Spatial and Temporal Analysis of Landscape Fragmentation in Cork Oak Woodlands: Are there differences between certified and non-certified areas?

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Mediterranean Forestry and Natural Resources Management

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Resumo

O sobreiro (*Quercus suber*) é uma espécie endémica do Oeste da bacia Mediterrânica. Os montados de sobreiro, sistemas silvo-pastoris de uso múltiplo, têm elevado valor económico, principalmente devido à produção de cortiça. Fontes de receita adicionais, no entanto, podem vir de outros produtos (por exemplo, produção de gado) ou através de pagamento por serviços do ecossistema (PSE). A gestão sustentável dos montados de sobreiro implica considerar outros serviços do ecossistema, para além da cortiça. Áreas contínuas, não fragmentadas de coberto de sobreiro, são essenciais para a gestão sustentável destes sistemas e serviços derivados. A degradação florestal e fragmentação do coberto contraria a sustentabilidade e o uso múltiplo dos montados de sobreiro. A certificação florestal, uma ferramenta que visa promover a gestão florestal sustentável, tem se expandido nas áreas de montado de sobreiro. Esta tese investiga o grau de fragmentação e perda de coberto florestal de sobreiro, entre 2005 e 2015, na zona de Coruche, Portugal, uma região coberta pela certificação florestal. Mais especificamente, comparam-se e quantificam-se alterações na paisagem durante o período considerado, usando quatro métricas de paisagem no programa FRAGSTATS 4.0: percentagem de paisagem (PLAND), densidade de bordadura (ED), razão de área de perímetro (PARA_MN) e índice de contiguidade (CONTIG_MN). Além disso, comparam-se diferenças nestas métricas entre áreas certificadas e não certificadas na área de estudo. Os resultados mostram que os valores médios de quatro métricas da paisagem são tendencialmente diferentes, mas que a perda de coberto florestal e o grau de fragmentação, entre 2005 a 2015, não é significativamente diferente (teste Man-Whitney) entre áreas com e sem certificação. Os resultados sugerem também que a perda de continuidade florestal é tendencialmente menor nas áreas certificadas. Este trabalho é um contributo para investigação futura sobre gestão sustentável e fragmentação do coberto florestal no montado de sobreiro.

Palavras-chave: Sobreiro, certificação florestal, métricas da paisagem, gestão florestal sustentável, fragmentação de habitat

Abstract

Cork oak (*Quercus suber*) is an endemic species to the western Mediterranean Basin. Cork oak woodlands have high economic value mainly due to cork production. Additional sources of revenue may come from other products (e.g. livestock production) as well as through payment for ecosystem services (PES). Sustainable forest management plan in cork oak woodlands should also consider ecosystem services. All these services imply large areas of cork oak woodlands and high forest coverage in cork oak woodlands landscape. Deforestation and forest degradation are barriers to achieve sustainable and multiple-use on cork oak woodlands landscapes (*montados*). Since 2000s, forest certification, a governance tool aiming to promote sustainable forest management, has been expanding in cork oak woodlands. In this study, I analyze the changes of fragmentation and forest cover loss on cork oak woodlands landscape, in *coruche*, Portugal, where the entire region had been covered by APFC forest certification from 2005 to 2015. More specifically, I compare and quantify changes in cork oak woodlands landscape within the period, by using four landscape metrics in FRAGSTATS 4.0, including percentage of landscape (PLAND), Edge density (ED), mean of perimeter area ratio (PARA_MN), and contiguity index (CONTIG_MN). Moreover, I compare the difference of these changes between certificated and non-certificated landscapes in the study area. My results show that the mean values of four landscape metrics are different, but based on the p-values of Mann–Whitney *U* test, the overall forest loss condition and fragmentation status, from 2005 to 2015, in certificated and non-certificated cork oak woodlands landscape are not significantly different. From 2013 to 2015, the area of forest loss in certificated cork oak woodlands shows continued sharp-decline trend, while in non-certificated cork oak woodlands it shows diametrically opposite steady-growing trend. This study can guide future researches on cork oak woodlands landscape and forest fragmentation.

Keywords: Cork oak, forest certification, landscape metrics, sustainable forest management, habitat fragmentation

Resumo alargado

O sobreiro (*Quercus suber*) é uma espécie endémica da bacia do Mediterrâneo Ocidental. O montado de sobro possui elevado valor económico principalmente devido à produção de cortiça. Fontes adicionais de receita podem vir de outros produtos (por exemplo, produção de gado), bem como através do pagamento por serviços do ecossistema (PES). O plano de gestão florestal sustentável em montado de sobro deve também considerar e beneficiar outros serviços do ecossistema. Todos estes serviços requerem grandes áreas de montado de sobro e elevada cobertura florestal na paisagem. Infelizmente, a desflorestação e a degradação florestal têm sido barreiras para se conseguir uma utilização sustentável e múltipla nas paisagens de montado de sobro (montados). Desde 2000, a certificação florestal, um instrumento de governação que visa promover uma gestão florestal sustentável, tem vindo a expandir-se no montado de sobro. Neste estudo, analisei as alterações da fragmentação e perda de cobertura florestal na paisagem do montado de sobro, em Coruche, Portugal, onde toda a região foi coberta pela certificação florestal APFC de 2005 a 2015. Mais especificamente, comparo e quantifico as alterações na paisagem de montado de sobro, utilizando quatro métricas de paisagem no FRAGSTATS 4.0, incluindo percentagem de coberto (PLAND), densidade de bordadura (ED), razão média da área perimetral (PARA_MN) e índice de contiguidade (CONTIG_MN). Os dados, usados nesta tese, são principalmente arquivos raster processados a partir de imagens de detecção remota obtidas por satélite. Os dados raster de cobertura florestal para a área de estudo foram obtidos a partir da plataforma Global Forest Change 2000-2019 da Universidade de Maryland, EUA. Este conjunto de dados global encontra-se dividido em blocos de 10 x 10 graus, e resolução espacial de 30 metros por pixel. A imagem utilizada no trabalho que cobre uma zona a sul de Lisboa (30-40N, 0-10W) onde se situa a área de estudo. Os dados sobre localização de parcelas de montado de sobreiro sob certificação florestal foram obtidos a partir de um trabalho de Doutoramento (Dra. Teresa Mexia) em curso que se baseou em dados do Inventário Florestal Nacional.

Esta tese, segue a metodologia e os princípios teóricos apresentados no livro Gergel S. E. et al, 2017. As métricas da paisagem foram desenvolvidas para quantificar padrões espaciais em paisagens heterogéneas, e evidenciam a interação entre padrões espaciais e processos ecológicos. Estas métricas visam descrever, definir e comparar paisagens classificando-as como, por exemplo: diversas, fragmentadas, agrupadas ou conectadas. O trabalho para esta tese dividiu-se em várias etapas, e recorreu a várias plataformas operacionais e de software. O primeiro estágio consistiu no processamento e transformação dos dados em ArcMap e ArcCatalog. Neste estágio, os dados raster foram reclassificados, recortados e transformados em imagens TIFF. O segundo estágio desenvolveu-se com recurso ao software Fragstats e Pycharm. Neste estágio, foram escolhidas as principais métricas de paisagem analisadas nesta tese. Fragstats é um programa de análise espacial, que calcula uma ampla variedade de métricas de paisagem. O Pycham é uma plataforma onde as análises espaciais podem ser conduzidas em linguagem python. Os resultados da análise das métricas de paisagem são depois armazenados em arquivos Excel. A última etapa consistiu na análise dos resultados obtidos em RStudio.

Nesta tese comparam-se métricas de paisagem as em montado de sobreiro certificado e não certificado. Foram usados testes T de Student quando os dados tinham distribuição normal ou testes U de Mann-Whitney para dados não paramétricos. Foi também analisada a variação do coberto de montado entre 2005 e 2015, e eventuais diferenças entre áreas de montado certificado e não certificado. Os resultados mostram que os valores médios das quatro métricas de paisagem analisadas não são significativamente diferentes. A métrica CONTIG_MN, um índice de continuidade e conectividade entre manchas de montado, foi tendencialmente diferente entre áreas certificadas e não certificadas (p=0,0531). Um valor mais alto de CONTIG_MN significa que as manchas na paisagem são mais adjacentes e conectadas tendo este valor sido mais elevado nas áreas certificadas.

Apresentam-se sugestões para melhorar os resultados obtidos em trabalhos futuros. Primeiro, é aconselhável ampliar a amostra analisando um maior número de parcelas. Neste trabalho foram analisadas 28 parcelas em áreas certificadas e 30 parcelas em áreas não certificadas. Em segundo lugar, o tópico de perda de coberto florestal e padrões de fragmentação deve ser abordado a escalas maiores sendo preferível realizar-se à escala regional ou nacional, e em diferentes regiões de Portugal ou de outros. Terceiro, os trabalhos sobre fragmentação da paisagem são preferíveis para escalas temporais superiores às usadas no trabalho como, por exemplo, 3 a 5 décadas ou até mais. Esta tese pode, no entanto, contribuir para investigação futura sobre a paisagem do montado de sobro e fragmentação florestal.

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1. Introduction

Forest certification aims to promote sustainable management of forests around the world. Within forest certification, managers and landholders voluntary commit with socio-economic and management standards within their estates. There are two major global forest certification schemes: Forest Stewardship Council (FSC) and the Program for the Endorsement of Forest Certification (PEFC) which together cover 12% of global forest area (UNECE/FAO 2019). FSC, in particular, was established in 1993, as an international non-profit, multi-stakeholder organization and was the original pioneer of forest certification. FSC promotes the responsible management of the world's forests, bringing together experts from the environmental, economic and social spheres. FSC aims to promote "environmentally appropriate, socially beneficial, and economically viable management of the world forests" (FSC, 2019). FSC was launched in Portugal in December 2006, and subsequently expanded rapidly across the country. By December 2019, there are around 126 thousand hectares of certified *montado*, which represents 17% of total area and 23 Chain of Custody certificates held by cork companies in Portugal (FSC Portugal, 2019). The PEFC was founded in 1999. It is an independent, non-profit, non-governmental organization which promotes sustainably managed forests through independent third-party certification. It is based in Geneva, Switzerland (PEFC, 2019). In Portugal PEFC certified already 269.000 hectares of forest, which represents 8% of the national forest total area. The certification of areas with cork oak trees represents 3% of this value, approximately 22 thousand hectares (PEFC Portugal, 2019). Cork oak woodlands are multiple use systems in which main production is cork, a non-wood forest product. Portugal is the country in the world with largest area of cork oak cover, and generation 50% of present of world's cork production. Well managed cork oak landscapes are also characterized by high biodiversity including, the occurrence of endemic and endangered vertebrate species and generate ecosystem services such as long-term carbon storage (Bugalho et al., 2011). In the next section of this thesis, I provide a complete literature review on cork oak woodlands, covering the history, ecology and management (including forest certification) of the system in Portugal. I also review the landscape ecology including fragmentation and other landscape metrics of cork oak woodlands.

1.1. Statement of work: cork oak management challenges

A. Quantify changes in cork oak woodlands landscape, namely fragmentation and forest cover loss, in the study area (Coruche) in Portugal between 2005 and 2015.

B. Compare cork oak woodlands fragmentation and cover loss between certified and non-certificated areas.

1.2. Research aims

A. General aim: To detect and investigate cork oak cover dynamics in the region of Coruche, Portugal.

B. Specific objectives:

1) Calculate cork oak landscape fragmentation metrics in study area between 2005 and 2015.

2) Assess potential differences in cork oak landscape fragmentation metrics between certified areas and non-certified areas.

1.3. Hypothesis

1) There are differences in landscape metrics between certificated areas and non-certificated areas.

2) In areas under forest certification, cork oak cover loss and fragmentation are lower than that in non-certified areas forest landscape in the study area.

2. Literature review

2.1 Cork Oak Woodlands

2.1.1 History and development of Cork oak woodlands

Cork oak, *Quercus suber L.*, is an endemic species of the western Mediterranean basin (Figure 2.1). It is an evergreen tree with sclerophyllous leaves, which grows in carbonate-free soils and is native both to western European countries (Portugal, Spain, Italy and France) and northern African countries (Morocco, Algeria and Tunisia) (Figure 2.1). Cork oak forests occupy an estimated area of over 2.2 million hectares in the West Mediterranean basin. Around 90% of the area of distribution of the species is found in Portugal, Spain, Morocco and Algeria (AMORIM, 2010). Cork oak is better adapted to grow in warm and humid or sub-humid conditions. Although the species may occur within a range of altitudes varying from sea level to 2000 meters its optimal growth occurs until 600 meter of altitude (Pereira, 2007). Since 1900s, there has been mainly unsuccessful tries to introduce cork oak in countries outside the western Mediterranean region. Although main tree product is its bark, the cork, the species have also been used as a decoration and shade tree along roadsides and or as viewing tree in botanical gardens. Reasonably good acclimatization has been attained in Bulgaria (Petrov & Genov, 2004), New Zealand (Macarthur, 1994), southern Australia, Chile, and California (Gomes, 2010). However, in none of these countries a successfully cork industry was developed, in spite of reasonably good growing conditions for cork oak. Despite an ongoing cork oak tree density decline, Portugal remains the largest world producer of cork, with a well-established cork industry, followed by Morocco, Italy (especially Sardinia), and Spain (Pereira, 2007).

2.1.2 Cork oak biology

Similar to other oak species within the *Fagaceae* family, cork oak has both female and male unisexual flowers in different inflorescences within the same individual tree. Most trees have flowers of both sexes, which results in a high level of self-incompatibility. Cork oak also produces acorns which mature within the same year as the flowers from which they originate as well as acorns that only grow and mature within the autumn of the following year. The proportion of acorns of the same or following year after flower formation varies spatially and temporally in response to environmental factors and meteorological conditions (Díaz-Fernández, Climent, & Gil, 2004). As other oak, cork oak has a very long life-cycle, especially for an evergreen tree species, which can last 200 years or more.

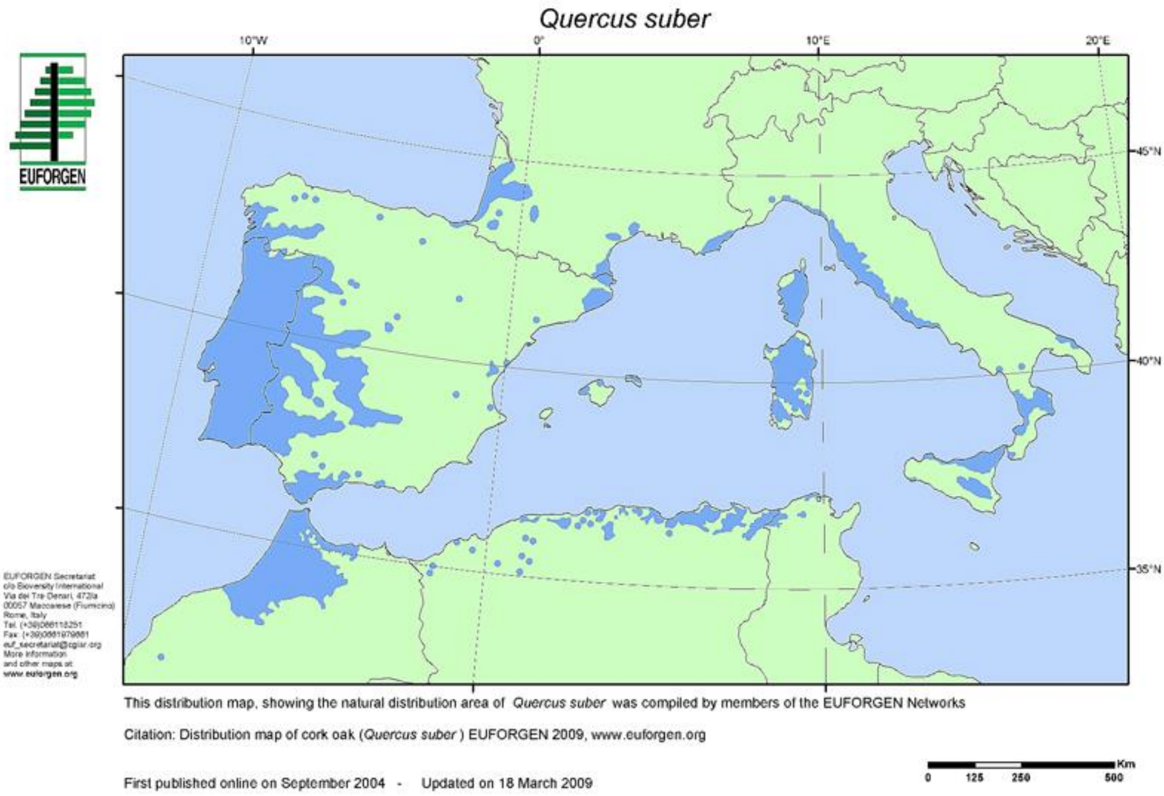


Figure 2. 1 Distribution of Quercus suber (cork oak) (Source: European Forest Genetic Resources Program: http://www.euforgen.org/species/quercus-suber/)

The species is also very well adapted to disturbances as fire or browsing by ungulates. Its outer bark is composed of a compact, elastic, and thermally insulating tissue of dead cells with highly impermeable walls (Pereira, 2007). This special bark, the cork, is also one of the major differences of cork oak from other relative species. Every year, a new layer of suberized cork cells is produced by cork oak, which does not come off but accumulates in the form of annual rings. Cork is usually harvested each 9 to 12 years without felling the tree. Cork, which can be as thicker as 150 mm, contributes to protect the tree against wild fire, mechanical damages and other disturbances (Pausas, 1997). When compared with other Mediterranean species, a thick cork confers a competitive advantage to cork oak and cork oak woodlands, which are resilient to periodic burning and fire. Except from extremely cold conditions, cork oak is also resistant prolonged droughts (Caldeira et al., 2015). The adaptive traits of cork oak evolved within the socio-ecological context of the Mediterranean regions and benefited people, including a crucial role in the wine industry as cork is mainly used as wine bottle stopper. Cork oak is indeed a symbolic Mediterranean species and considered a national tree species in Portugal.

2.1.3 Cork Harvest

Cork oak woodlands landscapes are mainly prized as a source for cork stoppers, the backbone of the cork economy. Cork stripping is best be done when the cork cambium is still active, between late spring and early summer. If conducted when cambium is inactive, cork stripping may damage and kill the tree as the inner bark is removed through the vascular cambium. Cork harvesting has attracted interest and inspired much admiration and curiosity. A major negative consequence of cork stripping may be the exposure of the unprotected trunk surface to pathogens (e.g. *Hypoxylon mediterraneum*) and the temporary reduction of protection against wildfire damage (Gomes, 2010).

2.1.4 Cork oak savanna

Mediterranean cork oak woodlands have been shaped by people that, through management or sometimes new plantations, developed cork oak areas with a relatively low ensity of trees, but where other activities such as livestock grazing may occur (Gomes, 2010). Cork oak woodlands have usually a low tree cover (30-60 *Q. suber* trees per hectare), at times mixed with Holm oak (*Quercus rotundifolia*) and, sometimes, with other tree species (e.g. *Pinus pinaster, Pinus Pinea*). Mediterranean cork oak woodlands have also high conservation valueas they are characterized by a diverse shrub understory intermixed within grassland patches that support high biodiversity. A heterogeneous combined mix of shrub formations interspersed with grasslands, fallows, and less often, cereal cops also characterizes the understory structure of the cork oak woodlands (Pulido, 2014). Also, active management and human use is necessary for cork oak woodlands to maintain their ecosystem services and functions (Gomes, 2010). Among ecosystem services, beyond cork production, recreation is very common (e.g. as it happens in the Natural Park of Los Alcornocales Natural in Spain) (Pausas, 2006) but services as long-term carbon storage, preventions against wildfire or regulation of the water cycle are also services commonly generated by cork oak woodlands (Bugalho et al 2011).

2.2 Cork Oak woodlands in Portugal

2.2.1 Cork Production in Portugal

In Portugal, cork oak (*Quercus suber L.*) stands cover 737 thousand ha, which concentrates 34 percent of the world’s area of cork oak forests and 23 percent of the national forest (Gomes, 2010). As the figure shows (Fig. 2.2), approximately 100,000 tons of cork are harvested each year. Portugal, which has a third of the total area of cork oaks, is the largest producer, being responsible for 50% of the world's cork production (AMORIM, 2010). Also, denominated as *montados*, cork oak woodlands contribute to the economic, social and environmental development of the country (Navarro, Catalao, & Calvao, 2019).

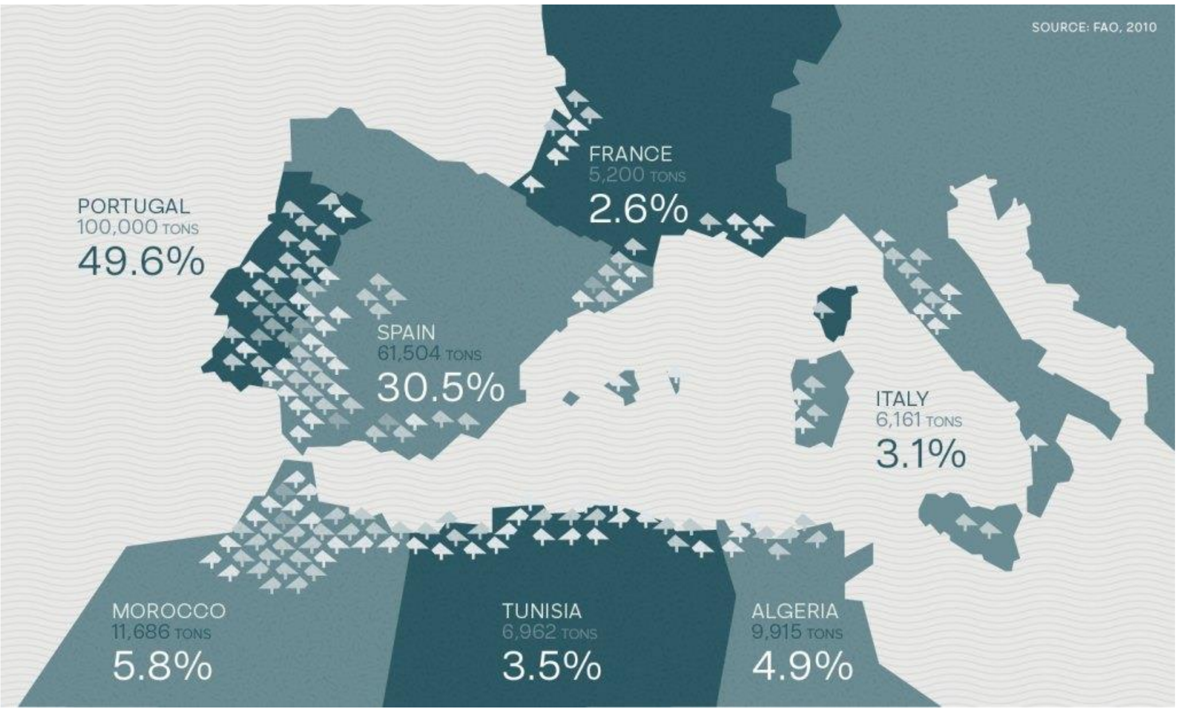


Figure 2. 2 Cork Production in Mediterranean countries (AMORIM, 2010).

As one of the two main countries, along with Spain, where the cork oak woodlands are mostly managed for cork production, Portugal is the country with the largest area of cork oak cover and main cork producer in the world. The world annual cork production is 374,000 tons, from which 51% is produced by Portugal and 23% is produced by Spain. The annual production of cork is relatively stable but fluctuations may occur due to climatic conditions or disturbances such as, for example, the 2003 forest wildfires or the 2004 drought in Portugal.

2.2.2 Cork oak woodlands inventory in Portugal

Portugal has completed the latest version of the national forest inventory in 2015, and is in the process of updating the next revisions of Inventory. The National Forest Inventory (NFI) is a public service provided by the Institute for Nature Conservation and Forests (ICNF), since 1963. The mission of NFI is to supply updated statistical and basic cartographic information regarding to the abundance, state and condition of the Portuguese forest resources, and therefore contributing with this information towards forest sustainable management. The first edition Portuguese National Forest Inventory took place during the years of 1965 and1966, when the first national forest evaluation occurred. It included a biometric characterization of forest stands based on the measurement of a sample of field plots. Since then, there were more five more National Forest Inventories at an approximately 10-year periodicity (Table 2.1). National Forest Inventories have become the cornerstone for forest policy and methods have evolved to allow the monitoring of forest transformation over time. The latest National Forest Inventory also

	Designations	Year of reference
NFI1	National Forest Inventory	1965
NFI2	1st National Forest Inventory Revision	1974
NFI3	2nd National Forest Inventory Revision	1985
NFI4	3rd National Forest Inventory Revision	1995
NFI5	5th National Forest Inventory	2005
NFI6	6th National Forest Inventory	2015

Table 2. 1 List of National Forest Inventory in Portugal since 1965.

included the evaluation of new forest features, including habitat identification, soil parameters characterization (through laboratory analysis) and fuel model assessment, to support new reporting requirements. The National Forest Inventories of Portugal and Spain provide information on cork oak distribution within the Iberian Peninsula (Figure 2.3). In Portugal, the area of highest concentration of cork oak woodlands is found south of the river Tagus in the regions of Alentejo and Tagus Valley, district of Setubal, Évora, Beja, Portalegre and Santarém (Pereira, 2007).

