4 Limitations and Future Studies

Limitations experienced in this study were:

- Availability of data for carbon density
- Personal limitations as to local knowledge

Future studies can be made using principles similar to the one presented on this study. It would be of great interest to continue this methodology with better density values for carbon stock. Also, the presence of auxiliary datasets could provide even superior estimates due to geographical inputs. It would also be of great interest to extrapolate methodologies such as this one to other CORINE land cover participating countries.

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APPENDICES

1. DETAILS ON CARBON DENSITY VALUES (Cruickshank et al., 2000)

Discontinuous urban fabric densities were achieved by first finding the proportions of built-over surfaces, grass and trees. This was done with the help of aerial photographs, high resolution satellite imagery and topographic maps of Belfast and Dublin where a percentage of each type was calculated to find an average. The average percentages for each type were multiplied by their respective carbon densities. Built areas were considered 0 t ha^{-1}, grass 0.9 t ha^{-1} (as in pastures), and 38 t ha^{-1} for trees (as in broad-leaved forest). The combined average lead to a total value of 3.1 t ha^{-1}.

Airports were studied in a similar way by using satellite s to achieve a proportion of built areas and grass. Studied showed that half the class was grass and therefore a values of 0.5 t ha^{-1} was used.

Green urban areas were used to categorize school and playing fields. Satellite s showed that this was in its majority grass with few trees and therefore a value of 0.9 ha^{-1} was used.

Sport and leisure facilities were mostly public parks and golf courses. Some previous studies gave the authors a lead into the actual carbon density of some areas. Other areas were studied by using again satellite imagery to address percentage of grass and trees. Final average values gave the authors a carbon density of 6.8 t ha^{-1} for this class.

Non-irrigated arable land carbon density values were applied using methodology found in literature (Adger, Subak 1996) and using government published yield and area data for the major arable crops found in that region. The final carbon density average for this class was of 2.2 t ha^{-1}.

Pastures were also obtained through previous carbon density studies applied to this specific class (Cruickshank, Tomlinson et al. 1998). A final value of 0.9 t ha^{-1} was used.

Annual crops associated with permanent crops for this study was associated with apple orchards and grass fields. A study similar to arable crops was used along with the defined pasture values. Final carbon density was found to be 3.2 t ha^{-1}.

Complex cultivation patterns were applied to regions where there were a mix of fields in arable and pasture. A fifty-fifty proportion was considered, resulting in a 1.6 t ha^{-1} density.

Principally agriculture with significant areas of natural vegetation was considered a difficult class to assign a value to. A field knowledge and inspection suggested that a value of 2.0 ha^{-1} should be used.

For forests and semi-natural areas, previous studies were used to obtain density values. The basic methodology was the use of national inventories from the year 1990 and apply factors to convert timber volume into carbon density. Broad-leaved forests resulted in an average value of 38 t ha^{-1}, conifer forests of 29.9 t ha^{-1} and mixed forest with 32.8 t ha^{-1}. The only observation is that mixed forest were considered to be an equal mix between broad-leaved and conifer.

Natural grassland values were achieved by using field knowledge and the comparison with pastures. Since natural grassland is typically not a grazing land, the authors used a slightly larger carbon density to overcome the fact that carbon tock is probably bigger. Therefore the adopted value of 1.5t ha^{-1} was used.

Moors and heath was recognized as being the same as one used in earlier studies. The value used was of 2.0 t ha^{-1}.

Transitional woodland-scrub values were obtained through previous private woodland inventories. It was estimated that half of the area was composed of grassland and half by woodland, resulting in an average of 14.5 t ha^{-1}.

Beaches, dunes and sand were also considered a difficult class to calculate carbon density for. The fact is that in some regions of Ireland, dunes may have vegetation, but since the area is so small, a value of 1.5 t ha^{-1} (natural grassland) was applied, considering that the overall impact of carbon stock would not be of great magnitude.

Sparsely vegetated areas were considered a class where bare rock and mostly moorland were found in different proportions. A proportion of 37.6% of moorland and heath species were considered, resulting in a 0.8 t ha^{-1} density.