2.2.3 Cork oak woodlands development in Portugal

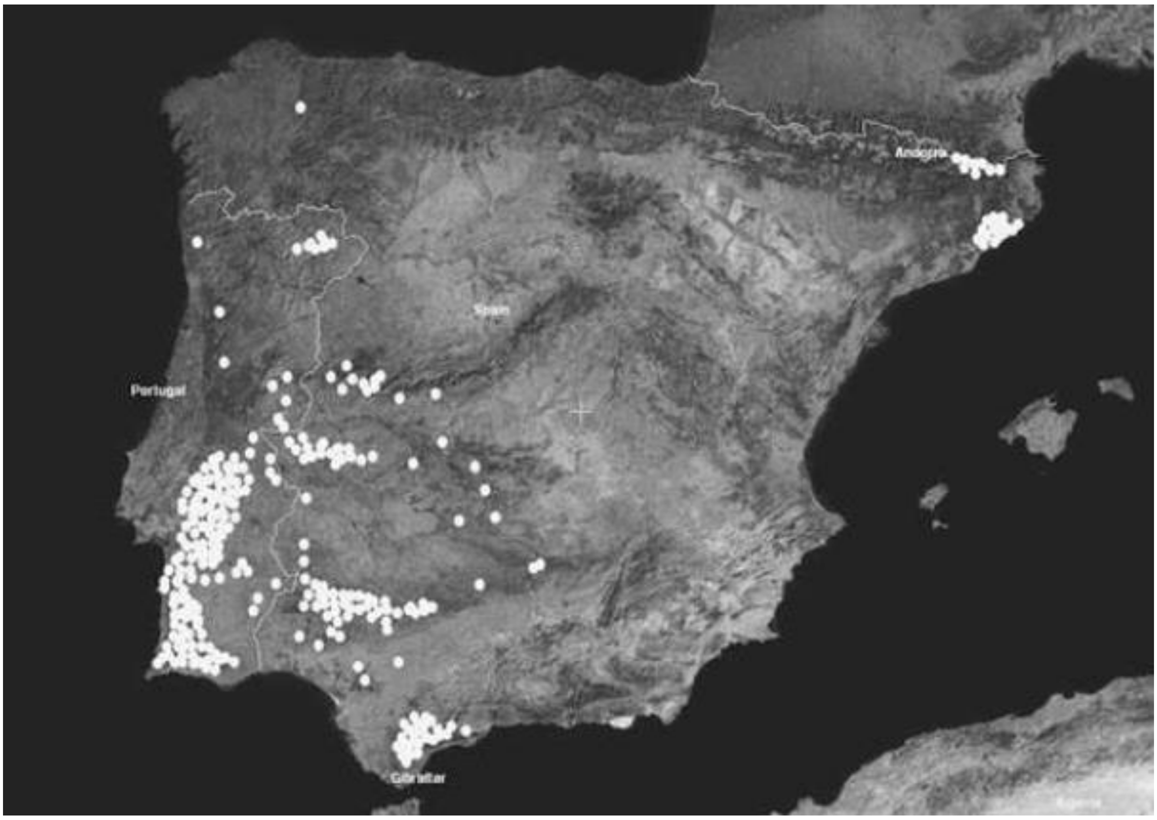
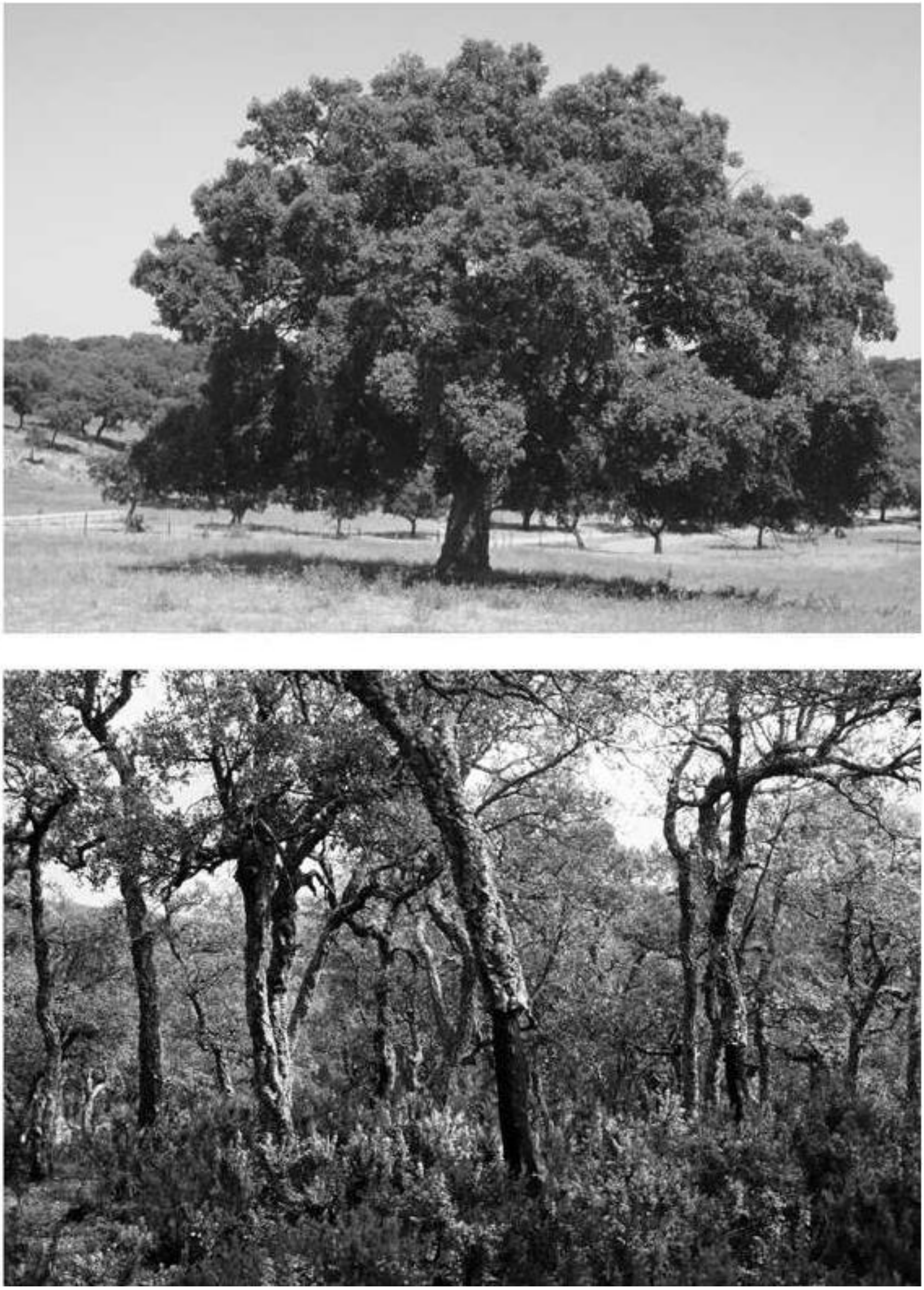


Figure 2. 3 Cork oak distribution map in Portugal and Spain (Pereira, 2007).

In Portugal, the importance of cork oak has been recognized very early by law, which can be chased back to the 13th century. People developed different types of silvo-pastoral systems around cork oak and within regional and historical differences. Open cork oak woodlands, with a relatively low density of trees and structurally similar to savannas, occur in southern Portugal and have other uses beyond cork production. Oak tree cover and density vary with site conditions. In more degraded lands, of high soil erosion, and poor soil quality, or where extreme drought is common, oak tree density may be less than twenty trees per hectare. Conversely, in areas of higher soil fertility, oak tree density may be over sixty trees per hectare. Other oaks (*Quercus rotundifolia*, *Quercus coccifera*), different conifers (Pinus pinaster, Pinus pinea) and various fruit trees, such as pear (*Pryuscommunis*), carob (*Ceratonia siliqua*), and olive (*Olea europaea*) can occur in cork oak woodlands also known as *montados* (Gomes, 2010). Montados are diverse, heterogenous and well adapted systems to the changeable and unpredictable Mediterranean climate factors. Originally, the *Montado* system was managed and designed to provide multiple goods and services, including pasture and browse for livestock, cereal cropping, firewood, charcoal, fruits, oils, berries, mushrooms and cork(Gomes, 2010). The demand and interest in cork production increased during the last two centuries, with the development of the wine industry and the use of cork as wine bottle stoppers. There are significant variations in cork production and quality among cork oak trees even within the same population. Also, remarkable differences in cork quality and other characteristics, occur between tree generations and individual trees. Typically, cork oaks have a low spreading form, thick branches and a limited height, which is ranges from 14 to 16 meters. When cork oak grows open and sparse woodland or savannas, it can have a very large crown. For example, some mature and old-grown trees are found to have crowns with 500 square meters projection size, together with large stem circumferences. Cork oak trees can also have narrower crowns and higher tree trunks in dense stands and more intensively planted forests (Figure 2.4) (Pereira, 2007). Changes in cork oak woodlands management occurred along time. Nowadays, in the managed *montado* system, the shape of cork oak trees differs from the non-managed system, partly because of tree pruning from early stages. Presently, many trees have a main stem bifurcation coming out from a low height followed up with two or three main boughs set with open angles to the stem, which finally shaped a circular crown with a flattened top. This tree form si perceived as the symbol for cork oak landscape and is used as the logo for cork related stuff (Figure 2.5), for example, for the Alentejo region or for the wine stoppers (H. Pereira, 2007).



(a)

(b)

Figure 2. 4 Comparison of cork oak sizes: (a) Isolated tree in open land (b) Closed trees in a dense forest stand (Pereira, 2007).

Figure 2. 5 (a) Typical cork oak architecture in the managed agro-forestry systems; (b) Symbol of natural cork wine stoppers (Pereira, 2007).

2.3 Forest Certification and the management of cork oak woodlands

2.3.1 Purpose of forest certification

Forest certification is a voluntary process under which forest managers and landowners comply with socio-economic and environmental management standards. Together with forest management certification there is the chain of custody certification, under which the industry is certified by assuring that a pre-defined proportion of certified raw material enters the chain of custody. Currently, forest certification cover over 526 million hectares of forests globally, namely through two dominant certification schemes: FSC and PEFC (Lee & Crook, 2019) (FSC "Facts & Figures," 2019). Forest certification may contribute to the United Nations sustainable development goals. SDG number 8, for example, refers to adequate working conditions and economic growth, SDG number 12, relates to responsible consumption and production and SDG number 15 refers to life on land. Under forest certification an independent third party, also known as certifier, assesses the quality of forest management and production following a set of standards, formulated by a public or private certification organization. The process of forest certification and followed up labelling service, is a method and marketing approach to inform the consumers that the sustainability of wood, forest resources and the production of goods, which adds market value to the certified forest products.

2.3.2 Forest certification organizations

Forest certification is a voluntary process under which, forest managers and landholders comply with socio-economic and environmental management standards, that are third-party independently audited

(Auld et al., 2008). Wood and non-wood forest products (e.g. cork) originated in certified areas are sold with a label, recognized by the market, which adds market value to such products. The main certification schemes are the Forest Stewardship Council (FSC) and the Programme for the endorsement of Forest Certification (PEFC). The policies of both PEFC and FSC are based on three pillars: social, economic and environmental impacts. PEFC was founded in 1999, and was considered a certification system better adapted to small forest owners and entrepreneurs. FSC was created in 1993 by NGOs of 25 different countries. By December 2019 (Fig. 2.6), 200 million hectares forest areas were certificated by FSC around the world ("Facts & Figures," 2019). FSC, as an international membership organization, it is a platform for forest owners, forest industries and environmental organizations to improve forest management practices. The international centre of FSC is based in Bonn, Germany and includes decentralized network of FSC partners distributed worldwide. In addition to a global standard of certification, FSC also developed national and regional standards adapted through public participation and discussion to different countries. These standards are closely aligned to the global certification standard and its criteria, but are adapted to local context situations.

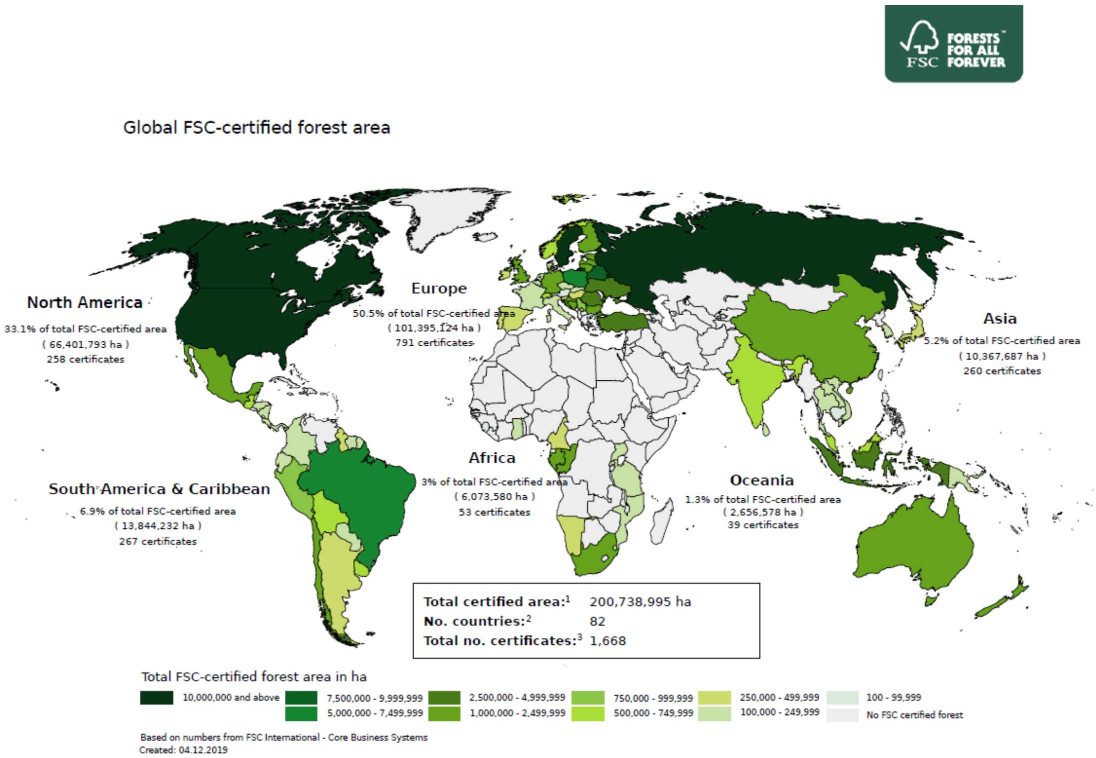


Figure 2. 6 Global FSC- certificated forest area ("Facts & Figures," 2019).

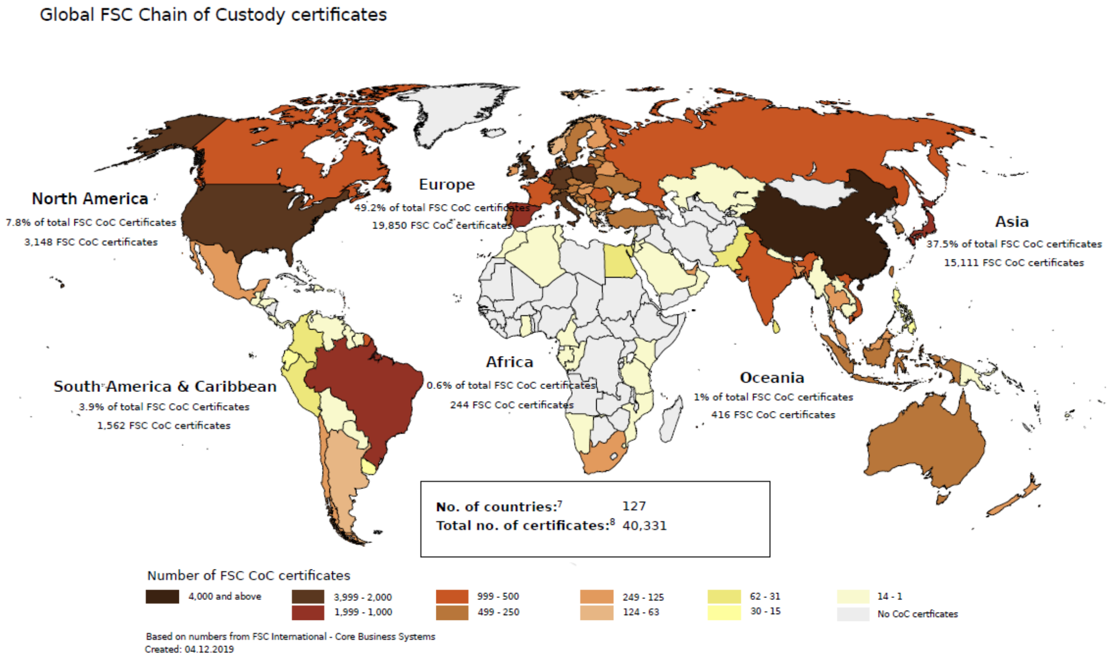


Figure 2. 7 Global FSC chain of custody certifications (“Facts & Figures,” 2019).

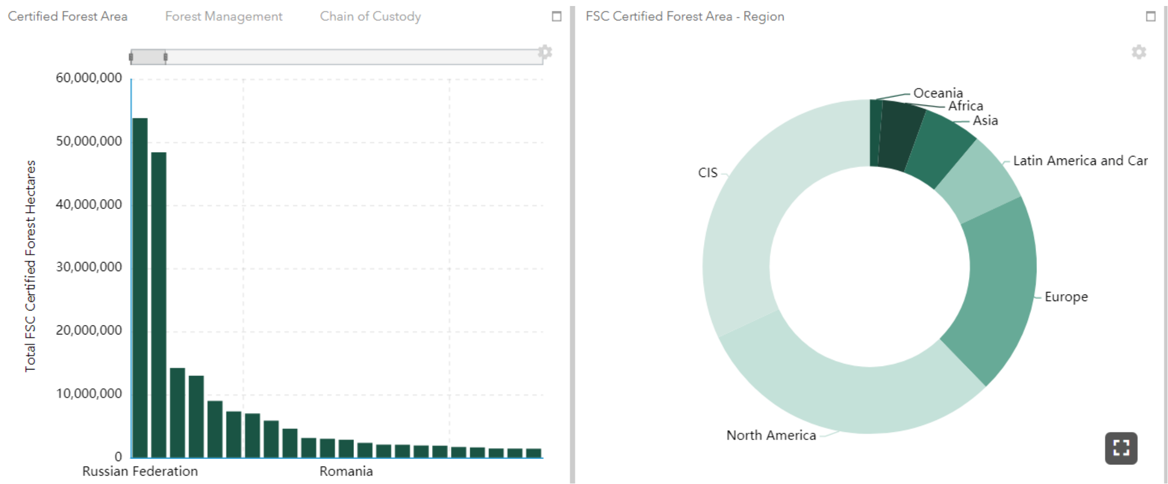


Figure 2. 8 PEFC certificated forest area by country. (Lee & Crook, 2019)

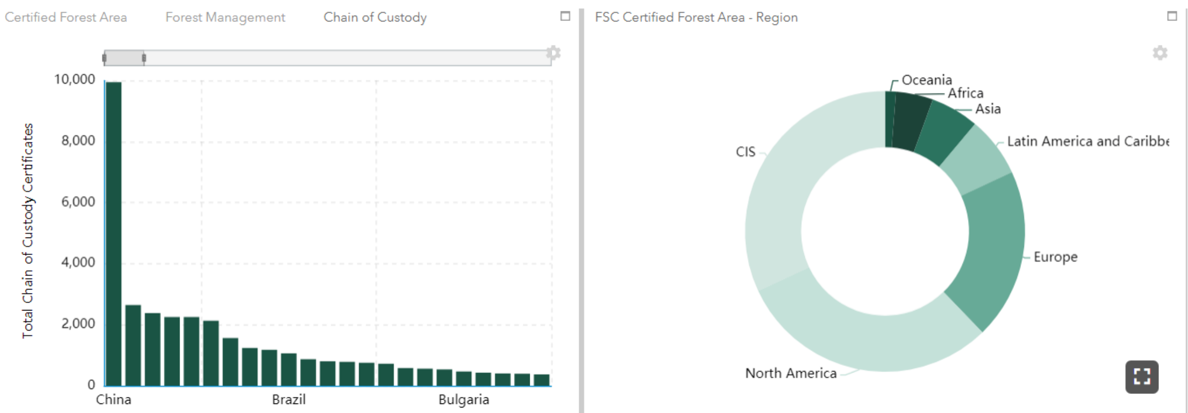


Figure 2. 9 PEFC certificated chain of custody by country. (Lee & Crook, 2019)

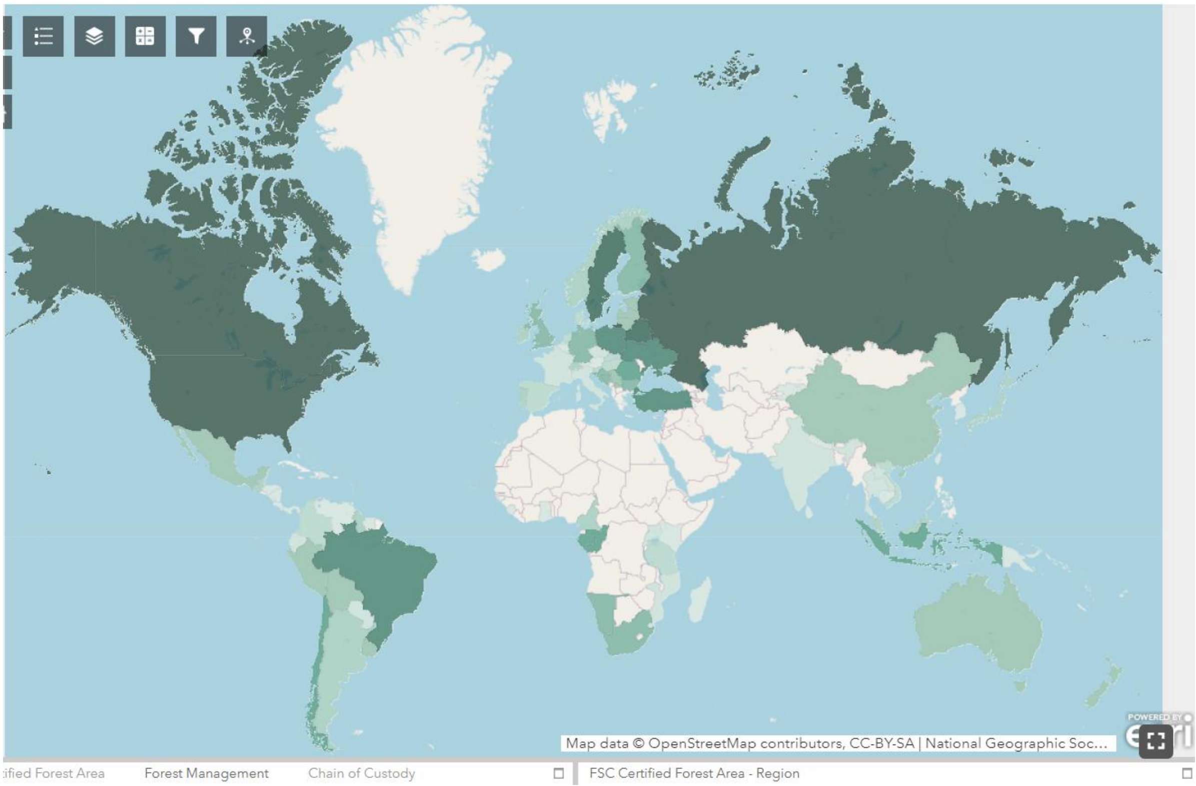


Figure 2. 10 Global PEFC- certificated forest area. (Lee & Crook, 2019)

By December 2019, FSC certification of forest management were applied in 82 countries worldwide, with total 1,668 certificates (Fig 2.6). The FSC certifications of chain of custody are applied in 127 countries with a total number of 40,331 certificates (Fig. 2.7). By the end of 2019, more than 325 million hectares of forest area (Fig. 2.8), almost the two thirds of all certificated forest areas around the world (Lee & Crook, 2019), were certified under the PEFC. Additionally, over 20,000 companies and organizations, located in over 70 countries, have achieved PEFC chain of custody certification (Fig. 2.9). The PEFC chain of custody monitors and tracks forest raw material source to the end product. Every step in the supply chain is closely monitored and independently audited to ensure that unsustainable and unclear raw material sources are excluded. By now, 53 national members, with 47 endorsed national certification systems, have joined forces under the PEFC umbrella to collaborate and promote the implementation of sustainable forest management (Fig. 2.10). FSC and PEFC differ in their frameworks. Although both systems aim for same end purpose The FSC standard is an international standard which is nationally and regionally adapted through public participation of stakeholders representing the social, economic and environmental chambers, which are levelled. PEFC forest management standards originated mainly within the forest industry. From the operation point of view, the roles of FSC and PEFC are different. FSC acts as a second party and issues the certification of the third-auditing parties themselves during the process. PEFC acts as a third party in the process and do not handle the certification details but use certified institutions in the process. In summary, the aim of FSC and PEFC is one and same, which is to create and implement sustainable forestry policy. They both hope to protect the forest resources against destruction and save resources for the future generations.

2.3.3 Certification of forest management and of the chain of custody

Certification of forest management monitors the management practices applied to forests. Certification of the chain of custody verifies if feedstocks and forest raw materials used by the industry, or kept during the production process, are controlled and separated from non-certified materials. Forest management certification standards address a broad range of economic, social, environmental aspects of forest management. Among others, management standards cover the workers performance and "gives voice" to communities and neighbours living around certified forest areas. Different stakeholders can be engaged in forest certification process through public participation. Public participation includes forest owners, entrepreneurs, associations, timber companies, pulp and paper companies (for example, UPM and Stora Enso) or, for example, flooring companies. Stakeholders can participate in forest certification processes for various interests and reasons. Such participation can be motivated by the expectation of improved product prices or, for example, increase and maintain the market share of their products. It may also be a way to promote and improve a product brand in respect to consumers as well as achieving social and environmental goals, such as the Millennium Goals of the United Nations. Forest certification is a market-based mechanism has promoted the sustainable use of forest resources. Indeed, consumers are putting more weight on the social and environmental responsibilities of forest products and tend to give preference to products with forest certification labels (FAO, 2014). Consumers may be willing to pay a higher than average price for this certification label. Currently, there is a discussion on whether consumers value certification of sustainability, based on social and environmental dimensions. For non-wood forest product such as coffee, based on market research, Lingnau suggest that certifications do not significantly increase the average consumers' willingness to pay for coffee products (Lingnau et al 2019). Other research work, however, suggest that stakeholders and participants in wood products supply chain are willing to pay a premium for certified raw materials which cover the costs invested in forest certification (Aguilar & Vlosky, 2007). This research, work considered data collected from the United States resident population, between 1995 and 2005. Results show that a higher probability of paying a premium are associated to consumers who are self-motivated and initiated to seek out certified products and who believe and have faith in the environmental impacts that forest certification brings to the ecosystems. Last but not least, there is also a strong relationship between the income of consumer and willingness to pay for forest certified products (Aguilar & Vlosky, 2007).

2.3.4 Forest certification in Portugal.

WWF launched Forest Stewardship Council (FSC) certification in Portugal in December 2006. Since than the forest certification process has subsequently expanded rapidly across the country.

WWF has been collaborating with the main association of cork oak producers in Portugal, APFC (Associação de Produtores Florestais de Coruche), within the context of forest certification, since 2008. WWF provided technical assistance for the management and conservation of biodiversity in cork oak landscapes and according to forest certification standards of cork production. Although cork oak is primarily exploited for cork production, this system generates other ecosystem services important both for people and companies. WWF have been promoting and motivating the sustainable management of cork oak landscapes through different approaches, including a project aiming to promote forest certification through payment for ecosystem services (PES). PES is a relatively innovative approach aiming to promote nature conservation by rewarding sustainable management practices. PES mechanisms vary widely from narrow to wider scales. At narrower scales, there schemes that work between private buyer and sellers, of ecosystem services in which voluntary and conditional transactions are arranged for the delivery of ecosystem services (ES). At broader scales, there are PES schemes between the ecosystem services providers and people who benefit from these ecosystem services and that usually pay these services indirectly ("Ecosystem Services Foreword", World Bank 2012). PES can be defined as a scheme under which the beneficiaries reward the ecosystem services providers, through market payment or subsidies. According to WWF, four main ES are being covered by PES schemes around the world today: watershed services, carbon sequestration, landscape beauty and biodiversity conversion (Limon, 2010). PES have been also applied in different countries in Europe, (for example, the Mediterranean countries (Sgroi et al., 2016) North America, , Mexico (Rodríguez-Robayo, Perevochtchikova, Ávila-Foucat, & De la Mora De la Mora, 2020), Costa Rica, Equador and other Latin America countries. WWF has a long term and (since 2007) international partnership with Coca Cola company to protect and clean water resources around the world. Such partnership gave origin to a PES scheme in the cork oak landscapes of Portugal (M. Bugalho & Silva, 2014). This PES scheme was implemented within the regions of Rivers Tagus and Sado watershed, located in southern Portugal, in the provinces of Ribatejo and Alentejo, and where the largest and continuous area of cork oak landscape occurs in Portugal. In this region cork oak covers over 0.5 million hectares, and it is located over the largest water aquifer of Iberian Peninsula and which is a strategic resource for Coca-Cola company. This PES initiative, named Green Heart of Cork (GHoC), aims to contribute to certification and the conservation of cork oak in Portugal. The GHoC project was launched in November, 2011. Through a GIS platform, geographic and digital information on biodiversity, forest cover and location of main aquifers was integrated into a web-GIS platform denominated HABEaS: Hotspot Areas for Biodiversity and Ecosystem Services (M. N. Bugalho, 2014)). The information generated by HABEaS was used to identify those ares important for the conservation of biodiversity and water resources (higher water recharge rates). The GHoC project relies on a payment for ecosystem services (PES)-like scheme and on voluntary market approaches to promote the sustainable management of cork oak landscapes within the region of the Tagus and Sado watersheds. Under this project, Coca-Cola agrees to pay a fee to those members of the cork oak producer forest association (APFC) that committed with FSC forest certification and were located in areas important for biodiversity and water conservation (M. N. Bugalho, 2014)). Target areas were identified through optimization procedures (Bugalho et al., 2016). Since its launched other companies have joined the project. To achieve the various goals of sustainable management in the cork oak woodland landscapes, It is possible to use approaches like, "Payment for ecosystem services" schemes, with the participation of Forest Stewardship Council (FSC) certification or Reducing Emission from Deforestation and Degradation and enhancement of carbon stocks (REDD+) programs, could create economic incentives that promote sustainable use and, ecological and economic viability of cork oak savannas, and of socioecological systems elsewhere (Bugalho et al., 2011). By the end of December 2013, there were 339,000 ha of certified by Forest Stewardship Council (FSC facts & figures, 2019). Within the forest certified area there were 100,000 ha of cork oak landscapes certified for cork production which approximately cover 30 percent of the total certificated area in the country.

2.4 Cork oak woodlands landscape values

Cork oak woodlands landscape represent one of the best cases in the Mediterranean countries, showing how a forest ecosystem comprises social, environmental, and economic functions, and how these functions (Fig. 2.11) were developed and have been maintained over hundred years (Bugalho et al 2009). In cork oak landscapes, forest areas alternate with multiple purpose agri-forestry farmland systems or livestock production. These unique landscapes also integrate biodiversity conservation services by harboring different plant and vertebrate species of conservation value (Bugalho et al 2011) that coexist with uses as forestry, agriculture, grazing, hunting, or other recreational uses (Bugalho et al 2009).

2.4.1 Cork production value

Cork oak is primarily utilized for cork production. Other uses and activities in cork oak landscape include, cattle grazing, hunting, and agriculture (Bugalho, 2009; Gomes, 2010). Cork is harvested between each 9 to 12 years, without cutting down the trees. Once the cork is harvested, the original phellogen cells die but later on, in a couple of years, another new layer of active phellogen differentiates in the outer phloem, maintaining the production of cork (H. Pereira, 2007). The cork oak tree is distinct in its high capability to regenerate a new outer bark after harvest (Pausas, 1997). The first quality cork is harvest when the tree is approximately 30 years old. After that, harvesting operation is conducted at 9 to 12 years intervals. This gap period is necessary for the trees to grow a new layer of bark, at approximately about 30 mm thick, before another cork harvest occurs. Approximately 300,000 tons of cork are harvested annually in the western Mediterranean Basin, and most of them, which is about 70 percent are transformed into bottle stoppers end product (Bugalho et al 2011). Beyond bottle stoppers, other end products include flooring, insulation material, for example, the external fuel tanks of NASA's Space Shuttle program(Lusa, 2020, July 6), clothes and accessories, or decorative objects. Globally, cork is the sixth most important non-wood forest product, with an estimated annual export value of US$329 million (Berrahmouni et al., 2007). Except from the international trading of raw cork materials, the processed end cork products also generate approximately US$2 billion in annual revenues (Berrahmouni et al., 2007). Although the spread and promotion of synthetic stoppers and metal screw-caps increased economic competition with traditional cork stoppers the cork industry as reacted to this completion through different activities such as better communication and novel cork end products. This competition and decreased market share has contributed to world market devaluation of cork (Gomes, 2010) which dropped approximately 30% between 2003 and 2009 but have now recovered.

2.4.2 Conservation and biodiversity value of cork oak woodlands

Cork oak forest landscapes have high biodiversity conservation value. Globally cork oak covers a surface area of over 2,700,000 ha (ICMC 1999), and these landscapes have several hundred years of history and human use. Cork oak landscapes provide connectivity, space and habitat requirements for a large number of species, including endemic and endangered vertebrate species. For example, one of the

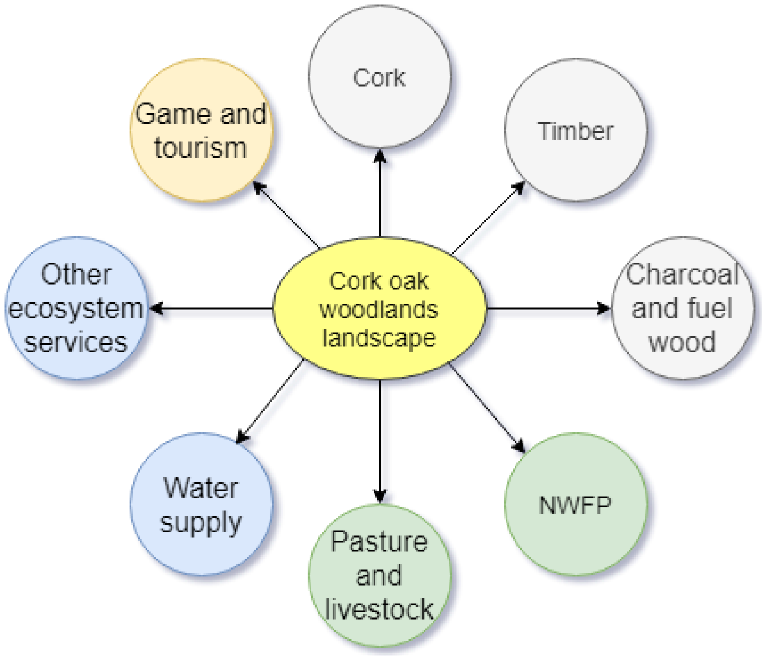


Figure 2. 11 Values of cork oak woodlands landscape (Surová & Pinto-Correia, 2008)

most critically endangered and magnificent Mediterranean mammals and predator species, the Iberian Lynx, *Lynx pardinus*, occurs in cork oak (Berrahmouni et al., 2007, Bugalho et al 2011). Cork oak forest landscape also provide important ecosystem services, such as long-term carbon storage (Bugalho et al, 2009). In terms of biodiversity, cork oak forest landscapes can also hold a high level of flowering plant species, varying from 60 to 100 per 0.1ha (Diaz et al. 2003). Most plant and fungi species from cork oak forest landscapes are non-timber forest products used for their aromatic, culinary or medicinal properties. Cork oak woodlands are classified ecosystems under the Pan European network of protected areas Natura2000 (Rosebro, 2016) and are also considered as a "biodiversity-based product system", as defined by the Convention on Biological Diversity (Ref). The different habitat types that coexist within the cork oak landscapes support a high diversity of animal and plant species. Human use and activities in cork oak landscapes have been crucial to maintain habitat heterogeneity and biodiversity value at both local level and regional level. Human-shaped cork oak woodlands (the Portuguese *montado* or the Spanish *dehesa*) also have grasslands of high plant species richness which may reach 135 species per 0.1ha (Diaz et al. 2003). Anthropogenic management and natural succession have created a multiplicity of ecotones (Blondel, 2006) in these systems. For instance, a wide variety of butterfly and passerine bird species exist in cork oak woodlands than dense forest, grasslands or croplands that are adjacent to these woodlands (Pulido, 2014). A wide range of species have benefited from the habitat continuity, which is offered in a long-term by the evergreen cork oak forest landscape. Within the cork oak landscape, varying tree structure, and shrubland and grassland areas compose a matrix which provides habitat for threatened species such as the Eurasian black vulture (*Aegypius monachus*), the vulnerable Iberian imperial eagle (*Aquila adalberti*), and the critically endangered Iberian lynx (*Lynx pardinus*) (Carrete & Donázar, 2005).

2.4.3 Carbon sequestration value

Cork oak savannas also play an important role in the global Carbon budget project (Lehmann 2010). As old growth forests (Luyssaert et al., 2008), cork oak savannas have been accumulating and maintaining carbon stock for long periods, through ecological succession processes. Old and large trees, with high crowns, store carbon above the ground whilst deeply developed root systems retain carbon under the ground. For instance, a cork oak savanna with an average 30 percent tree cover could sequester up to $140 gCm^{-2}yr^{-1}$ (Pereira, 2007; Bugalho et al 2011). Cork harvest slightly break down the balance of tree carbon system, which may lead to approximately 4 percent losses of the total cork oak tree biomass, between successive cork harvests (Pereira unpublished) which is relatively insignificant and negligible in relation to the effects on the whole carbon cycle and carbon storage of the ecosystem (Pereira unpublished).

2.4.4 Non timber forest products value

Beyond cork production, other products of economic value are harvested and used in cork oak woodlands. These are mainly non-timber forest products, such as acorns, resins and pine seeds from *Pinus pinea* or wood from *Pinus pinaster* which are pine trees that may coexist with cork oak in the system. In relation to acorns (used as animal feed but also for human consumption) these can be collected from cork oak (*Quercus suber)* but also other oak species such as, *Quercus ilex, Q. ilex subsp. ballota, Q. canariensis, Q. afares, Q. faginea, Q. pyrenaica*, and *Q. pubescens* that may occur. Aromatic plants, are also an important component and include species as *Myrtus communis, Pistacea lentiscus, Thymus sp., Rosmarinus officinalis*, which are harvested and have high value for cooking, cosmetic or medical products. Aromatic species may show up in the market either as raw materials or end products after chemical extraction processes. Other non-wood forest products related to food harvest, for example, mushrooms (*Boletus sp.* and truffles), honey, cereal crops, and other agricultural products, which can be cultivated in open patches within the cork oak woodlands. Livestock production is also an important use and cork oak landowners can raise species as cattle, pig, sheep, or goats that generate products as meat, milk, wool or leather. Hunting, both small (e.g. rabbits, red-legged partridge) or big game (e.g. wild boar, red deer) hunting is also a common activity in cork oak woodlands. Finally, different fruits can also be found from extensive planted trees or shrubs in the landscape, such as wild edible berries (*Myrtus communis, Arbutus unedo and Rubus sp.*), almonds, olives, or carob. Except from direct sales, these non-timber forest products also provide significant opportunities to develop ecotourism and recreational activities (Berrahmouni et al., 2007).

2.4.5 Other ecosystem services values

Above, I summarize the most economically driven and related values of cork oak forest landscapes. However, cork oak landscapes also provide ecosystems services not tradeable in market such as, soil conservation against landslides and degradation, buffering against climate change and desertification, clean water supply to surrounding communities, below ground water table recharge and above ground run-off control. At a broader scale, these ecosystem services are crucially important to humankind. Currently, forest managers, local government and environmental organizations have nor fully quantified the market value of such ecosystem services. Schemes such as, payment for ecosystems services (PES), escribed above may contribute to valuation and proper reward of cork oak producers also generating these services.

2.5 Landscape ecology and fragmentation in cork oak landscapes

As seen above, cork oak landscapes provide a range of ecosystems services under proper management. In this section, I introduce landscape ecology concepts to address and discuss the effects of fragmentation on different aspects of the cork oak landscapes. Landscape ecology concentrates on the relationship between spatial patterns and ecological processes. The concept of landscape ecology firstly appeared as logical and coherent area of research and application in 1980s. The concepts, theory and research methods of landscape ecology is now well developed and matured. The central subject of the discipline has been assimilated by ecological sciences. In recent years, the interest regarding to landscape ecology research and studies kept growing due to different factors. The more important drivers have been the critical need to understand the rapid and prompt changes that take place in our surround environment. These changes can be approached at wide and broad scales within landscape ecology (Donner, 2015).

2.5.1 Basic landscape ecology concepts and definitions

A landscape is an area that is heterogeneous in at least one aspect of interest (Greenberg, Gergel, & Turner, 2006). People have intuitional sense of the landscape concept and format. For example, it is simple to tell the difference between an agricultural and forested landscape, lowland and mountain landscape, urban and countryside landscape. Landscape ecology emphasizes the interaction between spatial pattern and ecological process, addressing spatial heterogeneity across a range of scales. The initial thought about the concept of "landscape ecology" was firstly introduced by German scholar Carl Troll in 1939 (Troll C., 1939). Landscape ecology fundamentally combines the spatial approach from geography science and functional approach from the ecology science. During the last four decades, scientists have changed and involved their understanding on landscape ecology. In 1983, Forman proposed his ideas that the landscape ecology focuses on the spatial relationships among landscapes, elements and ecosystems (Forman 1983). It tracks the flows and spatial correlation of energy and species among the elements. It also analyzes the ecological processes and dynamics of the landscape mosaics through time. In 1993, Wiens (Wiens et al., 1993)proposed that landscape ecology handles the relationship between the spatial configuration of mosaics and a broader range of ecological phenomena. In 1995, Pickett and Cadenasso (A Pickett & Cadenasso, 1995) proposed that landscape ecology is essentially the study that focus on the reciprocal effects of spatial patterns on ecological processes. In 2019, Francisco Rego proposed an insightful guide to the concepts and practices of modern landscape ecology (Francisco C. Rego, 2019). Jointly, through the development of landscape ecology, this set of definitions intelligibly stresses two important characteristics of landscape ecology. First, landscape ecology expressly addresses the importance of spatial configuration for ecological processes, under the fundamental presupposition that the accurate composition and spatial arrangement of a landscape mosaic affect its ecological system. Second, landscape ecology often deals with different spatial extents (Figure 2.12), but, in general, addresses broader scales. Also, landscape ecology considers human influence, has an obvious and dominant factor influencing the landscape patterns worldwide. Human activities are sometimes considered as an crucially important component of the landscape ecology definition (Greenberg et al., 2006). Definitions of commonly used terms in the landscape ecology, which is adapted and developed from Forman (1995) (Greenberg et al., 2006) are presented below (Table 2.2).

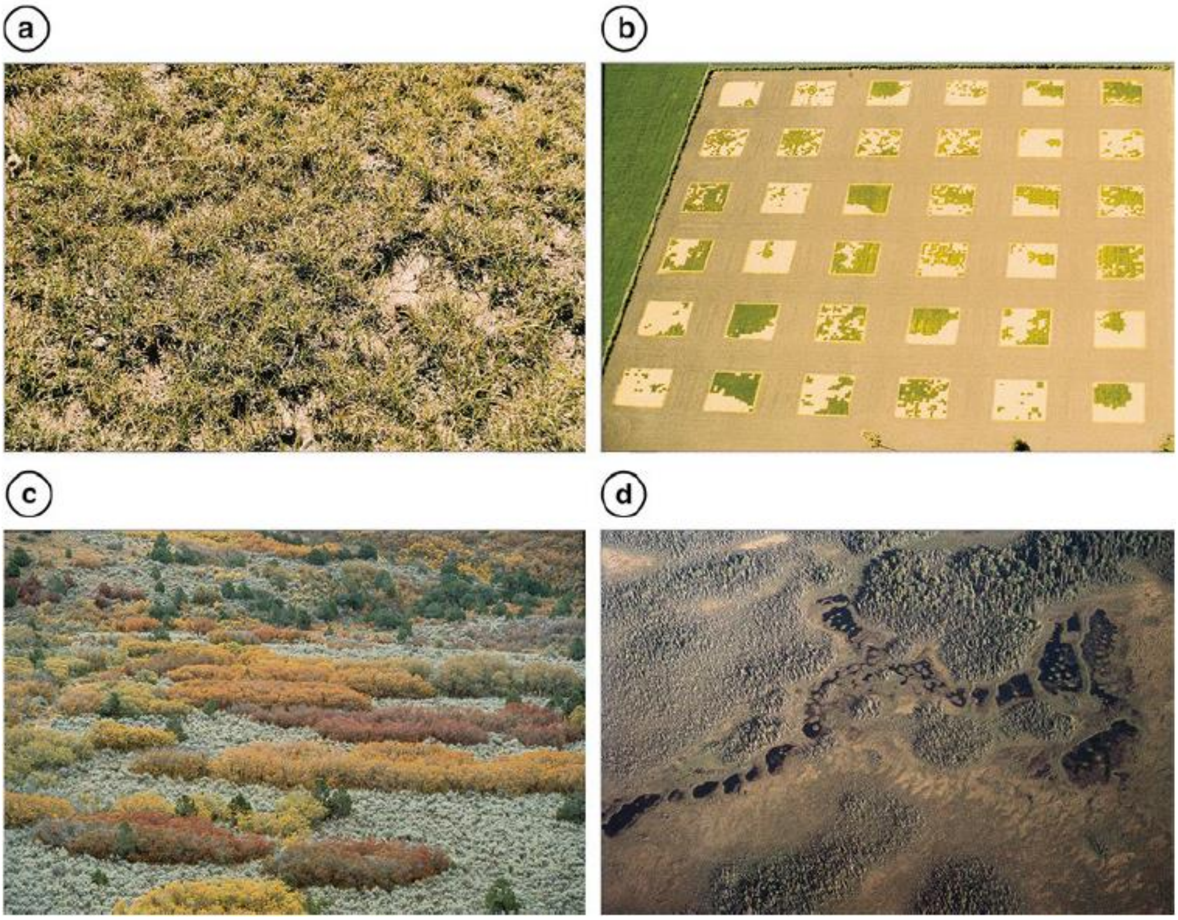


Figure 2. 12 Photos display the concept of landscape as a spatial mosaic in different spatial scales (Greenberg et al., 2006). (a) Micro landscape, from the perspective of a grasshopper. Vegetations cover in the 4 m^2 micro landscape that is occasionally disrupted by bare ground. (Photo by Kimberly A. With.) (b) Set of experimental micro landscapes used for exploring relative effects of habitat abundance and fragmentation on arthropod communities in an agroecosystem, including 12 plots of 16 m^2. (Photo by Kimberly A. With.) (c) Clones of Gambel oak (*Quercus gambelii*) in Colorado showing heterogeneity within approximately 1 km^2. (Photo by Sally A. Timker.) (d) Aerial photograph of a muskeg and string bog landscape, Alaska. (Photo by John A. Wiens.)

2.5.2 Landscape patterns

As we go into a landscape, we focus on the composition and spatial configuration of that landscape. More detailed, we observe what elements are present, how much is the relative

Term	Definition
Composition	What and how much is present of each habitat or cover type.
Configuration	A specific arrangement of spatial elements; often used synonymously with spatial structure or patch structure.
Connectivity	The spatial continuity of a habitat or cover type cross a landscape.
Corridor	A relatively narrow strip of a particular type that differs from the areas

	adjacent on both sides.
Cover type	Category within a classification scheme defined by the user that distinguishes among different habitats, ecosystems, or vegetation types on a landscape.
Edge	The portion of an ecosystem or cover type near its perimeter, and within which environmental conditions may differ from interior locations in the ecosystem; also used as a measure for the length of adjacency between cover types in a landscape.
Fragmentation	The breaking up of a habitat or cover type into smaller, disconnected parcels; often associated with, but not equivalent to, habitat loss.
Heterogeneity	The quality or state of consisting dissimilar elements, as with mixed habitats or cover types occurring on a landscape; opposite of homogeneity, in which elements are the same.
Landscape	An area that is spatially heterogeneous in at least one factor of interest.
Matrix	The background cover types in a landscape, characterized by extensive cover and high connectivity; not all landscapes have a definable matrix.
Patch	A surface area that differs from its surrounding in nature or appearance.
Scale	Spatial or temporal dimension of an object or process, characterized by both grain and extent.