Inland marshes were considered similar to natural grassland and were also given the value of 1.5 t ha^{-1}.

Peat bogs were separated into exploited and unexploited and according to past researches, an unexploited peat bog in that region has a value of 2.0 t ha^{-1}. Exploited peat bogs were considered a null value.Salt marshes also fallowed past researches and used a value of 2.0 t ha^{-1} even though this was considered high.

	Level 3 CLC Nomenclature	Area CLC90 (ha)	Carbon Density (t ha-1)	Total Carbon CLC90 (Mt)	Description
111	Continuous urban fabric	11158	0	0.00	
112	Discontinuous urban	83111	3.1	0.26	Image analysis and use of average for buildings (0 t/ha), grass (0.9 t/ha) and trees (28 t/ha)
121	Industrial / commercial units	8435	0	0.00	
122	Road, rail, associated land	1223	0	0.00	
123	Port areas	1315	0	0.00	
124	Airports	3439	0.5	0.00	Image analysis and use of average for buildings (0 t/ha) and grass (0.9 t/ha)
131	Mineral extraction	8407	0	0.00	
132	Dumps	444	0	0.00	
133	Construction sites	761	0	0.00	
141	Green urban areas	1951	0.9	0.00	
142	Sport and leisure	13854	6.8	0.09	Image analysis and use of average for grass (0.9t/ha) and trees (12t/ha)
211	Non-irrigated arable land	381439	2.2	0.84	Used literature (Adger and Subak, 1996) to express C values for major crops found in the country
212	Permantly irrigated land			0.00	Not applied
213	Rice fields			0.00	Not applied
221	Vineyards			0.00	Not applied
222	Fruit trees and berry plantations			0.00	Not applied
223	Olive groves			0.00	Not applied
231	Pastures	4760429	0.9	4.28	Used literature (Cruickshank et al., 1998) to express C values for hay, silage and grazing pastures found in the country
241	Annual crops with permanent crops	6386	3.2	0.02	Image analysis and use of average for Apple (13.5t/ha) and grass (0.9t/ha)
242	Complex cultivation patterns	250163	1.6	0.40	Mix of arable and pasture (50% each)
243	Principally agriculture, significant areas of natural vegetation	412662	2	0.83	Weighted estimate using field knowledge - natural grasslands, bogs, pasture, and agricultural areas with natural vegetation.
244	Agro-forestry areas			0.00	Not applied
311	Broad-leaved forest	42866	38	1.63	National inventories
312	Coniferous forest	299068	29.9	8.94	National inventories
313	Mixed forest	19928	32.8	0.65	Nequal mix of conifers and broadleaves
321	Natural grassland	263627	1.5	0.40	Adoption of higher value compapred to pastures because of grazing. No scientific reference
322	Moors and heathland	302671	2	0.61	Literature (Milne, 1994)
323	Sclerophyllous vegetation			0.00	Not applied
324	Transitional woodland - scrub	147733	14.5	2.14	Image analysis and use of average for discontinous trees and grass
331	Beaches, dunes, sands	15960	1.5	0.02	Natural grasslands value was used - class accounts for only 0.02% of ireland
332	Bare rocks	15320	0	0.00	
333	Sparsely vegetated areas	19977	0.8	0.02	Composition of areas was studied and a average for bare rock (0t/ha), moorland and heath (2t/ha)
334	Burnt areas	313	0	0.00	
335	Glaciers and perpetual snow			0.00	Not applied
411	Inland marshes	18407	1.5	0.03	Value of grasslands was applied
412	Peat bogs (unexploited)	957679	2	1.92	Literature (Milne and Brown, 1997)
412	Peat bogs (exploited)	151730		0.00	
421	Salt marshes	2882	2	0.01	Literature (Milne, 1994)
422	Salines			0.00	Not applied
423	Intertidal flats	44645	0	0.00	
511	Water courses	8159	0	0.00	
512	Water bodies	183540	0	0.00	
521	Coastal lagoons	1714	0	0.00	
522	Estuaries	3149	0	0.00	
523	Sea and Ocean			0.00	
	TOTAL	8444545		23.08	