Table 2. 2 Definitions of terms that are commonly used in landscape ecology (Greenberg et al., 2006).

amount elements are present, and how these elements are spatially arranged. In different landscapes, more or less, we can discover some regular patterns through the spatial configuration. For example, in a boreal forest landscape where the landscape is dominated by fires, it is possible to discover tracks of old forest, young forest, and early successional vegetation depending on time since fire. In a deciduous forest, we may notice small gaps in a continuous canopy of trees and boundaries of forest patches, which is dominated by different tree species. In the case of smaller extent landscapes, it is possible for us to observe complex patterns of vegetated and un-vegetated surfaces. From the examples above, we can tell that landscapes are unique because of the observed spatial patterns, which are driven by multiple factors including both deterministic and stochastic process. Contemporary landscapes are shaped by many forces, including both abiotic conditions (such as climate, topography, and soils) and biotic interactions (such as, competition, mutualism, herbivory, and predation) that can generate spatial patterns even when the environmental conditions are homogenous. Also, natural disturbances, natural succession, and past or present human activities that leads to land use changes are all important drivers of landscape configurations. In summary, geographical variations at broad scales set the constraints, within which biotic interactions and disturbances set the stage affecting landscape configurations. Presently, landscape patterns are shaped from multivariate causes that operate and interact over many spatial and temporal scales (Donner, 2015). Above, I listed the key drivers of landscape patterns, including the abiotic and biotic interactions, disturbance and ecological succession, and interaction with human land -use. In the following graphs, I will address these factors in more detail. The abiotic template includes climate, landform and soils. Climate refers to the compound, long term, and generally dominant weather of a region (Bailey, 1996). The climate behaves as a strong control on biogeographic patterns through the distribution of energy and water. At the broad scale, climate varies from latitude and continental position, who have impacts and influences on temperature and distribution of moisture. The impacts of climate are also modified by landform. Landform refers to the characteristic geomorphic features of the landscape. It is the result of geologic processes that produced physical relief patterns and the development of soils. Landforms can be classified into several types, near flat plains, rolling irregular plains, hills, low mountains and high mountains. They are identified on the principle of three major characteristics: (1) Relative amount of gently sloping land, which is no more than 8 percent, (2) Local topographic relief, (3) generalized profile, for example, where is the gentle sloping land. It could be in the valley bottom or in uplands. And, how much gently sloping lands are located in the place (Bailey, 1996). Another factor of the abiotic template is soil factor. In terrestrial landscapes, soils not only provide mineral nutrients and water, but also support mediums, which are required by the vegetation to grow on. The substrate and soils of the surrounding landscape also affect the chemical quality of the water in aquatic systems. To conclude, together, climate and landform establish the template upon which the soils and biotas of region develop (Donner, 2015). The second driver that shapes landscape patterns is biotic interactions among organisms. It can be positive such as facilitation, or negative, such as competition and predation. All these interactions lead to different dynamics of spatial configurations even within homogeneous environmental resources. With the premise of same abiotic template, the result of competition between two species could theoretically end up in homogeneous distribution by competitive exclusion, for example, by just one species remaining in the system (Chapman & Gause, 1935). The winner would be the best competitor who have the chance to establish itself throughout the landscape. Theoretically, it results in homogeneous exclusion. However, in the real condition, there are always important exceptions to competitive exclusion. In reality, a group of competing organisms may interact in different complex processes, which leads to different results of final distributions under many alternative stable states. These multiple stable states may often take place at the stage that several different species potentially occupy and dominate a site. About which specific species actually occupy and dominate the site depends on little and stochastic changes in the initial conditions (Sutherland, 1974). Landscape patterns also result from the activities of keystone species and influenced by dominant organisms. In many cases, dominant species define spatial patterns in the landscape. These dominant species have been termed foundation species, which defines the basic structure of the community by providing domestically steady conditions for other species. They provide habitats, modify and stabilize fundamental ecosystem processes, for example the nutrient cycling (Ellison et al., 2005). Within the context of abiotic template, foundation species transform the abiotic conditions and provide a resource base and substrate for other populations in the landscape. Another driver of shaping the landscape patterns is human land use factor. Both rate and direction can be changed by patterns of land use. The environment that organisms live, reproduce and scatter on is the result of interactions between land use patterns and abiotic template. Land use refers to the way that human utilize the land and its resources (Meyer, 1995). For example, human can use land to build parking lot and buildings, houses, recreation, industry or food production. Land cover is a related and similar term of land use, which means the dominant habitat and vegetation, for example, agriculture, wetland and forests. The last driver to shape landscape patterns is disturbance and succession. Disturbance and the subsequent succession process of vegetation contribute the most to the development of patterns on the landscape. Disturbance include any comparatively individual event take place in time that disturbs ecosystem, community, population structure, resource availability, substrate, or physical environment (White & Pickett, 1985), for example, fires, volcano eruptions, floods, and storms. Normally, we have a set of attributes to descried the characteristics of disturbances, such as, frequency, spatial extent and magnitude. The spread of disturbance and post disturbance recovery process is an important proxy that create patterns at a variety of spatial and temporal scales. Together with the other three drivers that we described before, disturbances shape heterogeneous footprint on both terrestrial and aquatic (for example, riverine) landscapes (Parsons et al, 2005).

2.5.3 Landscape metrics

Landscape metrics are developed and used by scientists and scholars to quantify spatial patterns in heterogeneous landscape, because landscape ecology emphasizes the interaction between spatial pattern and ecological process. These metrics seek to describe and define and compare landscapes across subjective concepts as, clumpy, dispersed, random, diverse, fragmented, clustered or connected. To understand the relationships between the landscapes that we study, it is necessary and to understand landscape metric, which are used to analyze and quantify landscape patterns. For example, if a landscape changes through time (from time point *t* to time point *t+1*), we are interested in quantifying such difference and knowing how patterns have changed. Another aim may be to compare two or more different landscapes or areas (within a given landscape) and detect how different or similar they are. In some cases, a political boundary could result in dramatically different landscape configurations, which is located in close proximity. For example, there are different forest cover patterns along the western boundary of Yellowstone National Park in USA (Turner & Gardner, 2015). In this thesis, my study covers both aims described above. Firstly, we focus on quantifying changes and fragmentation in cork oak forest cover in a study area located in Portugal. Such change may result from different management approaches, including, for example, forest certification. Therefore, we also compare potential differences in landscape metrics in cork oak landscapes where forest certification has been applied during last 15 years, as compared to cork oak landscapes without forest certification. Particularly, I compare landscape metrics of certificated cork oak plots with non-certificated plots in the study area. For the purpose of this thesis, I define two groups of landscape metrics. The first group of landscape metrics are simple. They focus on the composition of landscape, including the proportion of the landscape occupied by each cover type (P_i), dominance and diversity using Shannon Evenness index (Gergel S. E. et al., 2017). Proportion (P_i) of the landscape occupied by each cover type is the most fundamental one of all metrics. It is calculated by "Total number of cells of category *i*" divided by "Total number of cells in the whole landscape (from all categories)".

$$p_i = \frac{\text{Total number of cells of category } i}{\text{Total number of cells in the landscape}}$$

Proportions of different landscape types have a strong influence on other aspects of patterns, such as patch size and length of edge in the landscape (Gustafson & Parker, 1992). Also, the values of P_i are used in calculation of other metrics, where i = 1, and s is the total number of cover types in the map (satellite image). Next metric is named as "Dominance" or "Diversity and Dominance". Dominance (*D*) is used to describe the relative abundance of each cover type in the landscape. The formula to calculate *D* is listed below (O'Neill et al., 1988), where *S* is the amount of cover types, P_i is the proportion

$$D = \frac{\ln(S) + \sum_i [p_i * \ln(p_i)]}{\ln(S)}$$

of the *i*th cover type, and *ln* is the natural log function. The value rages from the maximum values of 1 and minimum value of 0. When the value is close to 1, it addresses that this landscape is dominated by one or very few cover types. In contrast, when the value is close to 0, it means that this landscape is consist of more cover types whose proportion are almost equal. The third index in this group is Shannon Evenness Index (*SHEI*). *SHEI* is calculated as the formula below (Greenberg et al., 2006), where S is the number of cover types, Pi is the proportion of the *i*th cover type,

$$SHEI = \frac{-\sum_i [p_i * \ln(p_i)]}{\ln(S)}$$

and ln is the natural log function. The values of *SHEI* also range from 0 to 1. The value of *SHEI* has the opposite meaning of *D* value. When the value is close to 1, it means that the proportions of each cover type are nearly equal. When the value is close to 0, it indicates that the landscape is dominated by one or several cover types. It is very important to understand that the normalization of metrics is mandatory, which assures that the values lay in a standardized range, for example from 0 to 1. In the formulas of *D* and *SHEI*, the normalization processes are applied by dividing maximum possible value of index *ln* (s). The second group of landscape metrics is defined as metrics of spatial configuration. They are a set of landscape metrics that are sensitive to the specific arrangement of different cover types on the landscape. With these metrics, we can understand the differences of configurations when comparing different landscapes. Within this thesis I investigate cork oak landscape configurations across type and management schemes (certification vs non-certification). I use three metrics to assess relationship among cork oak patches, edge and probability of adjacency. The first metric is Mean Patch Size (MPS). *MPS* is the arithmetic average size of each pattern on the landscape or each patch under the same cover type. It is always calculated as follow:

$$\text{MPS} = \frac{\sum_{k=1}^{m} A_k}{m}$$

m stands for the number of patches that is being selected. A_k stands for *k*th patch area. The next landscape metrics is about edge. Edge calculation provides useful reference to identify how cleft a spatial pattern is. , it can be calculated in several ways, for example, the total edge, edge density and edge area ratio. When two cells of different cover type are adjacent, the shared connected border part is counted as an edge. Every edge is counted once for each cover type in the landscape. For example, in this study, borders between cork oak woodlands and non-forest area will be counted twice. The first time, borders are counted as part of forest edges. The second time, same borders are counted as part of non-forest area edges. I focus on fragmentation of cork oak cover by using use two metrics on edge, including edge density and edge area ratio. The classification will include areas with forest loss detected and areas without forest loss detected. It is important to understand how sensitive edge calculations are to different factors, including data map borders and which have influences on the resulting edge counts and edge area ratios. It is crucial important to be consistent in both algorithm and units under the same set of analysis. The next metric is probability of adjacency ($q_{i,j}$). It shows the probability that a grid cell of cover type *i* is adjacent to a cell of cover type *j*. It is calculated as

$$q_{i,j} = \frac{n_{i,j}}{n_i}$$

the formula above, where $n_{i,j}$ = the amount of adjacent grid cells between cover type *i* and cover type *j*. N_i stands for the total amount of adjacencies of cover type *i*. $Q_{i,j}$ is sensitive to the fine-scale spatial distribution of cover types. It is also called as Q matrix. The value is between 0 and 1. High value indicate that the cells of cover type *i* have a high probability of being adjacent to the cells of cover type *j*. Conversely, if the value is low, the probability is low (Gergel S. E. et al, 2017).

2.5.4 Effects of fragmentation on forest landscapes

Deforestation is a problem worldwide especially in tropical forests, which is caused by both natural and anthropogenic disturbances (Lambin et al., 2001). Over the time, these disturbances remodel the spatial configuration of forest landscapes, which may result in the definitive loss of tree cover or changes in forest spatial patterns attributes (Wang, Tung, & Kao, 2006). It is crucial to monitor the disturbance and post disturbance effects on forest landscape recovery. Recent research regarding the monitoring of disturbances and reporting of forest indicators are supported by the regular and consistent measurements provided by Earth observation satellites. In the paper of Samuel, 2019, they used MODIS and Landsat data to explore trends associated with fire disturbance and recovery across boreal and temperate forests worldwide. In their study, the result showed that 181 million ha out of 2 billion ha of forests were burned by fire disturbance between 2001 to 2018, which is approximately 9 percent of the study area. They found a significant increasing trend of burned areas in Mediterranean forest of Chile with 8.9 percent per year, and a significant decreasing trend in temperate mixed forests in China with -2.2 percent per year. Regarding forest recovery after fire, they found out fast spectral recovery in temperate and mixed forests, with a substantial portion of pixels showing full recovery in 5 years. In contrast, montane grasslands shrublands, temperate coniferous forests and boreal forests showed a longer recovery period (Hislop et al., 2020). In another recent research (Gherardo, 2020), they analyzed spectral recovery rate of Mediterranean coppice forest from clear cut areas by using Landsat Time Series (LTS). Results showed that the coppice system is associated with rapid recovery rate within 2 to 4 years, compared to seeds or seedling spectral recovery of approximately 10 years in boreal and temperate forests (Chirici et al., 2020). This recent research have focused on forest landscape changes after disturbances, both natural and anthropogenic. A question that naturally arises is: How could we detect changes in forest landscape before disturbances occur, to anticipate forest low and allow action by decision makers. In this thesis, I focus on the Mediterranean cork oak forest landscape of Portugal. Cork oak (*Quercus suber* L.) woodlands are undergoing changes including land abandonment or intensification (Bugalho et al, 2011). These processes may cause oak cover losses (e.g., severe wildfire) or lead to woodland degradation. Monitoring changes in the spatial patterns of woodland, especially fragmentation of cork oak cover and patchiness within the landscape may potentially enable the forecasting and anticipate forest losses and allow mitigation of cover loss at an early stage. For example, a study (Costa et al., 2014) analyzed degradation processes in two cork oak woodlands located in Portugal and caused by disturbances as wildfire and oak mortality respectively. In both woodlands, there were similar decreasing on numbers of large cork oak cover patches. Also, by comparison, these authors found that degradation largely resulted in open canopy and clearance. High cork oak woodland degradation was found in patterns clearance larger than 3.7 and 3.4 percent, in more open canopy, they observed losses of 23.3 and 20.5 hectare per year, in the two study areas. Patch metrics, such as fragmentation, are considered a signature of upcoming cork oak woodlands (Costa et al., 2014). In addition to the relationship between fragmentation and deforestation, research has also linked forest fragmentation patterns and configuration with bird diversity (Cherkaoui et al., 2009). In the Mediterranean cork oak landscapes, for example, the maintenance of existing olive grove fragments and riparian galleries within the landscape affected positively the diversity and abundance of passerine bird assemblages (Leal et al., 2011).

Increase in bird abundance is probably caused by increased fruit resources in the landscape (Leal et al., 2011). From the patch habitat perspective, in the case of Portugal *montado* cork oak agroforestry landscape, higher number of mammalian species occur in areas with mixed patterns of orchards, olive yards and riparian vegetation. In this thesis, I will investigate how cork oak cover fragmentation varied between 2005 and 2015 and test if fragmentation patterns differ among areas with or without forest certification forest.

2.6 Sustainable management of cork oak landscapes

Today, the spatial distribution of and tree density within the cork oak woodland landscape are decreasing in both southwestern Europe (Pereira, Domingos, & Vicente editors, 2004) and northwestern Africa (Gomes, 2010). Cork oak woodlands are threatened by lack of use and abandonment in southwestern Europe and by overuse in northwestern Africa (Bugalho et al 2011). Both overuse and disuse affect the carbon balance, tree regeneration and leads to soil degradation, which resulted in increasing of tree mortality and reducing ecosystem carbon stocks (Tiessen et al.1998). With the observation of lacking cork oak health and low natural regeneration, the future of *montado* agroforestry landscape has been questioned. The sustainable management of cork oak woodlands are crucially important and urgently need to take actions. The risk of severe disturbances such as wildfires also increases in unmanaged cork oak woodlands. Other examples, relate to effects on soil carbon storage. For example, shrub encroachment may shift the soil carbon from below to aboveground plant biomass, and increase the risk of above ground carbon losses through wildfires (Jackson, Banner, Jobbaágy, Pockman, & Wall, 2002). Recently it has been shown that lack of cork oak regeneration in *montado* ecosystems may result from management intensity such as using heavy machinery, or high livestock grazing pressure. There are authors considering a maximum livestock pressure of 0.4 LU per hectare and a minimum soil cultivation rotation of 5 years to manage cork oak woodlands (Bugalho et al. 2009, Bugalho et al 2011,Arosa et al., 2017). Regarding to the cork oak regeneration, recent studies also suggest that abandonment and shrub encroachment may inhibit oak natural regeneration and ecological succession. Restoration management actions are required to undertake sustainable cork oak land use systems (Acácio & Holmgren, 2014). Variations in *montado* landscape structural were also found to be related to grazing management, which have implications on the conservation value of the system (Almeida et al., 2016). This study was conducted in 41 *montados* located in two municipalities of Alentejo region, Portugal, and showed that cattle grazing has increases cork oak cover fragmentation and that sheep grazing may increase the heterogeneity on *montado* landscape patches (Almeida et al., 2016). Regarding to the bird communities, a recent study suggest to manage the shrub layer, increase tree diversity and density, and maintain the mosaic cork oak landscape to improve the bird community richness (Pereira et al., 2014). Additionally, under the current global climate

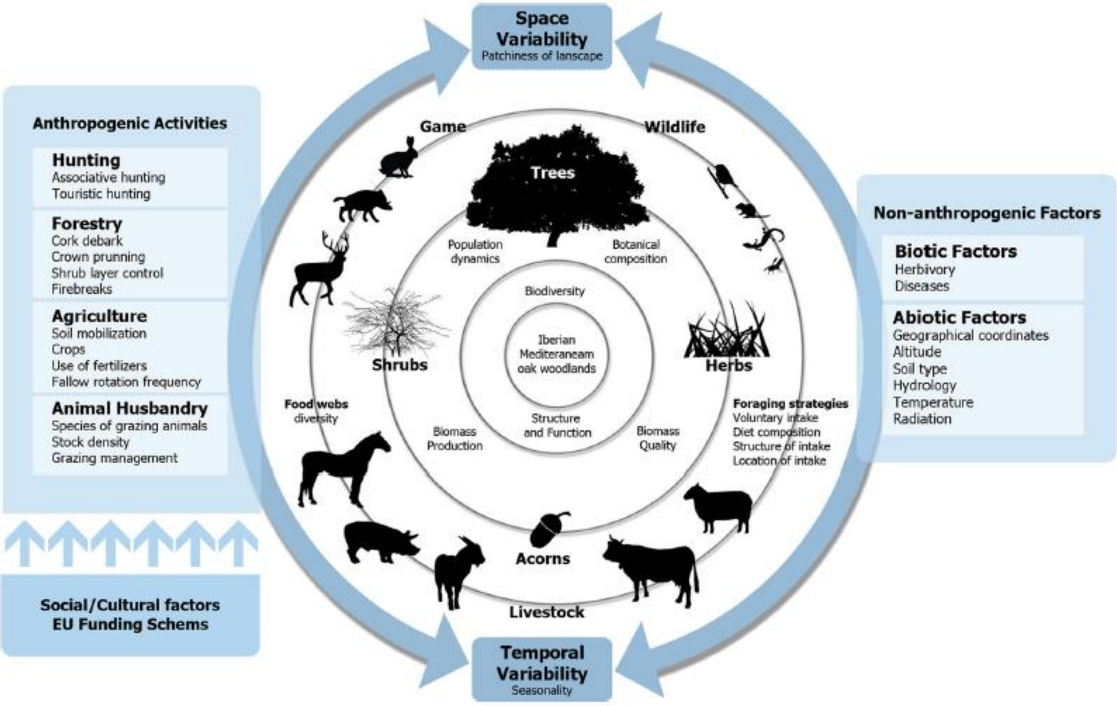


Figure 2. 13 *Montado* key characteristics and dynamics (Ferraz de Oliveira et al., 2013).

change, adaptive management may be required in cork oak landscapes (Canaveira et al., 2015). Results of this study showed that cork production and carbon stock may decrease by 20 and 30 percent, respectively, under different climate change scenarios (Palma et al., 2015). The different ecosystem services generated by (Figure 2.13) cork oak landscapes can be monitored through indicators for understanding and assessing most suitable management practices towards the sustainability of *montado* systems (Ferraz-de-Oliveira, Azeda, & Pinto-Correia, 2016). Forest certification in cork oak woodlands, aim to promote the maintenance of adequate forest cover, abundant natural cork oak regeneration and long-term rotational clearance of understory shrubs. It is also important to consider eventual trade-offs between species diversity, cork production, pasture production and carbon sequestration (Bugalho et al 2016). In this thesis, with temporal data (2005 to 2015) on cork oak cover in study area I test the effects of forest certification and sustainable management on cork oak cover fragmentation and other landscape metrics.

3. Study Area

3.1 Forest certification of cork oak in Coruche region

This study took place in the Coruche region, Portugal, where cork oak woodlands cover about 60% of the total land area. In 1992, a private forest owner from this region established the Forest Producers Association of Coruche (APFC) which aims to provide technical support to cork oak producers. Presently, APFC has developed into an association with more than 300 members that manage 174,000 ha of forest area. In 2006, driven by growing industry and market interests in certification process for natural cork products (stoppers), members of APFC raised interest in forest certification. Following the suggestion of APFC technicians, *APFCertifica*, a group certification scheme was created. It started with 4 members and 9 forest management units (FMUs), covering 6500 ha forest area. Until April 2008, the group project was awarded with an FSC certificate and developed to 12 members and 19 FMUs that cover 10,320 ha forest area. The forest management certification process, in Coruche, was initiated by the International market request for certificated cork stoppers. It finally leaded to a national request for APFC certificated cork feedstock from the industry (Sustainable & Cooperative, 2008).

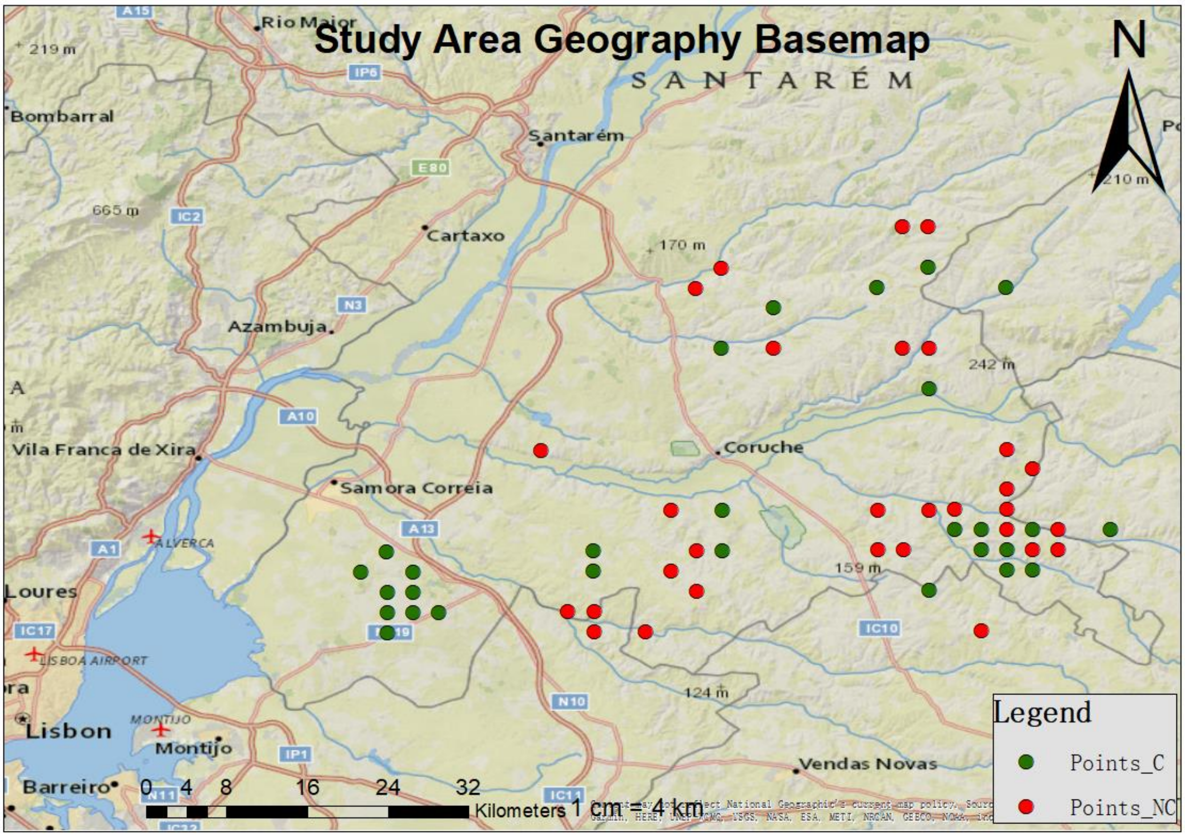


Figure 3. 1 Geographic location of study area in Coruche region, Portugal. (Point C stands for sample points that located in certificated cork oak woodlands and Point NC stands for sample points that located in non-certificated

cork oak woodlands.)

Until 2019, the year that latest version of forest losses Hansen data is available (Hansen, 2013), more than 10 years have passed. Hansen data is a global dataset that is divided into 10x10 degree tiles, consisting of six files per tile (tree cover 2000, gain, loss year, data mask, first and last year). All files contain unsigned 8-bit values and have a spatial resolution of 1 arc-second per pixel, or approximately 30 meters per pixel at the equator. In this study, I issued 58 forest units in total (Fig. 3.1), including 28 certificated forest units by APFC and 30 uncertificated forest units.