Table 7: Area, carbon density, and carbon stock of CORINE land cover classes in Ireland (Adapted from: Cruickshank, Tomlinson et al. 2000)

2. SUMMARY TABLES FOR THE VEGETATION CARBON STOCK STUDY OF CONTINENTAL PORTUGAL

ID	CLC Level 3 Nomenclature	Carbon Density (t ha^{-1})	Description of Choice
112	Discontinuous urban	4,71	Assumed to be equal to Disc. Urban Fabric Cold Temp (Pereira, Seabra et al. 2009): Intermediate value between Continuous urban Fabric and Gardens (Pereira, Seabra et al. 2009)
124	Airports	0,50	Assumed to be equal to Airports (Cruickshank, Tomlinson et al. 2000): 50% built surfaces and 50% grass
141	Green urban areas	9,42	Assumed to be equal to Gardens, parks, etc Cold Temp (Pereira, Seabra et al. 2009): Assumed equal to Mixed Montado (Pereira, Seabra et al. 2009)
142	Sport and leisure	9,42	Assumed to be equal to Gardens, parks, etc Cold Temp (Pereira, Seabra et al. 2009): Assumed equal to Mixed Montado (Pereira, Seabra et al. 2009)
211	Non-irrigated arable land	5,00	Assumed equal to Annual Cropland (Pereira, Seabra et al. 2009) GP-LULUCF table 3.3.8: Annual Cropland. Below ground: assumed already included in above ground biomass
212	Permantly irrigated land	5,00	Assumed equal to Annual Cropland (Pereira, Seabra et al. 2009): GP-LULUCF table 3.3.8: Annual Cropland. Below ground: assumed already included in above ground biomass
213	Rice fields	5,00	Assumed equal to Annual Cropland (Pereira, Seabra et al. 2009): GP-LULUCF table 3.3.8: Annual Cropland. Below ground: assumed already included in above ground biomass
221	Vineyards	21,00	Assumed equal to Permanent Crops (Pereira, Seabra et al. 2009): GP-LULUCF table 3.3.8: Temperate (all moisture regimes). Assuming 10 year average age (GP-LULUCF table 3.3.2 recommends 30 years, but that time interval appears too large for the dominant permanent crops in Portugal, orchards and vineyards.)
222	Fruit trees and berry plantations	21,00	Assumed equal to Permanent Crops (Pereira, Seabra et al. 2009): GP-LULUCF table 3.3.8: Temperate (all moisture regimes). Assuming 10 year average age (GP-LULUCF table 3.3.2 recommends 30 years, but that time interval appears too large for the dominant permanent crops in Portugal, orchards and vineyards.)
223	Olive groves	21,00	Assumed equal to Permanent Crops (Pereira, Seabra et al. 2009): GP-LULUCF table 3.3.8: Temperate (all moisture regimes). Assuming 10 year average age (GP-LULUCF table 3.3.2 recommends 30 years, but that time interval appears too large for the dominant permanent crops in Portugal, orchards and vineyards.)
231	Pastures	6,00	Assumed to be equal to Grasslands Cold Temp (Pereira, Seabra et al. 2009): Above ground biomass: GP-LULUCF, Table 3.4.2, considering the default carbon fraction of dry matter (0.5); Root-shoot ratio: GP-LULUCF Table 3.4.3 Root-to-Shoot Ratios for the Major Savannah/Rangeland Ecosystems of the World.
241	Annual crops with permanent crops	13,00	Assumed to be equal to 50% Annual Crops (Pereira, Seabra et al. 2009) and 50% Permanent Crops (Pereira, Seabra et al. 2009)
242	Complex cultivation patterns	11,52	Assumed to be equal to Mosaic with all other Types (Pereira, Seabra et al. 2009): Sum of biomass in forest/undercover (10%), according to forest specie, bush land (10%), and annual cropland (80%)
243	Principally agriculture, significant areas of natural vegetation	11,37	Assumed to be equal to 50% Annual Crops (Pereira, Seabra et al. 2009) and 50% Bushlands (Pereira, Seabra et al. 2009)
244	Agro-forestry areas	8,22	Assumed to be equal to Mosaic Agriculture with Q. Suber (Pereira, Seabra et al. 2009): Sum of biomass in forest/undercover (10%), according to forest specie, bush land (10%), and annual cropland (80%)