3.2 Vegetation cover and climate in *Coruche* region

Coruche, also known as the world capital of cork, plays a crucial important role in cork production that has global impact in this industry. It belongs to a predominately rural area, adjacent to the Lisbon metropolitan area (Figure 3.1). The climate in Coruche region is typical Mediterranean sub humid type with hot and dry summers. The normal annual average precipitation and temperature is 704 mm and

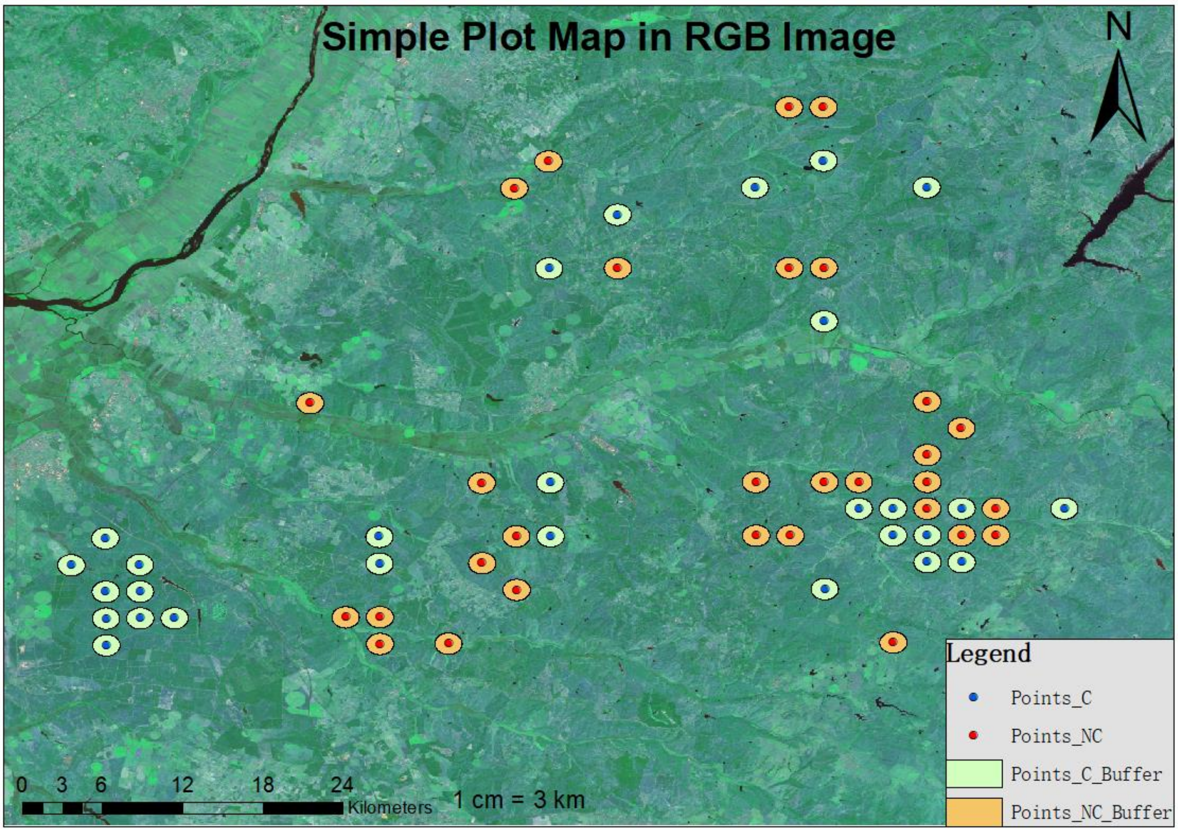


Figure 3. 2 Location and vegetation coverage of simple plots in RGB image. (Source: Hansen/ UMD/ Google/ USGS/ NASA, points C stands for plots selected form certificated cork oak woodlands landscape and point NC stands for plots selected from non-certificated cork oak woodlands landscape. The size of all sample plots is 2 km^2)

15.6°C respectively. The precipitation in this region is mainly concentrated in winter, which creates a window of dry period from June to September (Ribeiro & Tomé, 2002). As we can see from the RGB image (Figure 3.2), in this region 69 percent of the area is covered by cork oak (de Fátima Ferreiro & Sousa, 2019). Since2007 forest certification, namely FSC certification, has been expanding in cork oak landscapes. I identified certificated and uncertificated cork oak areas, which were identified as discrete and evenly distributed points in a map of cork oak woodland. These areas are clustered in the middle region of the study area, surrounded by farms, pastures, cultivated areas and rural communities. The circle plots in Kelly color were extracted from certificated cork oak woodlands. In contrast, circle plots in orange colors were extracted from non-certificated cork oak woodlands. Both circles are 2 km^2 in size, with the radius of 0.8 km. These sample plots shapefiles are created by buffer tool in ArcMap and the GPS location is copied from sample points data, which is provide by Dr. Teresa Mexia, from School of Agriculture (ISA), the University of Lisbon.

4. Data collection

Digital remote sensing data are now widely used and accessible to from several websites, for example NASA, USGS and Plant explorer, to many researchers and students in the university as well as research institutes. The US Landsat and French Spot satellites provide frequent and spatially wide scale worldwide coverage remote sensing data. These data had been rather expensive for many years, but the recent open access to the storage of Landsat imagery provides free data and facilitates current studies. Additionally, since 2015, the European Space Agency's Multispectral Instrument on the sentinel-2 satellite have been providing global multispectral images every 10 days with the resolution of 10 meters times 10 meters. The range of latitude is from 83 degrees north to 56 degrees south. All Sentinal-2 products are free of charge and open to all data users, including the general public, scientific and commercial users under the terms and conditions prescribed by the European Commission's Copernicus Program. As it is known, the resolution of satellite images decreases with increasing scales of landscape analysis. For studies varying from regional to global scales, MODIS data can be used. Airborne scanners like LIDAR, which means light detection and ranging, can also provide complementary image data with fine resolution to match target aspect and specificities of the study areas.

4.1 Original data access

In this thesis, I downloaded raster data of forest cover for the study area from the Global Forest Change

2000-2019 platform of the University of Maryland, USA. This global dataset is divided into tiles of 10x10 degrees, containing unsigned 8-bit values and spatial resolution of 30 meters per pixel. I downloaded image under the classification of (30-40N, 0-10W) that covers the south part of Lisbon where the study area is located (Fig. 4.1), we can see that the original raster data of Hansen 2000-2019 global forest loss is presented in the format of raster data with stretch values, which improves the appearance of the data by spreading the pixel values along a histogram from the minimum and maximum values defined by their bit depth. In my case, this 8-bit raster dataset is stretched from 0 to 19, but in theory the 8-bit data could provide 256 different levels of gray (Gergel, S. E., 2017). From low value to high value, it indicates the severity of forest cover losses. Our sample plots are located within pixels with different values. The coordinated information of APFC sample plots are provided by National Forest Inventory (NFI) in Portugal. The latest version of national forest inventory by NFI, 6th inventory, was conducted in 2015.

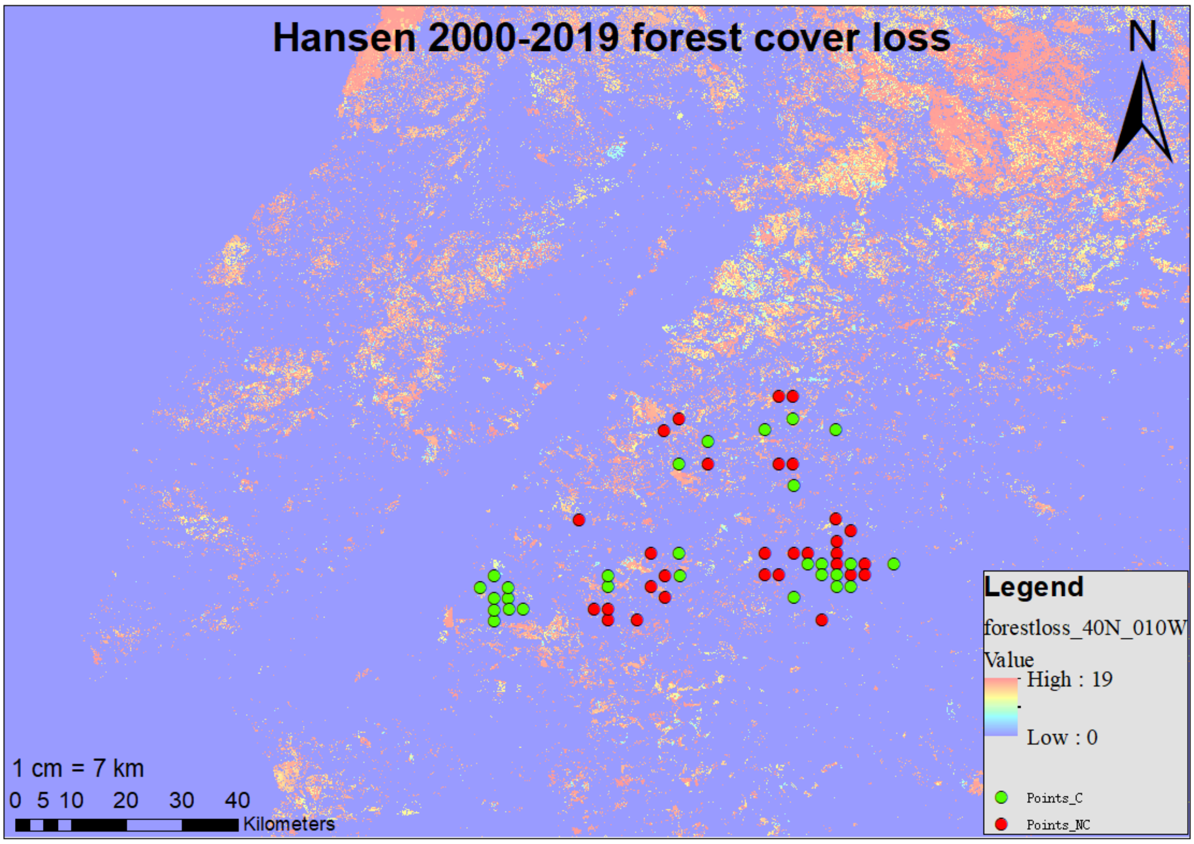


Figure 4. 1 Hansen forest cover loss data 2000-2019 (40N,10W). (Source: Hansen/ UMD/ Google/ USGS/ NASA, Value 0 stands for initial year 2000, and value from 1 to 19 stands for the forest loss detected in each year from 2001 to 2019 respectively)

4.2 Data process

Landscape data can be stored in a geographic information system (GIS) for ease of use and display. In most of the cases computer programs for landscape analysis are designed for use with raster data. Vector data versions is less frequently used. In raster format, a landscape is divided into a grid of square cells that are equal in size. The size of grid cell determines the resolution of the mapped data. Irregularly shaped landscape can be represented within a rectangular perimeter larger than the landscape itself by setting the "background" cells to a value that indicates "no data", for example 0 or 255 in value. In vector format, lines are defined by the boundaries of polygons that are various in shape and size. The mapping unit is not even. The minimum unit correspond to minimum patch size in the mapping landscape. Raster data are more widely used in landscape analysis not only because it is easier to analyze in computer programs but also because most satellite imagery is in raster format. It is also important to consider the accuracy of spatial data or map upon which the analysis of landscape pattern is performed.

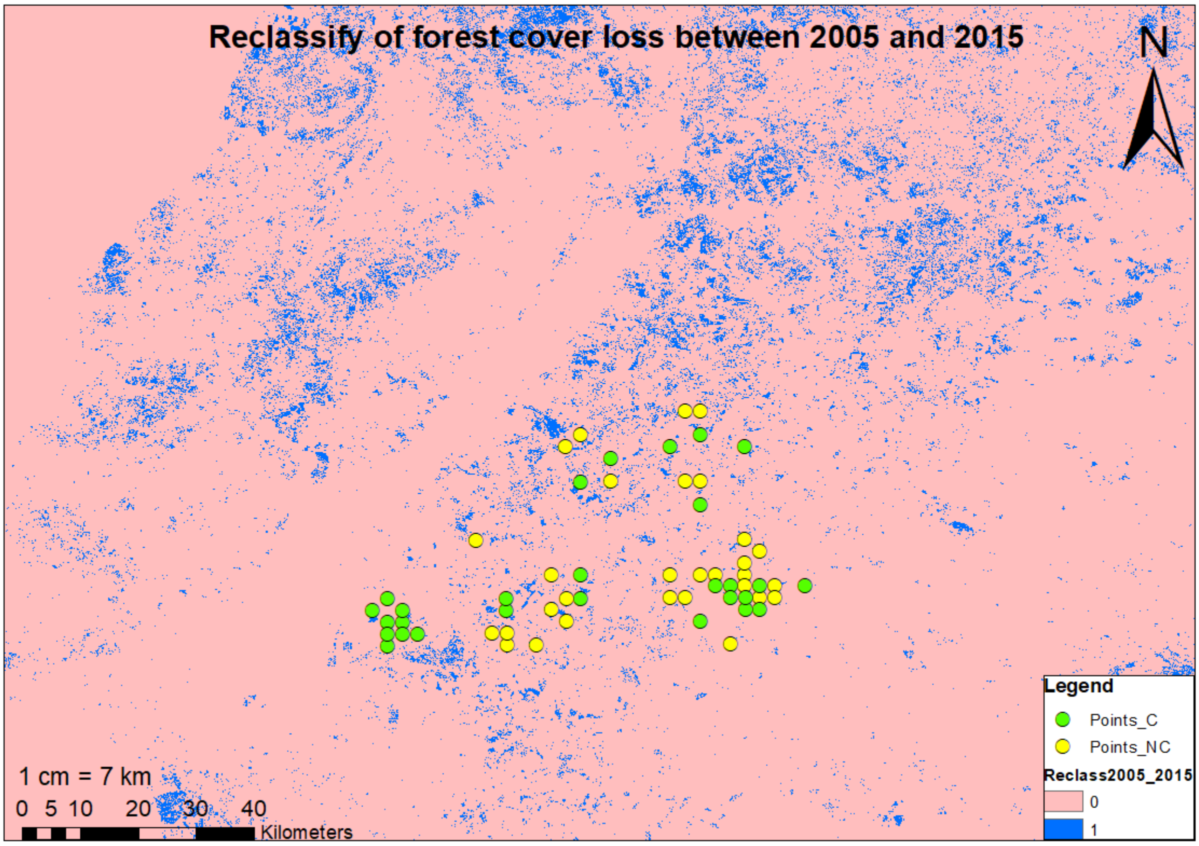


Figure 4. 2 Reclassified forest cover loss data (40N,10W). (class 1 stands for forest loss detected in cork oak landscape from 2005 to 2015 and forest losses are not detected in class 0 during the study period)

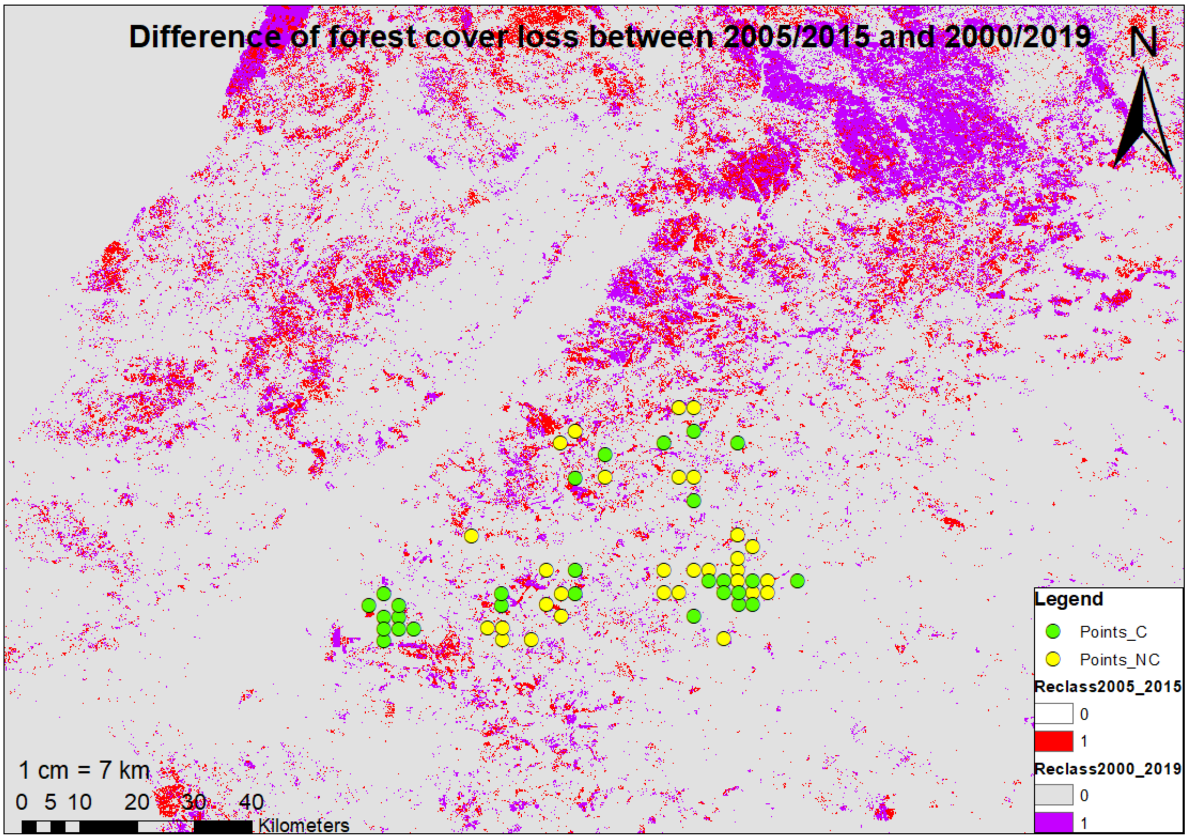


Figure 4. 3 Compare different classification of forest cover loss data. (class 1 stands for forest loss detected in the study period and no forest loss is detected in class o during the period)

The classification, number and type of categories selected for each dataset, has a very strong effect on the numerical results of any pattern analysis. The same landscape could present very different spatial patterns under different classification systems. In this thesis, the original forest cover loss data have been classified by stretching values from 0 to 19. The value 0 stands for no loss of forest cover whilst values from1 to 19 refer classes of forest cover loss between 2001 and 2019, for example, value 1 stands for the forest losses detected in year, 2001, and value 2 stands for 2002 and value 19 stands for 2019. I also investigate forest cover losses between certificated and non-certificated cork oak forest landscape between 2005 and 2015. To achieve this, I have to reclassify the raster data. Forest cover loss (raster data) map after reclassification is shown in figure (Fig. 4.2). Only two classes (values) are presented in the map, in which 0 stands for the forest cover loss outside the selected year, for example, from 2000 to 2004, and, from 2016 to 2019. Similarly, 1 stand for the forest cover loss within the selected year between 2005 and 2015. In this way, we can tell that the same map data can be very different under different classification, especially when class values are changed (Figure 4.3).

5. Methodology

5.1 Software

In this study, we use four computer programs to deal with the data. To start with, we use ArcGIS to display and deal with sample plots shapefile and forest cover loss raster data. Then, we used ArcCatalog for batch export and transform the raster data clips to TIFF images that we need for next step calculation. Next step, we use FRAGSTATS to deal with the landscape pattern analysis and metrics calculation. FRAGSTATS is the most widely used software for landscape analysis, with comprehensive interface and powerful functions. It offers three options to calculate the metrics including, "landscape metrics" for dealing with the entire landscape, ""class metrics" for cover type, and "patch metrics" for individual patches. In this study, we choose "class metrics" to calculate metrics for the forest cover loss class. After the calculation, I export the result into excel tables. To better display and summarize the relations between, quantified metrics result and our study objects, I choose RStudio for result analysis and discussion. Table (Tab. 5.1) below shows how computer programs and their corresponding data interact and work in the whole study.

Data file	Software	Usage
NFI point data	ArcMap	Provide XY coordinate for certificated and non-certificated sample plots.
Point buffer		Simulate 2 km^2 sample plot area from both certificated and non-certificated study area.
Buffer(split)		Split the sample plots by original ID to provide individual buffer.
Reclassified Raster		Reclassify the forest cover loss data by selected years (2005-2015).
Resample raster		Resample the cell size of raster data to fulfill the calculation requirements.
Clipped raster plot	ArcCatalog	Batch export, from raster to TIFF format.
Tiff images	FRAGSTATS	Raw image for fragmentation metrics calculation.
Export file		Show the storage path and format of FRAGSTATS file.
Batch Import file		Batch import code generated by python code.
Excel result	RStudio	Import the FRAGSTATS result to excel for analysis in R.

Table 5. 1 Computer programs and corresponding data.

5.2 Principles and calculation

Before we start to calculate and analyze patterns, we need to define the concept of patch. The definition of a patch is intuitive, but this definition needs to be translated (by establishing a set of rules) into a computer algorithm to identify patches on a gridded landscape. We need the computer algorithm to recognize a contiguous group of cells with the same value, so we need to define the meaning of contiguous. In the current study of landscape ecology, two rules to define patch concept are wildly used and FRAGSTATS software support both sides. They are known as four nearest-neighboring cells (horizontal or vertical neighbors only) adjoining the cells of interests and eight nearest-neighboring cells (horizontal, vertical and diagonal neighbors). Within the same data, you could come out different results by using different rules, which include number of patches, mean patch size and measures of habitat connectivity. Below I describe an example of the same map under different rules (Figure 5.1), where very different results are displayed.

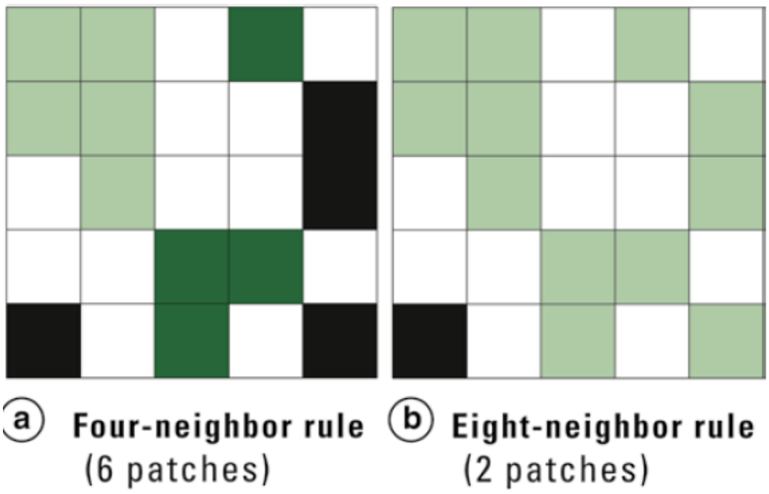


Figure 5. 1 Illustration of the patches identification (colored) on the same map under different rules.

From the pattern results, we can tell that under the four-neighbor rule, three are more patches on numbers, and the sizes of them are smaller. Also, the habitat appears less connected, compared to the eight-neighbor rule. In summary, the four-neighbor rule is more conservative and stricter to small independent patches. It is therefore important to specify the condition of study area before choosing and setting the rule to be used in the algorithm. Having a general diagnose and view of the landscape, contributes to set proper algorithm rules. Inside the map data, if several cover types are considered and enrolled in the calculation for pattern analysis, to avoid missing the small difference cover type patches, and to increase the result accuracy, it is more recommended to use the four-neighbor rule. Conversely, if only one or few cover types are found in the map data, eight-neighbor rule could also come out with good result. In this study, as we mentioned before, we only have one cover class in the raster data and also the TIFF image. So, for an accurate result, I choose to use the "eight-neighbor rule" as using the "4-neighbor rule", may originate a "fake fragmentation" result, due to its strict and conservative calculation method.

5.3 Technique roadmap

In Figure below (Fig. 5.2), I illustrate the first part roadmap of the whole study footprint. It is built and conducted in the model builder of ArcMap. To start with, we need as a first step to check the raw data, including points file and forest cover raster cells. It should be noticed that the original point is obtained in KML format which is not supported in ArcMap, so I need to transform it to point layers before putting into use. Then I checked the values table of the point layer including ID, the type and coordinate information. To separate the certificated points and non-certificated points, I choose to copy the feature and divide by certification class in the value table. Now, the point data is ready for use. In a second step, I reclassified the raster data by unique classes and set the value of non-selected years to "0". The reclassified raster has the 2 value classes "0" and "1", no data is also defined as "0". The next step was to build a buffer zone around sample plots. In this step, my input file was the point layer, both certificated and non-certificated. I chose to build 2 km^2 round buffer with the radius of 0.8 km around certified and non-certified. Such buffer size is suitable as it is neither too small for calculation nor too big to maintain the accuracy. Also, for the buffer file, I need both buffers in individual layers and together in one layer. To get individual buffers, I used tool "split by attributes" under the analysis tool box. "Original ID" was used as split field. The final step of the methodology consisted in clipping. We need to clip raster data for individual sample plots from the whole raster layer. It is recommended to re-sample the re-classify raster data before we clip. "Resample" tool under the data management tool box help us adjust the cell size of raster data. It is mandatory to check and fix the (X, Y) cell size so that it could fulfill the calculation requirements. Then, we use the "clip" tool under the data management tool box to cut the raster. It should be noticed that I use the "Iterator" function to cut raster automatically instead of manually.

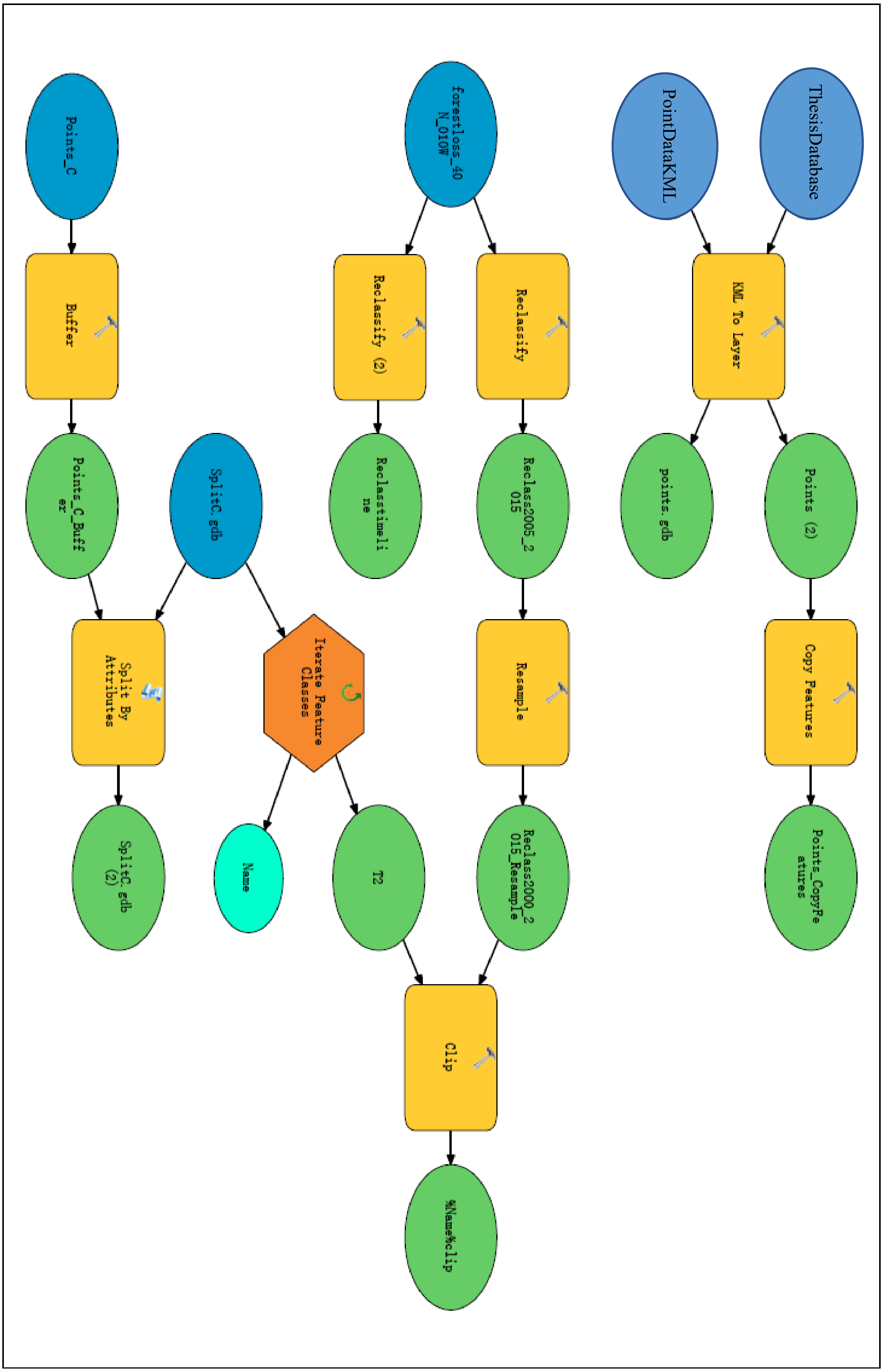


Figure 5. 2 Methodology roadmap of tools and data process in ArcGIS, created by model builder.

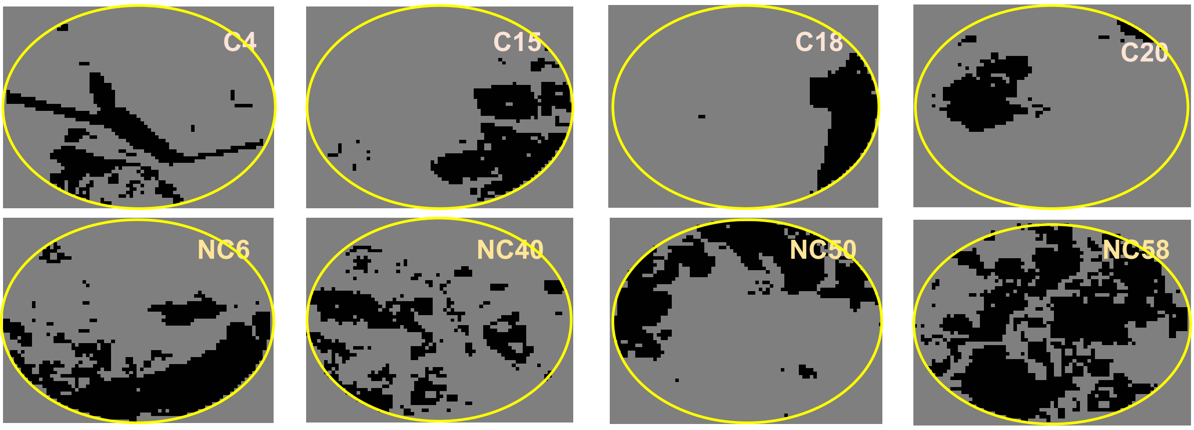


Figure 5. 3 Examples of TIFF images in certificated (C4, C15, C18, C20) and non-certificated plots (NC6, NC40, NC50, NC58). Black patterns stand for class 1, where forest loss is detected. Grey pattern inside the round border stand for class 0, where forests are remained on the landscape and no forest loss is detected. Gray patterns outside the round border stand for the background.

In the second part of methodology (Figure5.4) used in this study I combined several programs to calculate and quantify the landscape metrics of sample plots in the study area. Firstly, I start with the ArcCatalog. I selected all the files in the geodatabase and exported the raster files to TIFF format. Afterwards, I store the TIFF images in two folders, one for certificated and the other for non-certificated plots. At this stage, there already is a view of the sample plots in the landscape under the classification (Figure 5.3). The black patterns stand for areas of forest losses within the cork oak landscape, (class value “1”) and the grey patterns stand for areas without forest losses (class value “0”). Only visual diagnose is not adequate to compare the cork oak forest fragmentation condition between certificated plots and non-certificated plots. In the next step, I used FRAGSTATS to quantify landscape metrics. In the previous ArcGIS work, when I use iterator to clip the image, I saved the clipped raster file with “%Name%”, which means that the files are named by their ID. In the next step, I used python to set a range “i” from 1 to 58 and replace the name part in the code command. After that, I got the batch import code for both certificated plots and non-certificated plots. Finally, the last step consisted in importing all files to FRAGSTATS and calculate selected landscape metrics under the “8-beighbor rule”. In this study, I focused on the fragmentation of cork oak forests in certificated and non-certificated areas between 2005 and 2015. For this, I choose four landscape metrics for calculation, including percentage of landscape (PLAND), Edge density (ED), mean of perimeter area ratio (PARA_MN), and contiguity index (CONTIG_MN).

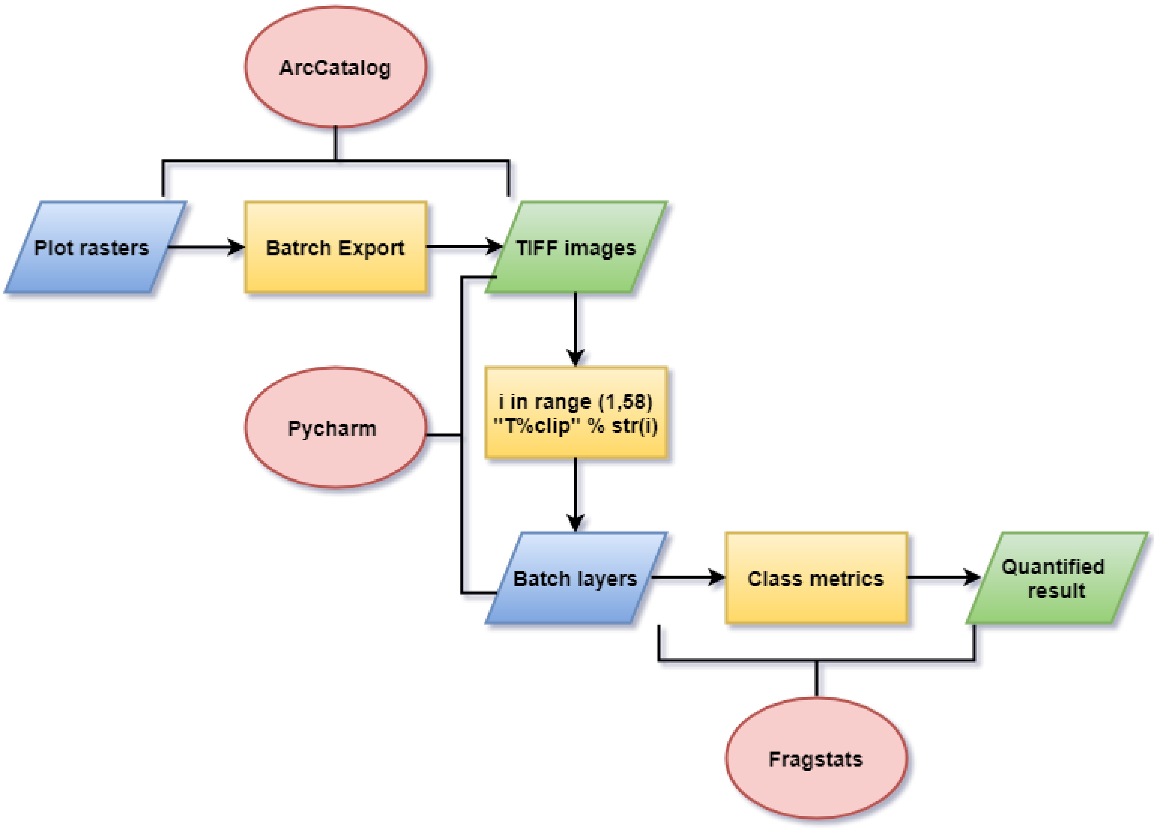


Figure 5. 4 Methodology roadmap (second part) of data process and computer programs.

6. Result and analysis

After the calculation of landscape metrics in the FRAGSTATS, I got the quantified results in certificated plots and non-certificated plots. Detail information on class 0 and class 1 for every single plot is in appendix (Appendix 1). The results of statistics Mann–Whitney U test for comparing all landscape metrics in certificated and non-certificated areas on cork oak woodlands landscapes for both classes are also in appendix (Appendix 2). Below a list of tables and figures provide an overall of results on fragmentation in cork oak landscapes by metric and the differences between certificated and non-certificated landscapes. Results are shown and analyzed separately by classes. We have two classes in total. Class 0 stands for the remained areas in cork oak woodland landscape where no forest loss is detected. Class 1 stands for areas in the cork oak woodlands where forest losses are detected. In the tables below, I summarize the average results of 4 landscape metrics from the 58 sample plots of cork oak forest in both certificated and non-certificated areas. But, as we know, only the average values are not rigorous enough to determine the significance of these differences in a statistical point of view. So, we also need to check our datasets and then run the statistical tests in RStudio. First, we need to check if our data are independent. Our sample plots are selected randomly from certificated and non-certificated cork oak woodlands. They are all clipped from different area and none of them are calculated for more than one time. So, our data are independent from each other. Second, we need to check if the samples are drawn from populations with same variances, which means if the variances of landscape metrics are equal between certificated dataset and non-certificated dataset. In this step, we use the *F*-test of equal variance and p-value to judge. The null hypothesis is that the true ratio of variances between certificated data and non-certificated data is equal to 1. Third, we need to check if samples are drawn from population with a normal distribution. This step is very important for us. If our data is following the normal distribution, I can use student's *t*-test to determine if the means of certificated dataset and non-certificated dataset are significantly different from each other. Otherwise, if our data is not following the normal distribution or the assumption of independent samples *t*-test is violated, I would use Mann-Whitney *U* test to investigate whether the means of certificated dataset and non-certificated dataset are significantly different from each other. The confidence interval for *F*-test, *t*-test and Mann-Whitney *U* test is 95 percent. First, I start with class 0, whose results present the fragmentation condition on cork oak woodlands landscape within the period, from 2005 to 2015.

6.1 Results and contrast of cork oak woodlands landscape fragmentation

In this table (Table6.1) of results, I summarize the average results of 4 landscape metrics from the 58 sample plots of cork oak forest in both certificated and non-certificated areas. But, as we

Study area (Class 0)	PLAND	ED	PARA_MN	CONTIG_MN
Certificated	96.824	257627	3601581.8	0.747
Non-certificated	95.037	437694	3615899.2	0.746
Equal variance *F*-test p-value	0.1536	0.169	0.0009	0.0025
Mann–Whitney *U* test p-value	0.1469	0.1107	0.0865	0.0783
Confidence interval	0.95			

Table 6. 1 Quantified landscape metrics (average value) of remained patterns and statistics Mann–Whitney U test

p-value in certificated and non-certificated areas on cork oak woodlands landscape from 2005 to 2015.

The first metric is PLAND, from the table and figure (Figure 6.1), we can see that the average percentage of remained forest in certificated areas, 96.82%, is higher than the average percentage, 95.03%, in non-certificated areas. Also, in Fig. 6.1 (a2), we can tell that with the same maximum percentage of 100 in both certificated and non-certificated areas, the minimum remained forest percentage in non-certificated areas is 69 percent, which is much lower than 77 percent, which is the remained forest percentage in the certificated areas. To test the significance of remained forest percentage difference in certificated and non-certificated cork oak woodlands landscape, we start with the equal variance test. From the table above (Tab. 6.1), we can see the p-value of PLAND variance test is 0.1538, which is bigger than 0.05. So, we cannot reject the null hypothesis. And, we believe that our samples are drawn from datasets with equal variance. Then we need to check if the PLAND results are following the normal distribution. From the figure below (Fig. 6.2), we can tell that the PLAND results from certificated and non-certificated areas are not following the normal distribution. Most points are not located in a straight line. With datasets that do not follow the normal distribution, I choose Mann–Whitney U test in the next step to compare the difference. From the table (Tab. 6.1) above, we can see that the p-value of Mann–Whitney U test is 0.1469. The p-value is higher than 0.05, so I cannot reject the null hypothesis. For PLAND metric, I accept that the values between certificated area and non-certificated area are not statistically different.

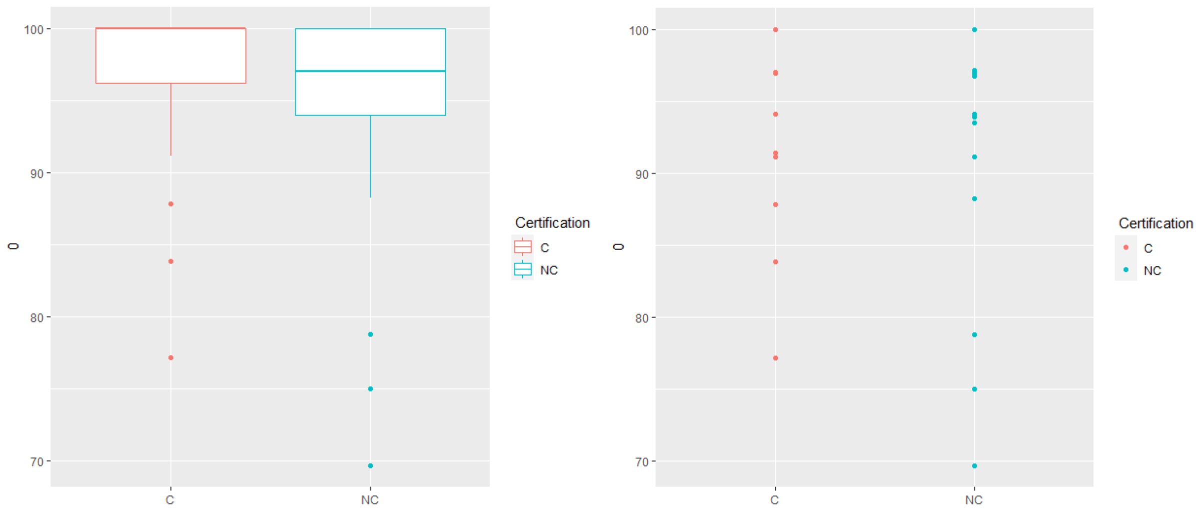


Fig.(a1) Cork oak forest coverage percentage in certificated and non-certificated plots

Fig.(a2) Cork oak forest coverage percentage in certificated and non-certificated plots

Figure 6. 1 PLAND of remained forest on the cork oak woodlands landscape from 2005 to 2015 in sample plots.

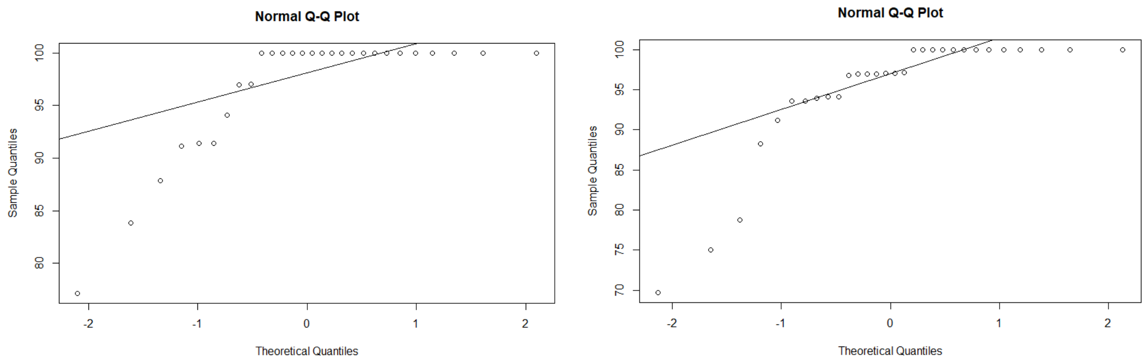


Figure 6. 2 Remained forest normal QQ plot of PLAND result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

The second metric is ED, edge density. It shows the density of edges, which reflects and accesses the shape and size of patches. From the table (Tab. 6.1) and figure (Fig. 6.3), we can see that average value of forest edge density in certificated cork oak woodlands is lower than that in non-certificated area. Whilst in figure 6.3, b2, we can see that the maximum edge density in non-certificated plot is much higher than that in certificated area. To test the significance of remained forest percentage difference in certificated and non-certificated cork oak woodlands landscape, we start with the equal variance test. From the table above (Tab. 6.1), we can see the p-value of ED variance test is 0.169, which is bigger than 0.05. So, we cannot reject the null hypothesis. And, we believe that our samples are drawn from datasets with equal variance. Then we need to check if the ED results are following the normal distribution.

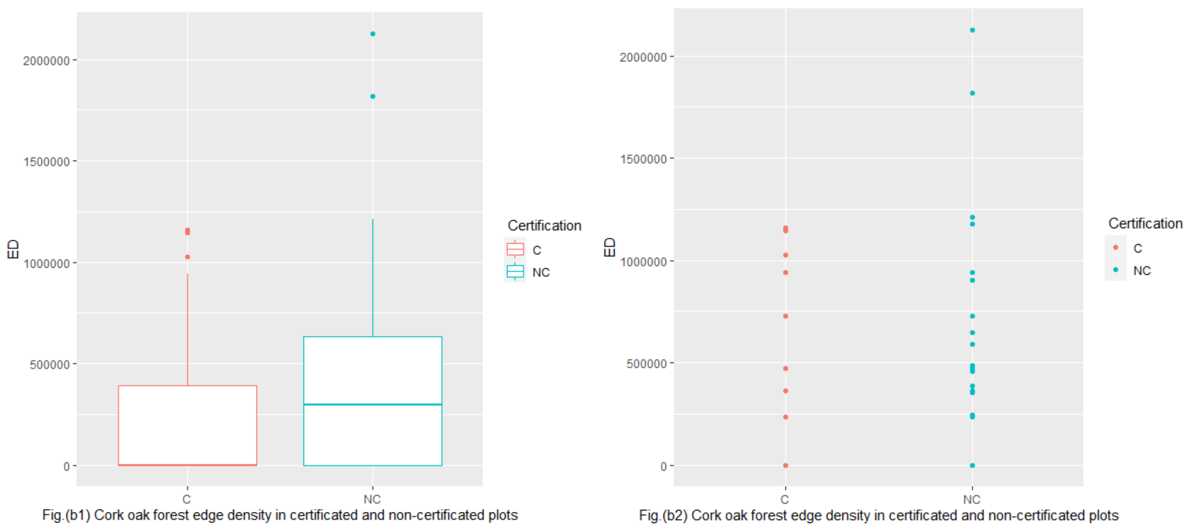


Figure 6. 3 ED of remained forest on the cork oak woodlands landscape from 2005 to 2015 in sample plots.

From the figure below (Fig. 6.4), we can tell that the ED results from certificated and non-certificated areas are not following the normal distribution. Most points are not located in a straight line. Again, I choose Mann–Whitney U test in the next step to compare the difference. From the table (Tab. 6.1) above, we can see that the p-value of Mann–Whitney U test for ED is 0.1107. The p-value is higher than 0.05, so I accept the null hypothesis. For ED metric, I accept that the values between certificated area and non-certificated area are not statistically different. The third index is PARA_MN, mean of perimeter area ratio, this is the most important index to evaluate the fragmentation status. As we can tell from the name, it is a ratio between perimeter and area. When the value is low, it means the landscape have more large area components and the patches are more integrated. When the value is high, it means the landscape have more small area components and the patches are more fragmented and fall apart. From the table (Tab. 6.1) and figure (Fig. 6.5), we can see that the PARA_MN value of certificated area is lower than non-certificated area. From figure 6.5, c2, there is one exception value can

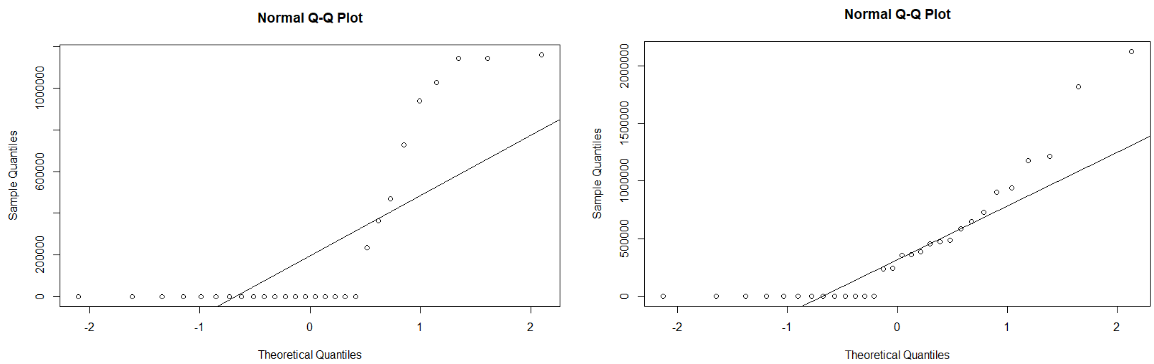


Figure 6. 4 Remained forest normal QQ plot of ED result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

be detected. That plot from certificated area has an extremely high ratio. But, except from that all other plots, in certificated area, are located in lower-value zone, compared to plots in non-certificated area. The p-value of equal variance test is 0.0009, which is much smaller than 0.05. So, I am able to reject the null hypothesis and believe that the variances of two datasets, certificated and non-certificated, are not equal. When this initial assumption is not correct, we cannot run the two-sample *t*-test. So, I choose the Mann–Whitney U test. From the table (Tab. 6.1) above, we can see that the p-value of Mann–Whitney U test for PARA_MN is 0.0865. The p-value is slightly higher than 0.05, so I accept the null hypothesis.

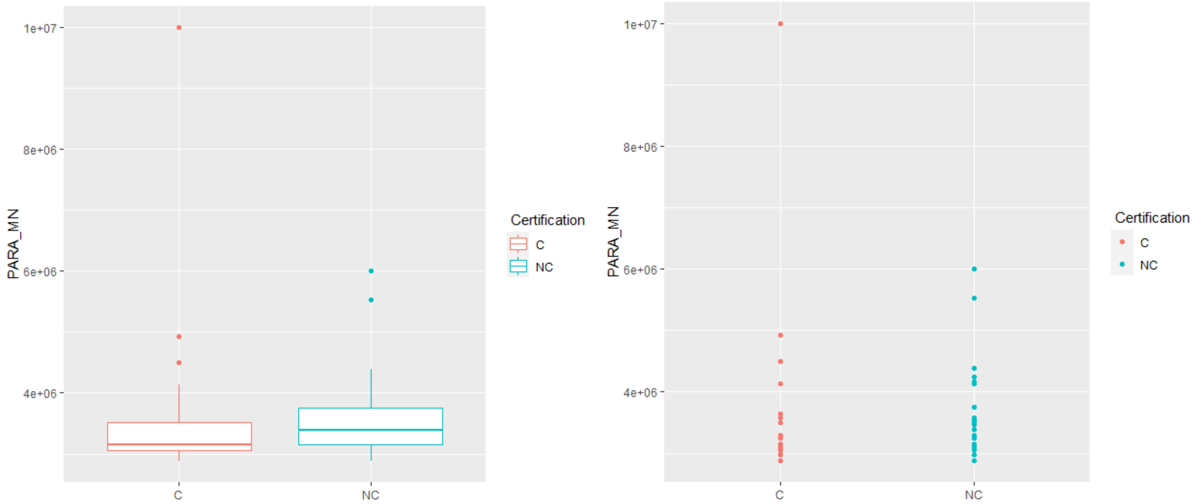


Fig.(c1) Cork oak forest perimeter-area ratio in certificated and non-certificated plots

Fig.(c2) Cork oak forest perimeter-area ratio in certificated and non-certificated plots

Figure 6. 5 PARA_MN of remained forest on the cork oak woodlands landscape from 2005 to 2015 in sample plots.