ID	CLC Level 3 Nomenclature	Carbon Density ($t\ ha^{-1}$)	Description of Choice
311	Broad-leaved forest	28,24	Assumed to be equal to 33% Eucalyptus[1] (Pereira, Seabra et al. 2009), 33% Quercus Suber[2] (Pereira, Seabra et al. 2009) and 33% Quercus Rotundifolia[2] (Pereira, Seabra et al. 2009). 1) Includes biomass in trees and undergrowth cover; aboveground tree biomass from Pereira et al (2002); aboveground undergrowth biomass from Silva (Unpublished); Root-to-Shoot Ratios: Soares & Tomé (2004). 2)Includes biomass in trees and undergrowth cover; aboveground tree biomass from Pereira et al (2002) corrected to include only forest>30% cover; aboveground undergrowth biomass from Silva (Unpublished) ; Root-to-Shoot Ratios: GP-LULUCF Table 3A.1.8: Temperate Broadleaf forest function of ALB per ha
312	Coniferous forest	59,48	Assumed to be equal to Pinus pinaster (Pereira, Seabra et al. 2009): Includes biomass in trees and undergrowth cover, aboveground tree biomass from Pereira et al (2002), aboveground undergrowth biomass from Silva (Unpublished), Root-to-shoot Ratios: GP-LULUCF Table 3A.1.8: Conifer Forest Plantation function of ALB per ha
313	Mixed forest	40,80	Includes biomass in trees and undergrowth cover; aboveground tree biomass from Pereira et al (2002) average of all species; aboveground undergrowth biomass from Silva (Unpublished) ; Root-to-Shoot Ratios: GP-LULUCF Table 3A.1.8: Temperate Broadleaf forest function of ALB per ha (Pereira, Seabra et al. 2009)
321	Natural grassland	6,00	Assumed to be equal to Grasslands in cold Temp (Pereira, Seabra et al. 2009) Above ground biomass: GP-LULUCF, Table 3.4.2, considering the default carbon fraction of dry matter (0.5); Root-shoot ratio: GP-LULUCF Table 3.4.3 Root-to-Shoot Ratios for the Major Savannah/Rangeland Ecosystems of the World.
322	Moors and heathland	17,74	Assumed to be equal to Bushlands (Pereira, Seabra et al. 2009) Above ground equation yr=-0.1177 yr2 * 1.8511 yr + 1.9582 from Santos Pereira (2002) for full-growth (8 yr), Root-to Shoot Ratios: GP-LULUCF Table 3A.1.8 Shrubland
323	Sclerophyllous vegetation	17,74	Assumed to be equal to Bushlands (Pereira, Seabra et al. 2009) Above ground equation yr=-0.1177 yr2 * 1.8511 yr + 1.9582 from Santos Pereira (2002) for full-growth (8 yr), Root-to Shoot Ratios: GP-LULUCF Table 3A.1.8 Shrubland
324	Transitional woodland - scrub	17,74	Assumed equal to Bushlands (Pereira, Seabra et al. 2009): Aboveground: equation yr=-0.1177 yr2 + 1.8511 yr + 1.9582 from Santos Pereira (2002) for full-grow (8 yr); Root-to-Shoot Ratios: GP-LULUCF Table 3A.1.8 Shrubland
333	Sparsely vegetated areas	3,00	Assumed to be equal to Sparse Vegetation Cold Temp (Pereira, Seabra et al. 2009): Sparse vegetation assumed half the biomass of grassland (Pereira, Seabra et al. 2009)
411	Inland marshes	1,50	Assumed to be equal to Grasslands in Ireland (Cruickshank, Tomlinson et al. 2000)
421	Salt marshes	2,00	Assumed to be equal to Salt Marshes in Ireland (Milne 1994; Cruickshank, Tomlinson et al. 2000)