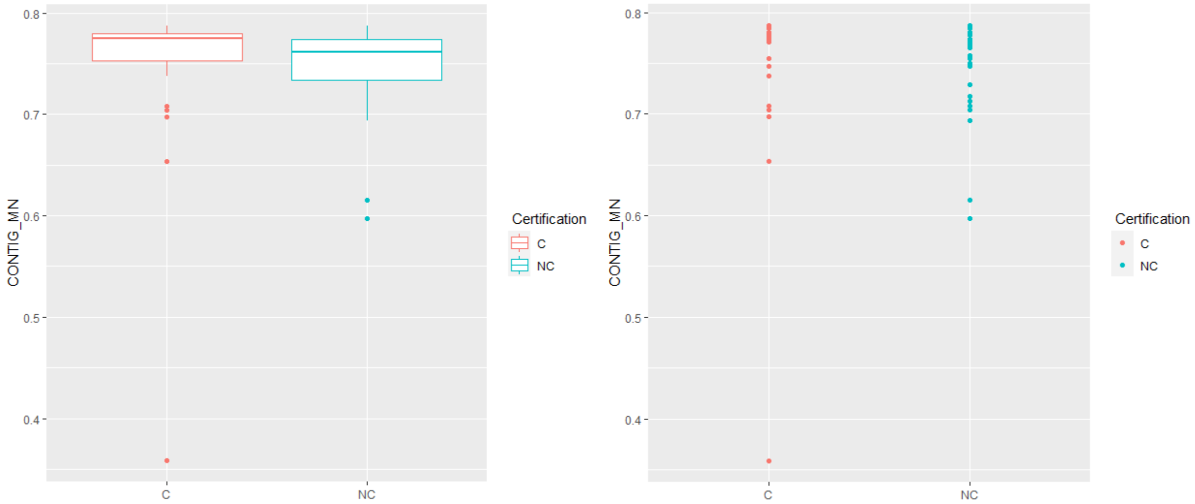


Fig.(d1) Cork oak forest contiguity in certificated and non-certificated plots

Fig.(d2) Cork oak forest contiguity in certificated and non-certificated plots

Figure 6. 6 CONTIG_MN of remained forest on the cork oak woodlands landscape from 2005 to 2015 in sample plots.

For PARA_MN metric, I accept that the values between certificated area and non-certificated area are not statistically different. The last metrics is CONTIG_MN, the mean of contiguity index. This metric indicates the adjacency and spatial connectedness of patches in the landscape. A higher value of CONTIG_MN means the patches on the landscape are more adjacent and connected. From the table above (Tab. 6.1), we can tell that there is little difference between the certificated mean value, 0.747, and non-certificated mean value, 0.746. Also, from the figure below, Fig. 6.6, we can tell that more CONTIG_MN values in non-certificated dataset are listed in low value zone. To test the significance of this difference, first, I need to run variance F-test. The p-value is 0.0025, which is much lower than 0.05. Under the confidence interval of 95 percent, I can reject the null hypothesis and believe that two sets of

CONTIG_MN values have different variances. Without the same variances, we cannot run two-sample *t*-test. I run Mann-Whitney *U* test to compare the difference of mean values. From the table (Tab. 6.1) above, we can see the p-value of Mann-Whitney *U* test is 0.0783. So the mean values of CONTIG_MN from certificated and non-certificated datasets are not significantly different in a statistical point of view. With all results of selected four landscape metrics in table and figures, we can compare the relations between the certificated and non-certificated areas. Even though we can tell some differences on the mean values of four landscape metrics, but based on p-value from Mann-Whitney *U* test, I come out with the conclusion that the result of four landscape metrics from certificated cork oak woodlands landscape and non-certificated cork oak woodland landscape are not statistically different from each other. In summary, the fragmentation status on certificated and non-certificated cork oak woodlands landscape show no significant difference.

6.2 Results and contrast of cork oak woodlands landscape forest loss

In the previous part of result, we just analyzed the results of four selected landscape metrics for class "0", to understand and compare landscape fragmentation between certificated and non-certificated cork oak woodlands. All relations of those metrics pointed out that the fragmentation condition in non-certificated cork oak woodlands landscape is not statistically different with that in certificated cork oak woodlands landscape. To exam this relation and come out to accurate conclusion, I decided to do the same analysis on class "1", the forest loss patterns.

Study area (Class 1)	PLAND	ED	PARA_MN	CONTIG_MN
Certificated	9.88083333	801505	12814815	0.175466667
Non-certificated	8.75812	772401	14674510	0.07119412
Equal variance *F*-test p-value	0.4198	0.2542	0.3115	0.2351
Mann–Whitney *U* test p-value	0.3578	0.6465	0.0718	0.0531
Confidence interval	0.95			

Table 6. 2 Quantified landscape metrics of cork oak forest loss in certificated and non-certificated areas from 2005 to 2015.

Here is the table (Tab. 6.2) that shows the average values of landscape metrics, resulted from 9 plots in the certificated area and 17 plots from the non-certificated area. The size of dataset is even smaller in this part cause no forest loss are detected in some plots. Only from the numbers of plot where forest loss took place between 2005 to 2015, we

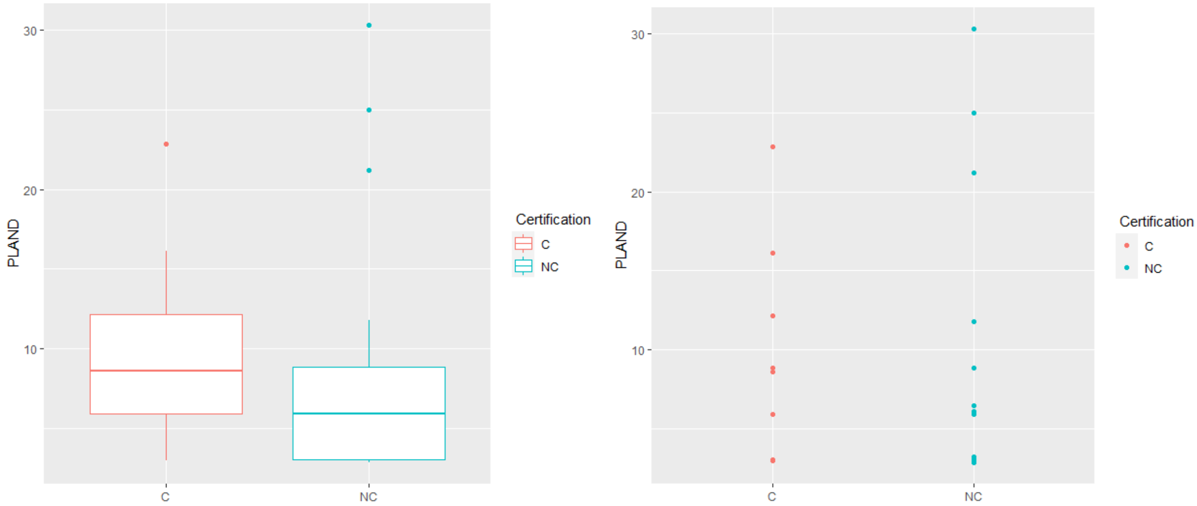


Fig.(e1) Forest loss percentage in certificated and non-certificated plots

Fig.(e2) Forest loss percentage in certificated and non-certificated plots

Figure 6. 7 PLAND of forest loss on cork oak woodlands landscape from 2005 to 2015 in sample plots.

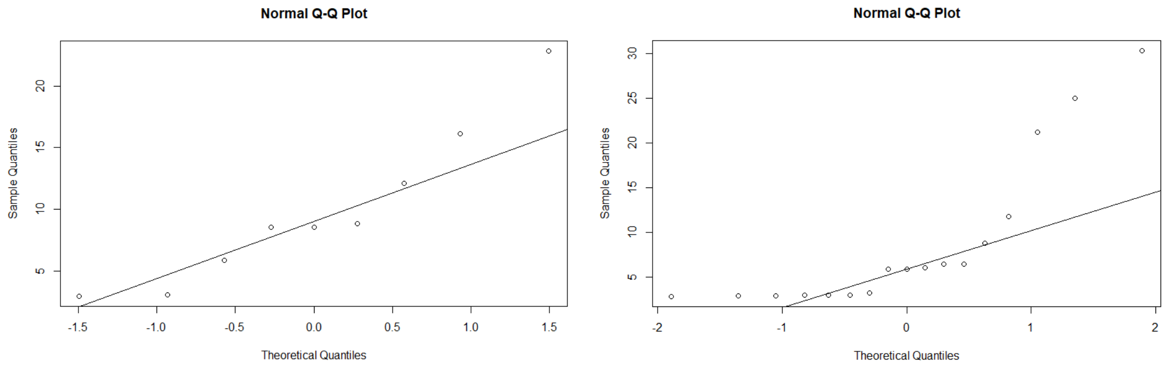


Figure 6. 8 Forest loss normal QQ plot of PLAND result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

can tell the difference. But, still, we need to test the difference through t-test or Mann–Whitney *U* test in a statistics point of view. Start with PLAND, from the table (Tab. 6.2) and figure (Fig. 6.7), we can see the average percentage of forest loss detected in certificated area is higher than the average of forest loss detected in non-certificated area. But from figure, Fig 6.7 (e2), we can see that the maximum percentage of forest loss in certificate area is 22.85, while two more higher percentage of forest loss, 25 and 30.3, are detected in non-certificated area. To test the significance of forest loss percentage difference in certificated and non-certificated cork oak woodlands landscape, we start with the equal variance test. From the table above (Tab. 6.2), we can see the p-value of PLAND variance test is 0.4198, which is bigger than 0.05. So, we cannot reject the null hypothesis. And, we believe that our samples are drawn from datasets with equal variance. Then we need to check if the PLAND results are following the normal distribution. From the figure above (Fig. 6.8), we can tell that the PLAND results from certificated and non-certificated areas are not following the normal distribution. Most points are not located in a straight line. In the next step, I choose Mann–Whitney U test to compare the difference. From the table (Tab. 6.2) above, we can see that the p-value of Mann–Whitney U test for PLAND is 0.3578. The p-value is higher than 0.05, so I accept the null hypothesis. For PLAND metric, I accept that the forest loss percentage values between certificated area and non-certificated area are not statistically different.

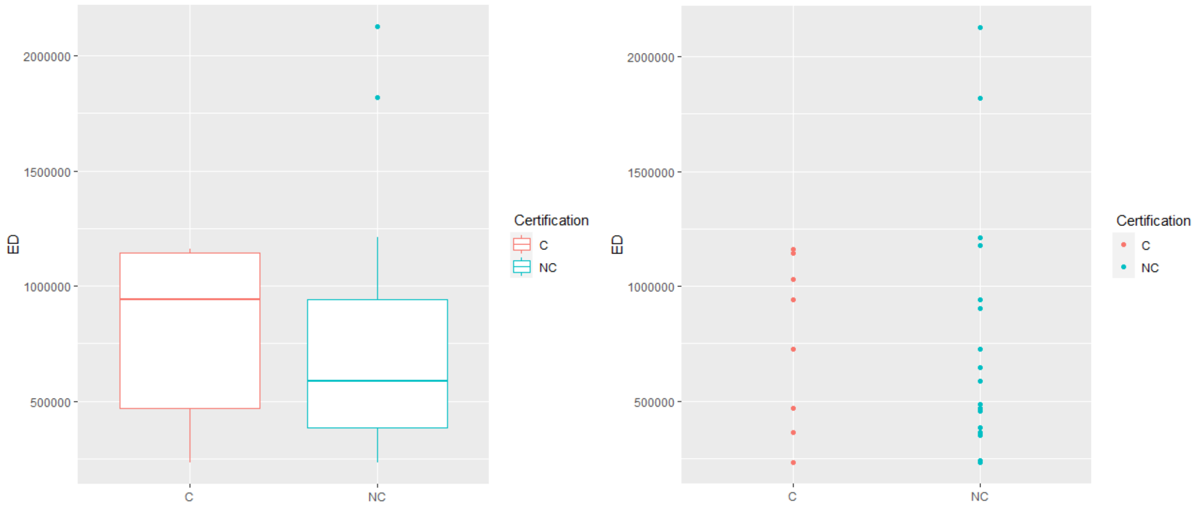


Fig.(f1) Forest loss edge density in certificated and non-certificated plots

Fig.(f2) Forest loss edge density in certificated and non-certificated plots

Figure 6. 9 ED of forest loss on cork oak woodlands landscape from 2005 to 2015 in sample plots.

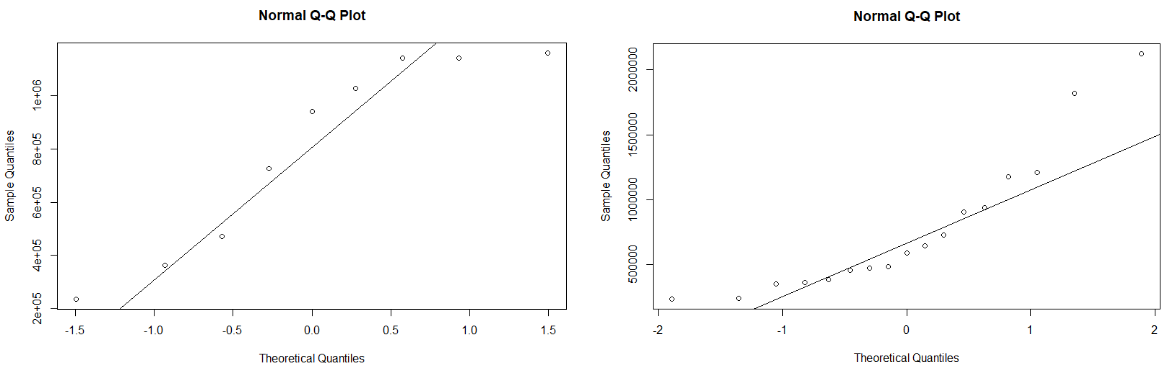


Figure 6. 10 Forest loss normal QQ plot of ED result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

The second metric is ED, from the table (Tab. 6.2) and figure (Fig. 6.9), we can see the average edge density in certificated area is higher than that in non-certificated area. It seems that average number of forest loss patches is higher in certificated area. But, from the figure, Fig 6.9 (f2), we see that the maximum ED value detected in non-certificated area is much higher than the maximum of certificated area. The third metric is PARA_MN, mean of perimeter area ratio, which is the most related landscape metric to fragmentation status. From the table (Tab. 6.2) and figure (Fig. 6.11), we can tell that the mean value of PARA_MN in certificated area is lower than non-certificated area. Also, from the figure, Fig 6.11 (g2), we can see that lower ratio value is detected in certificated areas.

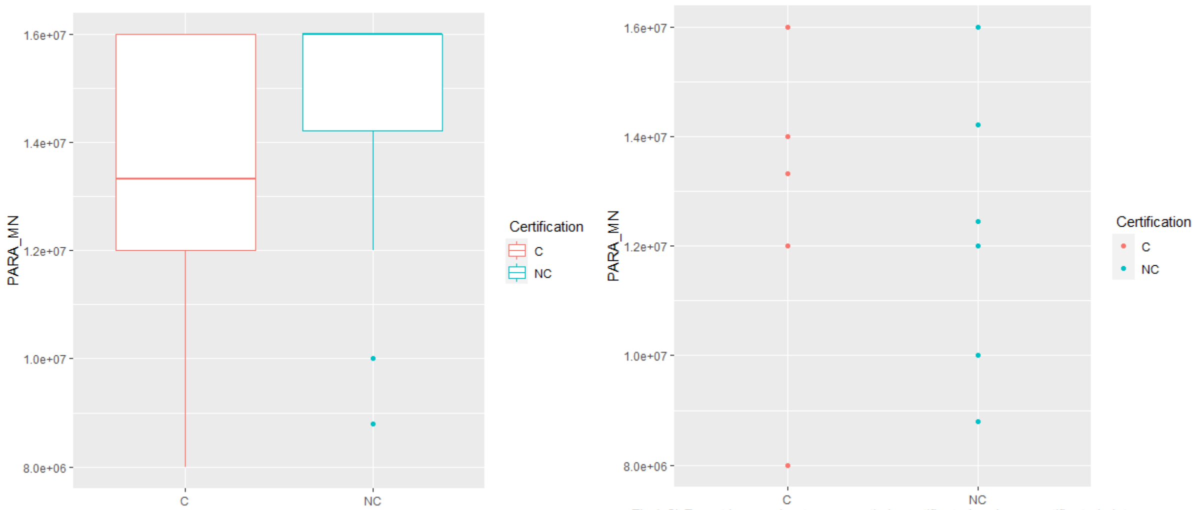


Fig.(g1) Forest loss perimeter-area ratio in certificated and non-certificated plots

Fig.(g2) Forest loss perimeter-area ratio in certificated and non-certificated plots

Figure 6. 11 PARA_MN of forest loss on cork oak woodlands landscape from 2005 to 2015 in sample plots.

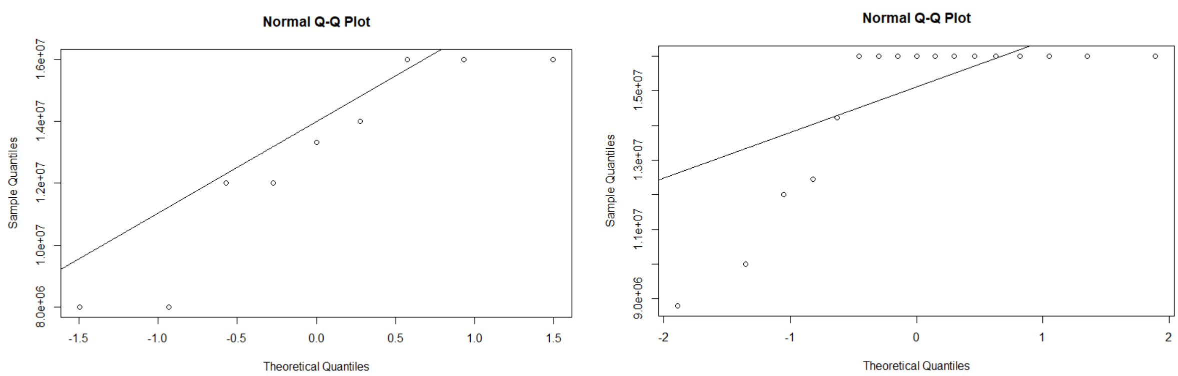


Figure 6. 12 Forest loss normal QQ plot of PARA_MN result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

The fourth metric is CONTIG_MN, from the table (Tab. 6.2) and figure (Fig. 6.13), we can see that both average and maximum contiguity in certificated area is higher than non-certificated area. To test the significance of forest loss ED, PARA_MN and CONTIG_MN differences in certificated and non-certificated cork oak woodlands landscape, we start with the equal variance test. From the table above (Tab. 6.2), we can see the p-value of ED, PARA_MN and CONTIG_MN variance test is 0.2542, 0.3115 and 0.2351, respectively, which are all bigger than 0.05. So, we cannot reject the null hypothesis. And, we believe that our samples are drawn from datasets with equal variance. Then we need to check if the results of these three metrics are following the normal distribution. From the figures above (Fig. 6.10, Fig. 6.12 & Fig. 6.14), we can tell that the results of these three metrics from certificated and non-certificated areas are not following the normal distribution. Most points are not located in a straight line.

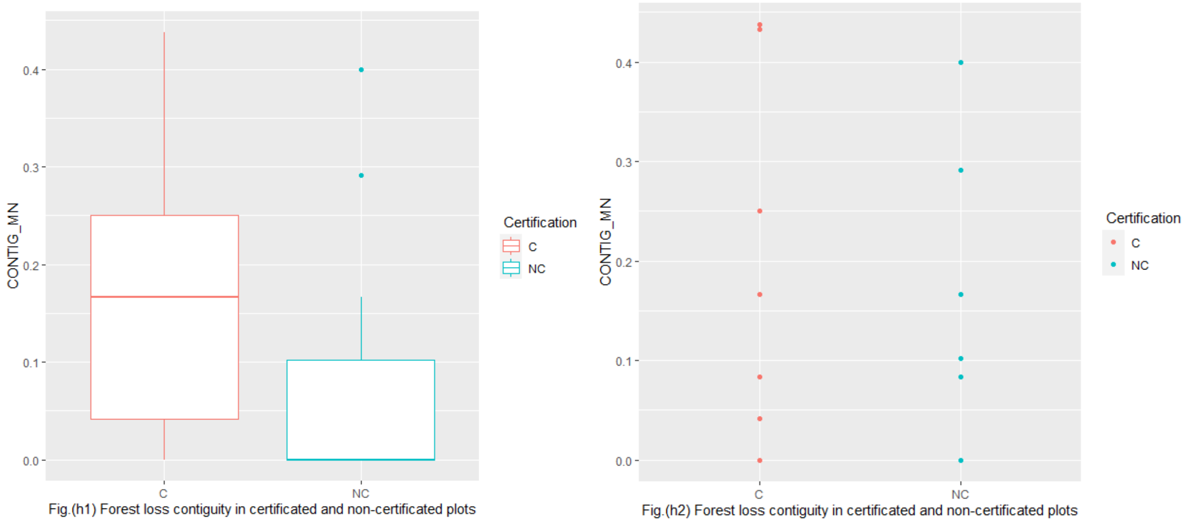


Figure 6. 13 CONTIG_MN of forest loss on cork oak woodlands landscape from 2005 to 2015 in sample plots.

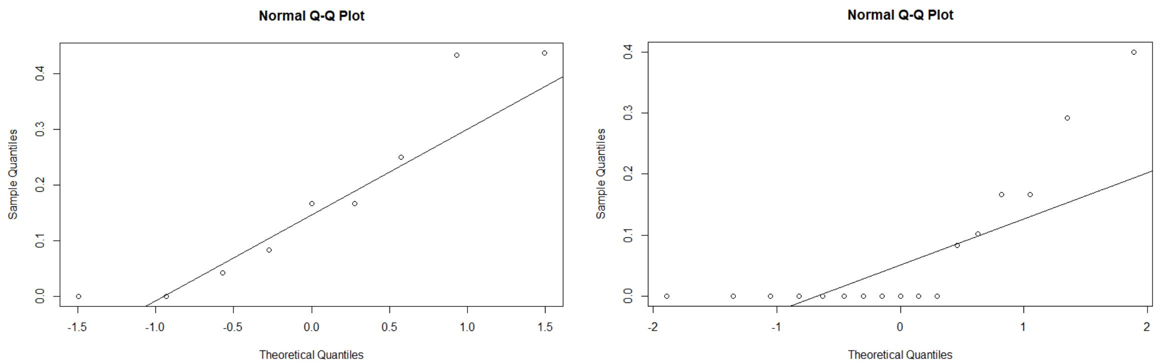


Figure 6. 14 Forest loss normal QQ plot of CONTIG_MN result in certificated and non-certificated cork oak woodlands. (Figure on the left shows data from certificated area and figure on the right shows data from non-certificated area.)

In the next step, I choose Mann–Whitney U test to compare the difference. From the table (Tab. 6.2) above, we can see that the p-value of Mann–Whitney U test for ED, PARA_MN and CONTIG_MN are 0.6465, 0.0718 and 0.0531, respectively. The p-values are all higher than 0.05, so I accept the null hypothesis. For all four metrics, I accept that the forest loss values between certificated area and non-certificated area are not statistically different. From the analysis of results in tables and figures, we can summarize that even though the mean values show some differences, but, statistically, the mean values of pattern percentage (PLAND), edge density (ED), mean of perimeter area ratio (PARA_MN) and contiguity index (CONTIG_MN) from certificated and non-certificated cork oak landscape are not significantly different. In summary, the forest loss condition on certificated and non-certificated cork oak woodlands landscape show no significant difference.

6.3 Trend analysis of forest loss on cork oak woodlands landscape through timescale

As we mentioned previously, this study covers a time scale of ten years. The result of landscape metrics provides us an overall quantified understand of final result, although it is important to understand the process and forest cover trends within this period of ten years, before reaching proper conclusions. Here I use a classification of forest loss in each year from 2005 to 2015, in order to reflect such trends. From the map (Fig. 6.15), we can see the sample plots with ID from 1 to 58. White color represents plots in certificated forest area and red color represents plots in non-certificated areas. The color of forest loss raster from light blue to purple shows the lost year from 2005 to 2015. As we can see from the left part of figure, where certificated plots clustered (Fig. 6.16), some part of the forest loss took place in the early period, 2005, around plot 23, and almost no new forest loss showed up during the period, but very small forest loss patch took place in late 2014. Conversely, in the area non-certificated cork oak woodlands, between plot 40 and plot 53, also plot 50 and plot 35, we can see that large new forest loss patch showed up since 2012. Another landscape change phenomenon (Fig. 6.17) shows that, some plots, for example, plot 58 and plot 6, with forest loss in the early year,2006, of the period in non-certificated area, continued showing up new forest loss patches in the middle year, 2010, and late year, 2014 and 2015, of this period. Also, combined with details of forest loss area (FLA) each year (Fig. 6.18), from 2005 to 2015, in certificated and non-certificated area, we can clearly see that the area of forest loss is higher in non-certificated area in most of the years, except from 2008 and 2012. This trend and difference in FLA become more obvious in the later years of the period. From 2013 to 2015, when FLA in certificated areas keeps dropping down, the FLA in non-certificated areas still climbs up, whose trend is just the opposite.