Table 8: Identification of each CLC class along with its respective carbon density equivalent and the description of choice (Adapted from: Cruickshank, Tomlinson et al. 2000; Pereira, Seabra et al. 2009)

ID	CLC Level 3 Nomenclature	Carbon Density (t ha^{-1})	Area (ha)			Carbon Stock (Mt)			Carbon Stock Change (%)		
			1985	2000	2006	1985	2000	2006	1985-2000	2000-2006	1985-2006
111	Continuous urban fabric	0.00	10409	12077	12233	0.00	0.00	0.00			
112	Discontinuous urban	4.71	161934	202359	215250	0.76	0.95	1.01	25.0	6.4	32.9
121	Industrial / commercial units	0.00	16513	29706	33698	0.00	0.00	0.00			
122	Road, rail, associated land	0.00	568	2256	7679	0.00	0.00	0.00			
123	Port areas	0.00	1303	1475	1585	0.00	0.00	0.00			
124	Airports	0.50	3861	4216	4303	0.00	0.00	0.00	9.2	2.1	11.4
131	Mineral extraction	0.00	6107	12248	13661	0.00	0.00	0.00			
132	Dumps	0.00	333	748	972	0.00	0.00	0.00			
133	Construction sites	0.00	3054	5721	6518	0.00	0.00	0.00			
141	Green urban areas	9.42	1593	1761	1761	0.02	0.02	0.02	10.5	0.0	10.5
142	Sport and leisure	9.42	5274	9053	11491	0.05	0.09	0.11	71.7	26.9	117.9
211	Non-irrigated arable land	5.00	1091747	1019417	981760	5.46	5.10	4.91	-6.6	-3.7	-10.1
212	Permantly irrigated land	5.00	137237	203804	210523	0.69	1.02	1.05	48.5	3.3	53.4
213	Rice fields	5.00	55245	54401	52825	0.28	0.27	0.26	-1.5	-2.9	-4.4
221	Vineyards	21.00	196575	222741	228989	4.13	4.68	4.81	13.3	2.8	16.5
222	Fruit trees and berry plantations	21.00	95493	100566	100994	2.01	2.11	2.12	5.3	0.4	5.8
223	Olive groves	21.00	271093	262925	263050	5.69	5.52	5.52	-3.0	0.0	-3.0
231	Pastures	6.00	54414	42104	41875	0.33	0.25	0.25	-22.6	-0.5	-23.0
241	Annual crops with permanent crops	13.00	433467	405789	404023	5.64	5.28	5.25	-6.4	-0.4	-6.8
242	Complex cultivation patterns	11.52	624547	609908	607104	7.19	7.03	6.99	-2.3	-0.5	-2.8
243	Principally agriculture, significant areas of natural vegetation	11.37	736812	700128	686893	8.38	7.96	7.81	-5.0	-1.9	-6.8
244	Agro-forestry areas	8.22	634862	628700	621495	5.22	5.17	5.11	-1.0	-1.1	-2.1
311	Broad-leaved forest	28.24	1059381	1125182	1007057	29.92	31.78	28.44	6.2	-10.5	-4.9
312	Coniferous forest	59.48	786609	708603	533994	46.79	42.15	31.76	-9.9	-24.6	-32.1
313	Mixed forest	40.80	561501	545340	475551	22.91	22.25	19.40	-2.9	-12.8	-15.3
321	Natural grassland	6.00	185626	176157	171883	1.11	1.06	1.03	-5.1	-2.4	-7.4
322	Moors and heathland	17.74	314538	289461	284585	5.58	5.14	5.05	-8.0	-1.7	-9.5
323	Sclerophyllous vegetation	17.74	264811	225002	206625	4.70	3.99	3.67	-15.0	-8.2	-22.0
324	Transitional woodland - scrub	17.74	896661	1019204	1411490	15.91	18.08	25.04	13.7	38.5	57.4
331	Beaches, dunes, sands	0.00	11137	11083	11075	0.00	0.00	0.00			
332	Bare rocks	0.00	23750	23836	23863	0.00	0.00	0.00			
333	Sparsely vegetated areas	3.00	99016	100528	100835	0.30	0.30	0.30	1.5	0.3	1.8

ID	**CLC Level 3 Nomenclature**	**Carbon Density (t ha^{-1})**	**Area (ha)**			**Carbon Stock (Mt)**			**Carbon Stock Change (%)**		
			1985	**2000**	**2006**	**1985**	**2000**	**2006**	**1985-2000**	**2000-2006**	**1985-2006**
334	Burnt areas	0.00	46274	29688	32862	0.00	0.00	0.00			
335	Glaciers and perpetual snow										
411	Inland marshes	1.50	1048	1119	1139	0.00	0.00	0.00	6.8	1.7	8.7
412	Peat bogs										
421	Salt marshes	2.00	18391	18191	18142	0.04	0.04	0.04	-1.1	-0.3	-1.4
422	Salines	0.00	7089	7200	7200	0.00	0.00	0.00			
423	Intertidal flats	0.00	1733	1733	1911	0.00	0.00	0.00			
511	Water courses	0.00	20748	20590	19871	0.00	0.00	0.00			
512	Water bodies	0.00	28855	34600	52989	0.00	0.00	0.00			
521	Coastal lagoons	0.00	8417	8465	8488	0.00	0.00	0.00			
522	Estuaries	0.00	16392	16292	16138	0.00	0.00	0.00			
523	Sea and Ocean	0.00	2713	2752	2751	0.00	0.00	0.00			
					TOTAL	**173.08**	**170.22**	**159.97**	**-1.7**	**-6.0**	**-7.6**
						CLC90	**CLC00**	**CLC06**	**1985-2000**	**2000-2006**	**1985-2006**

Table 9: Carbon density, Area, vegetation carbon stock and carbon stock change results for Continental Portugal

Mega Class	**Area (ha)**			**Carbon Stock (Mt)**						**Carbon Stock Change (Mt)**					
	1985	**2000**	**2006**	**1985**	**%**	**2000**	**%**	**2006**	**%**	**85-00**	**%**	**00-06**	**%**	**86-06**	**%**
Artificial Areas	210950	281621	309149	0.83	0.5	1.06	0.6	1.14	0.7	0.23	27.5	0.08	7.9	0.31	37.6
Agriculture	2959817	2921655	2891142	31.40	18.1	31.25	18.4	31.18	19.5	-0.15	-0.5	-0.08	-0.2	-0.23	-0.7
Agriculture with Natural Areas	1371675	1328828	1308387	13.60	7.9	13.13	7.7	12.92	8.1	-0.47	-3.4	-0.21	-1.6	-0.68	-5.0
Forests	3304153	3398329	3428093	115.52	66.7	114.25	67.1	104.64	65.4	-1.27	-1.1	-9.61	-8.4	-10.88	-9.4
Natural Areas	973412	883998	860121	11.73	6.8	10.52	6.2	10.09	6.3	-1.20	-10.3	-0.44	-4.2	-1.64	-14.0
Water	77124	82699	100238	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
TOTAL				**173.08**	**100**	**170.22**	**100**	**159.97**	**100**	**-2.86**	**-1.7**	**-10.25**	**-6.0**	**-13.11**	**-7.6**

Table 10: Information on area size, vegetation carbon stock and carbon stock change over the adapted mega class nomenclature

3. SUMMARY TABLES FOR MMU STUDY

	STUDY AREA - CASTRO VERDE - MINIMUM MAPPING UNITS															
	1 ha		3 ha		5 ha		10 ha		15 ha		20 ha		25 ha		CLC90 25 ha	
CLC CLASS	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**
111	118	0	110	0	99	0	101	0	77	0	94	0	94	0	0	0
112	195	920	158	746	118	554	111	523	96	451	46	218	56	265	215	1011
121	69	0	66	0	66	0	66	0	66	0	66	0	66	0	73	0
122	15	0	15	0	15	0	15	0	20	0	18	0	18	0	0	0
131	36	0	36	0	36	0	41	0	41	0	27	0	27	0	0	0
141	12	112	12	112	8	76	0	0	0	0	0	0	0	0	0	0
211	38878	194390	39133	195665	39428	197138	40037	200186	40368	201841	40498	202492	40842	204209	37839	189195
212	18	92	18	91	19	94	0	0	0	0	0	0	0	0	0	0
221	2	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
222	11	234	7	140	7	140	0	0	0	0	0	0	0	0	0	0
223	514	10792	473	9923	440	9238	363	7622	314	6593	296	6218	275	5783	395	8303
231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1118	6710
241	158	2058	123	1593	112	1458	64	830	49	643	30	385	53	689	38	493
242	205	2357	188	2164	177	2042	160	1847	155	1790	177	2040	131	1504	489	5636
243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4850	55149
244	2377	19542	2395	19690	2362	19416	2200	18080	2148	17654	2071	17025	1875	15412	7857	64581
311	7427	209728	7430	209811	7429	209804	7526	212546	7547	213135	7577	213988	7542	212975	1532	43275
312	13	782	13	797	16	935	16	935	26	1576	27	1626	27	1626	0	0
313	34	1394	34	1394	37	1503	27	1095	27	1095	27	1095	27	1095	0	0
321	4176	25055	4150	24903	4120	24719	4015	24089	3959	23756	3966	23797	3966	23794	0	0
322	1812	32152	1748	31001	1651	29291	1445	25628	1293	22933	1322	23448	1266	22467	0	0
323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	758	13454
324	533	9451	520	9218	511	9061	473	8384	477	8454	437	7758	416	7375	1764	31294
332	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
511	260	0	260	0	260	0	260	0	267	0	250	0	250	0	0	0
512	91	0	69	0	48	0	38	0	27	0	27	0	27	0	28	0
TOTAL	56958	509099	56958	507246	56958	505470	56958	501766	56958	499921	56958	500090	56958	497194	56957	419101

Table 11: Area and carbon stock values for the MMU study area of Castro Verde

	STUDY AREA - NELAS - MINIMUM MAPPING UNITS															
	1 ha		3 ha		5 ha		10 ha		15 ha		20 ha		25 ha		CLC90 25 ha	
CLC CLASS	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**
111	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	385	1812	357	1680	312	1471	291	1371	276	1300	280	1318	306	1442	429	2021
121	115	0	99	0	96	0	73	0	80	0	58	0	77	0	35	0
131	14	0	16	0	19	0	19	0	19	0	21	0	32	0	0	0
141	6	59	6	55	6	55	0	0	0	0	0	0	0	0	0	0
211	1914	9570	2036	10178	2116	10582	2203	11014	2484	12420	2361	11806	2443	12214	38	189
212	306	1528	293	1467	252	1259	227	1133	221	1106	278	1390	285	1423	0	0
221	719	15100	696	14618	624	13107	572	12010	417	8752	415	8716	390	8195	1115	23413
222	56	1170	46	960	41	871	25	531	18	370	29	618	31	659	0	0
223	263	5517	225	4735	209	4382	157	3289	191	4011	120	2519	64	1348	53	1109
241	1462	19006	1613	20965	1779	23123	1998	25972	2008	26108	2027	26356	2015	26192	66	861
242	191	2204	191	2197	178	2053	114	1310	21	237	21	237	0	0	3575	41184
243	24	276	10	116	6	68	0	0	0	0	0	0	0	0	586	6661
244	56	456	32	260	12	96	0	0	0	0	0	0	0	0	0	0
311	196	5545	134	3792	111	3127	87	2465	102	2893	106	3005	78	2190	0	8
312	2772	164854	2846	169308	2855	169829	2834	168572	2840	168944	2984	177462	3017	179462	5414	322017
313	1719	70131	1825	74480	1875	76499	1829	74616	1843	75208	1904	77688	1843	75205	0	0
321	19	113	13	78	16	98	12	71	0	0	0	0	0	0	0	0
322	1118	19833	1021	18114	972	17236	1053	18687	1005	17824	1048	18599	1043	18500	605	10728
323	2	36		0	0	0	0	0	0	0	0	0	0	0	0	0
324	1418	25156	1326	23521	1309	23215	1308	23212	1266	22456	1167	20700	1218	21608	958	16995
331	58	0	38	0	38	0	19	0	19	0	1	0	0	0	0	0
332	26	0	16	0	18	0	23	0	33	0	23	0	0	0	0	0
511	31	0	31	0	31	0	31	0	31	0	31	0	31	0	0	0
512	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	12874	342367	12874	346523	12874	347072	12874	344252	12874	341628	12874	350412	12874	348440	12874	425186

Table 12: Area and carbon stock values for the MMU study area of Nelas

STUDY AREA - MORA - MINIMUM MAPPING UNITS																
	1 ha		3 ha		5 ha		10 ha		15 ha		20 ha		25 ha		CLC90 25 ha	
CLC CLASS	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**	**Area (ha)**	**Stock (t)**
112	152	718	135	638	131	615	131	616	141	663	142	667	150	706	237	1115
121	24	0	14	0	10	0	10	0	0	0	0	0	0	0	0	0
141	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
142	8	75	9	85	9	85	17	161	17	161	0	0	0	0	0	0
211	4539	22694	4668	23340	4765	23825	4862	24310	4883	24417	4789	23946	5010	25050	5112	25559
212	983	4915	984	4918	1003	5017	979	4896	910	4551	921	4604	937	4683	1290	6451
213	918	4588	939	4694	964	4819	985	4924	984	4919	1017	5085	1096	5478	539	2695
221	41	858	42	887	30	640	48	1012	59	1232	36	756			60	1265
222	230	4824	222	4661	238	4988	242	5081	259	5436	235	4933	263	5530	35	732
223	1913	40170	1910	40103	1873	39336	1890	39693	1933	40603	1941	40758	1837	38579	1590	33394
231	210	1261	216	1295	224	1342	219	1316	196	1177	232	1391	199	1195	66	398
241	313	4063	303	3944	237	3077	195	2531	181	2347	164	2131	94	1216	1035	13451
242	158	1824	154	1775	153	1757	142	1633	129	1484	136	1568	120	1382	473	5445
243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	1227
244	2118	17409	2005	16481	1922	15797	1660	13643	1538	12641	1512	12432	1313	10789	19465	160005
311	22431	633463	22575	637522	22731	641922	23019	650065	23217	655656	23268	657076	23423	661466	12091	341445
312	737	43832	725	43135	705	41938	681	40494	662	39386	675	40152	613	36486	233	13868
313	7736	315611	7791	317865	7881	321537	8028	327553	8108	330823	8258	336919	8413	343231	1421	57995
321	233	1399	206	1235	188	1130	155	930	153	916	92	553	86	519	0	0
322	216	3836	197	3502	178	3161	176	3119	111	1974	123	2189	137	2428	0	0
323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
324	803	14247	737	13078	641	11380	478	8479	443	7855	367	6508	255	4515	495	8785
331	22	0	13	0	13	0	0	0	0	0	0	0	0	0	0	0
511	276	0	277	0	274	0	281	0	281	0	274	0	274	0	0	0
512	274	0	212	0	165	0	138	0	130	0	153	0	116	0	84	0
TOTAL	44335	1115796	44335	1119159	44335	1122367	44335	1130453	44335	1136241	44335	1141668	44335	1143253	44334	673830

Table 13: Area and carbon stock values for the MMU study area of Mora