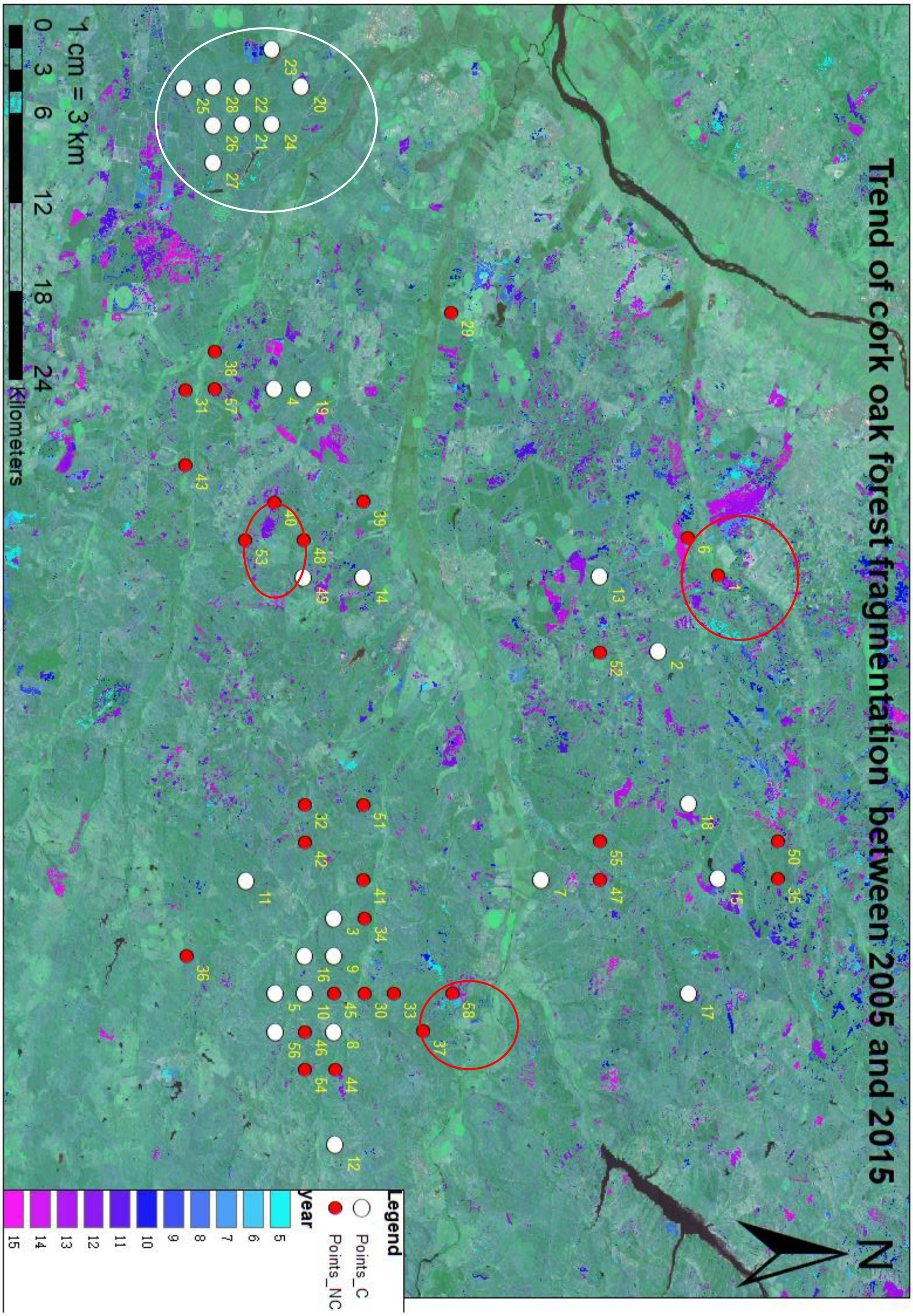


Figure 6. 15 Trend of fragmentation and forest loss between 2005 to 2015 in the study area.

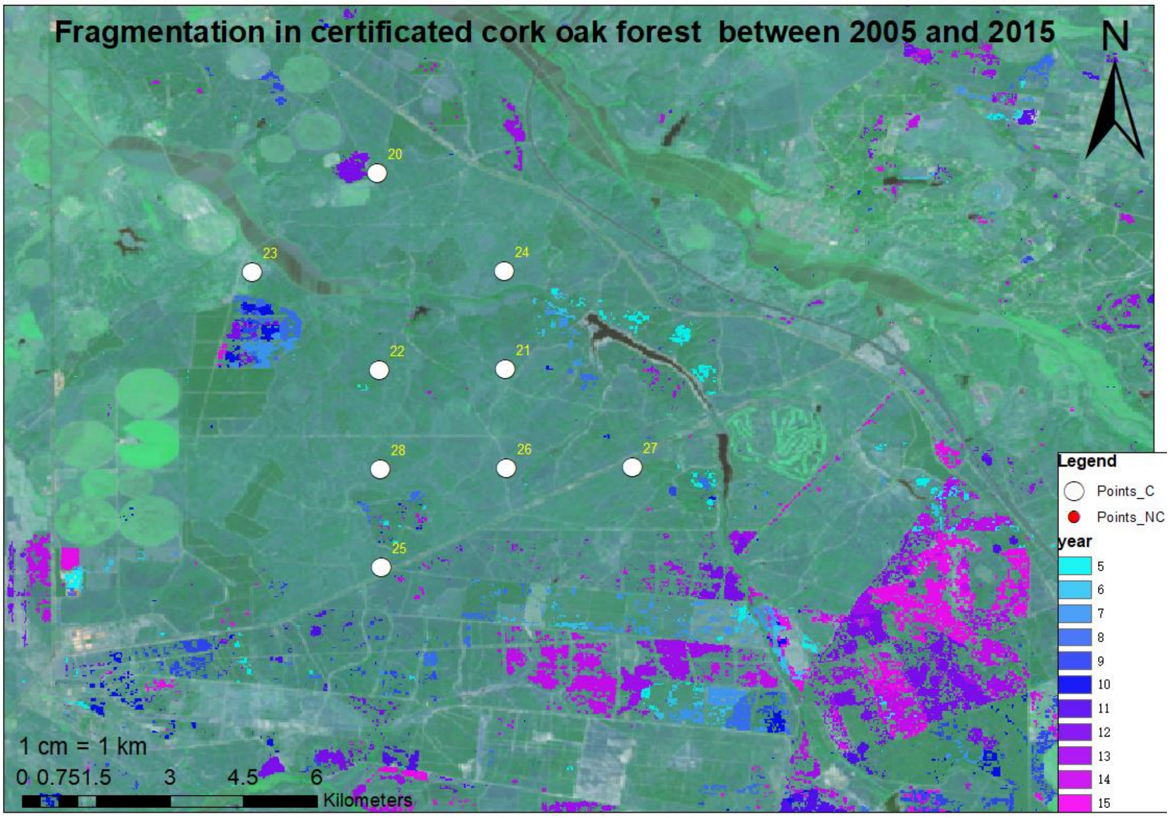


Figure 6. 16 Trend of fragmentation and forest loss between 2005 to 2015 in certificated area.

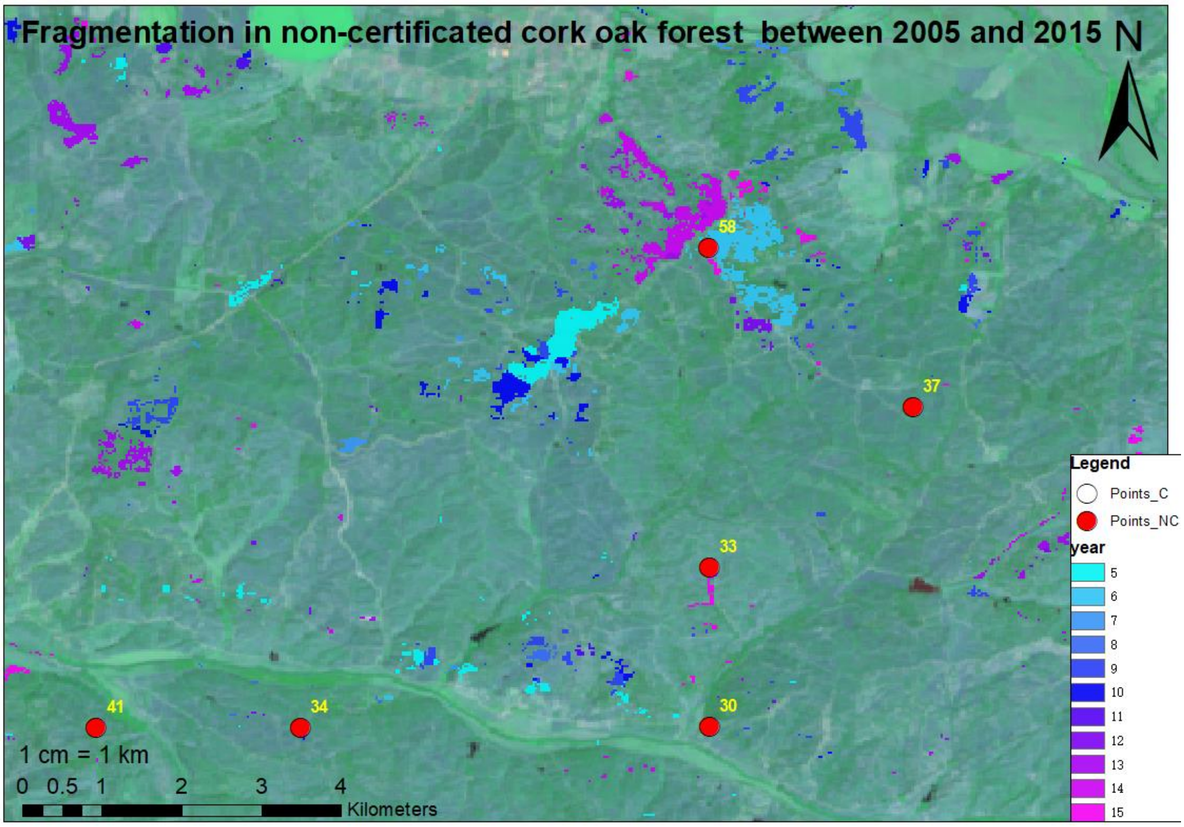


Figure 6. 17 Trend of fragmentation and forest loss between 2005 to 2015 in non-certificated area.

Figure 6. 18 Area of forest cover loss between 2005 to 2015 in certificated and non-certificated area (the unit is counted by number of pixels in the raster data, size of every pixel is 900 m2).

7. Discussion

Studies of quantifying and assessing forest degradation and fragmentation using landscape metrics have been found in both oak woodlands and other forest landscapes worldwide. A study analyzed fragmentation patterns of oak woodlands over a period of 50 years, from 1958 to 2007, on three landscapes, in Southern Portugal comprised the civil parishes of Ulme (UL), São Bartolomeu da Serra (SB) and Alcoutim (AL), in Portugal. They calculated a set of landscape metrics to comparing the fragmentation over the time, including number of patches (NP), mean patch size (MPS), core area, isolation and edge contrast. In the study areas, the number of patches in oak woodlands increased up to almost 300 percent, while patch size decreased to less than 40 percent of initial state (UL). The result showed that fragmentation occurred concomitantly with woodlands loss and was severely amplified after 1995 (Costa et al., 2014). In another study, the northeastern region (NER) of India is has been assessed under threat of forest degradation and fragmentation. In the study, landscape metrics including number of patches, shape index and Shannon's entropy index are used to access terms of disintegration that patches turn into smaller fragments, which leads to ecosystem degradation and loss. Results shows that total forest area in the NER had an evident decrease from 1972 to 1999. The mean SI value for patch size of 1-10 km^2 and 10-50 km^2 had significantly increased from 1982 to 1987, which leads to the complex shape of patches. It also indicates that severe fragmentation and forest loss have occurred within the period (Lele et al., 2008). Also, another study assessed the land use and land cover (LULC) changes for the last four decades, from 1975 to 2013, in center Araguaia river basin of northwest Brazil. The temporal changes of landscape composition and configuration was calculated and compared by landscape metrics, including class area (CA), percentage of class area (PLAND), patch density (PD), the largest patch index (LPI), mean patch area (AREA_MN), edge density (ED), mean perimeter-area ratio (PARA_MN), mean core area (CORE_MN), and mean proximity index (PROX_MN), using the 8-neighbor rule. During the study period, native vegetation was reduced by 26 percent, in which forest cover was the most threatened pattern with significant areal reduction and fragmentation. Landscape metrics indicating fragmentations showed high correlation between indigenous lands and strictly protected areas (R^2=0.8, $p<0.05$). Results showed that protected areas mitigate fragmentation, but their roles and effect may differ (Garcia et al., 2017). Cork oak is an endemic species to the western Mediterranean Basin. Cork oak woodlands have high economic value mainly due to cork production. Presently, the production of cork oak is still the main interest for most medium and small cork oak woodlands owners and companies in the industry. Fluctuations of cork market prices, wine market, and new material bottle stoppers, or unexpected events such as the COVID-19 pandemic, cause changes in the world economy. Additionally, climate change, may also affect cork oak woodlands. Therefore, focusing on cork production alone may not be the most sustainable way to maintain cork oak woodlands (*montados*). Other interests and perspectives must be considered in sustainable management plans for cork oak woodlands, including valuation of non-wood forest products, clean water resources, game hunting and tourism, pasture and livestock or other ecosystem services as carbon sequestration and other services. All these interests and targets mentioned above need large and continuous areas of cork oak patches and high coverage of cork oak within the landscape. Forest loss and fragmentation may lead to forest degradation, which is a barrier to sustainable and multiple-interests management of cork oak woodlands (*montados*). Forest certification and payment for ecosystem services may contribute to achieve sustainable management of cork oak woodlands. In general, my results are relevant for assessing how forest certification may contribute to cork oak woodland conservation. Results could not support my null hypothesis, that forest certification contribute to reduce fragmentation and forest loss in cork oak woodlands. However, imperfection is the direction of further research. To think critically, our sample plots from both certificated and non-certificated datasets are not following the normal distribution. In my opinion, compared to studies from other scholars, some details should be improved and noticed to get a better and significant result on future landscape fragmentation studies:

1) It is preferred to expand the size of datasets and amount of sample plots. I analyzed 28 plots in certificated areas and 30 plots in non-certificated areas. This sample size was not enough. It should be big enough to cover as much cork oak woodlands patterns as possible on the landscape. Moreover, when analyzing of forest loss, I only had 17 plots with forest lost patches in non-certificated areas and only 9 plots with forest loss patches in certificated areas, which is even smaller. Therefore, to assess proper differences in number of forest loss patterns we should have a higher number of plots also for other regions of Portugal. One unexpected result suggested that the average percentage of forest loss patterns in 9 plots in certificated cork oak woodlands was higher than the average cork oak forest loss patterns of 17 plots in non-certificated cork oak woodlands but this could be caused by the small population of sample datasets we analyzed.
2) The topic of forest loss and fragmentation patterns should be addressed in a larger scale of landscapes. It is preferred to be carried out in a regional or national landscape, using larger sample

sizes and different regions of Portugal or even other countries in future and research on the topic of the cork oak woodlands (*montado*) landscapes. As the studies that I mentioned above, it focused on the forest fragmentation of the whole region of northeastern India (Lele et al., 2008) and three evergreen oak landscapes in Portugal (Costa et al., 2014).

3) The landscape fragmentation studies are preferred to carried out in a long timescale. The three studies above compared the fragmentation of evergreen oak woodlands in Portugal in a period of 50 years (Costa et al., 2014), fragmentation related to land use and land cover changes and protect areas in northwest Brazil in a period of 40 years (Garcia et al., 2017), and the forest fragmentation in India in a period of 27 years (Lele et al., 2008), respectively. In my study, I compared the cork oak woodlands fragmentation between certificated and non-certificated area from 2005 to 2015, with in a period of 10 years. The timescale is short. As we know, cork oak woodlands and other type of forests are complex landscape. The ability of resistance and stability is correlated with the abundance and diversity of land cover types on the landscape. It may need a long period of time before severe and significant fragmentation occur. As we can see from the figure (Fig. 6.18), very different trend of forest loss is also detected at the end of 10-year period, from 2013 to 2015. More significant result and difference might be found if we wait and extend the study period to 2025. I suggest future studies on landscape fragmentation could try to extend the study period to 3 to 5 decades or even longer.

Furthermore, I suggest the future researches related to forest certifications of cork oak woodlands and others forest landscapes should not only focus on the impacts of production and biodiversity hotpots but also fragmentations, forest degradation and other landscape ecology aspects. In this study, my results showed that no significant differences of forest loss and fragmentation are found between certificated and non-certificated area in the study area. In other words, APFC certification have not significantly improved the forest loss and fragmentation condition on cork oak woodlands in Coruche, Portugal. More research and contribution of forest certification on forest loss and fragmentation in cork oak woodlands and other forest landscapes should be carried out in both Portugal and other countries worldwide, which is also associated with to reducing emissions from deforestation and forest degradation (UN-REDD) program and action.

8. Conclusion

Based on previous result and analysis of quantified landscape metrics, visual diagnoses of forest loss raster for each year and forest loss area in certificated and non-certificated area, I conclude that between 2005 and 2015:

1) Even though the mean values of four landscape metrics (PLAND, ED, PARA_MN and CONTIG_MN) that we used are different in both classes (class 0 and class 1), but based on the p-values of Mann–Whitney *U* test, there is no significant difference between certificated and non-certificated cork oak woodlands landscape, from statistics point of view.
2) The forest loss condition and fragmentation status in certificated and non-certificated cork oak woodlands landscape are not significantly different from each other, based on results of Mann–Whitney *U* test.
3) In most cases, forest loss patches that showed up in early years of the period did not continue, develop and last long in certificated cork oak woodlands landscape. Conversely, forest loss patches that showed up in early years of the period spread, develop and expanded in non-certificated cork oak woodlands landscape.
4) In most years, the area of forest loss in non-certificated cork oak woodlands is larger than the area of forest loss in certificated cork oak woodlands. In the later years of the period, forest loss area shows a declined trend in certificated cork oak woodlands but an increasing trend in non-certificated cork oak woodlands.

Based on above four points in my conclusion, the differences of four selected landscape metrics are not significant from a statistical point of view. But, from a long-term consideration, forest certification may contribute to decrease fragmentation and forest loss of cork oak landscapes (*montado*) in Coruche municipality, Portugal.

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10. Appendix

10.1 Result of landscape metrics for all sample plot in class 0

ID	PLAND	ED	PARA_MN	CONTIG_MN	CERTIFICATION
T2	96.9697	363636.3636	3500000	0.7552	C
T3	100	0	3058823.529	0.7745	C
T4	91.4286	1142857.143	4500000	0.6979	C
T5	100	0	3058823.529	0.7794	C
T7	100	0	3151515.152	0.7778	C
T8	100	0	3151515.152	0.7727	C
T9	100	0	3096774.194	0.7742	C
T10	100	0	3250000	0.7708	C
T11	100	0	3294117.647	0.7745	C
T12	100	0	3096774.194	0.7742	C
T13	100	0	3151515.152	0.7778	C
T14	91.1765	941176.4706	4129032.258	0.7043	C
T15	77.1429	1142857.143	10000000	0.359	C
T16	100	0	3058823.529	0.7794	C
T17	97.0588	470588.2353	3636363.636	0.7374	C
T18	87.8788	727272.7273	3586206.897	0.7471	C
T19	91.4286	1028571.429	4500000	0.7083	C
T20	83.871	1161290.323	4923076.923	0.6538	C
T21	100	0	3058823.529	0.7794	C
T22	100	0	2888888.889	0.787	C
T23	94.1176	235294.1176	3000000	0.776	C
T24	100	0	3250000	0.7708	C
T25	100	0	3058823.529	0.7794	C
T26	100	0	3058823.529	0.7843	C
T27	100	0	3111111.111	0.787	C
T28	100	0	2971428.571	0.781	C
T49	100	0	3151515.152	0.7778	C
T56	100	0	3151515.152	0.7778	C
T1	88.2353	588235.2941	3466666.667	0.75	NC
T6	69.697	1212121.212	4173913.044	0.7174	NC
T29	100	0	2888888.889	0.787	NC
T30	100	0	3151515.152	0.7778	NC
T31	94.1176	470588.2353	3250000	0.7656	NC
T32	100	0	3058823.529	0.7843	NC
T33	100	0	2971428.571	0.781	NC
T34	100	0	3393939.394	0.7677	NC
T35	96.7742	387096.7742	3466666.667	0.7556	NC
T36	100	0	3096774.194	0.7742	NC
T37	100	0	3058823.529	0.7794	NC

T38	97.0588	235294.1176	3393939.394	0.7677	NC
T39	93.5484	903225.8065	4137931.035	0.7126	NC
T40	78.7879	1818181.818	5538461.539	0.6154	NC
T41	100	0	3294117.647	0.7696	NC
T42	97.0588	352941.1765	3393939.394	0.7576	NC
T43	91.1765	1176470.588	4387096.774	0.6935	NC
T44	96.9697	484848.4848	3750000	0.7292	NC
T45	100	0	3096774.194	0.7742	NC
T46	100	0	3151515.152	0.7727	NC
T47	93.9394	727272.7273	4129032.258	0.7043	NC
T48	100	0	3111111.111	0.787	NC
T50	93.5484	645161.2903	3586206.897	0.7471	NC
T51	100	0	3250000	0.7708	NC
T52	97.1429	457142.8571	3529411.765	0.7549	NC
T53	96.9697	242424.2424	3500000	0.7552	NC
T54	96.9697	363636.3636	3750000	0.75	NC
T55	100	0	3250000	0.7708	NC
T57	94.1176	941176.4706	4250000	0.7083	NC
T58	75	2125000	6000000	0.5972	NC

10.2 Result of landscape metrics for all sample plots in class 1

ID	PLAND	ED	PARA_MN	CONTIG_MN	CERTIFICATION
T2	3.0303	363636.3636	16000000	0	C
T4	8.5714	1142857.143	16000000	0.0417	C
T14	8.8235	941176.4706	14000000	0.0833	C
T15	22.8571	1142857.143	8000000	0.4375	C
T17	2.9412	470588.2353	16000000	0	C
T18	12.1212	727272.7273	12000000	0.25	C
T19	8.5714	1028571.429	13333333.33	0.1667	C
T20	16.129	1161290.323	8000000	0.4333	C
T23	5.8824	235294.1176	12000000	0.1667	C
T1	11.7647	588235.2941	10000000	0.2917	NC
T6	30.303	1212121.212	8800000	0.4	NC
T31	5.8824	470588.2353	16000000	0	NC
T35	3.2258	387096.7742	16000000	0	NC
T38	2.9412	235294.1176	16000000	0	NC
T39	6.4516	903225.8065	16000000	0	NC
T40	21.2121	1818181.818	12444444.44	0.1667	NC
T42	2.9412	352941.1765	16000000	0	NC
T43	8.8235	1176470.588	16000000	0	NC
T44	3.0303	484848.4848	16000000	0	NC
T47	6.0606	727272.7273	12000000	0.1667	NC

T50	6.4516	645161.2903	16000000	0	NC
T52	2.8571	457142.8571	16000000	0	NC
T53	3.0303	242424.2424	16000000	0	NC
T54	3.0303	363636.3636	16000000	0	NC
T57	5.8824	941176.4706	16000000	0.0833	NC
T58	25	2125000	14222222.22	0.1019	NC

10.3 Results of statistics Mann–Whitney U test for all landscape metrics in class 0 from RStudio

 # 10.3.1 PLAND Mann–Whitney U test

wilcox.test(PLAND ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: PLAND by CERTIFICATION

W = 505.5, p-value = 0.1469

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-2.353527e-05 3.030255e+00

sample estimates:

difference in location

5.080689e-05

 # 10.3.2 ED Mann–Whitney U test

wilcox.test(ED ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: ED by CERTIFICATION

W = 326, p-value = 0.1107

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-3.636364e+05 5.906622e-05

sample estimates:

difference in location

-2.27005e-05

 # 10.3.3 PARA_MN Mann–Whitney U test

wilcox.test(PARA_MN ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1

Wilcoxon rank sum test with continuity correction

data: PARA_MN by CERTIFICATION

W = 309.5, p-value = 0.08654

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-3.484848e+05 4.111348e-04

sample estimates:

difference in location

-151515.2

 # 10.3.4 CONTIG_MN Mann–Whitney U test

```
wilcox.test(CONTIG_MN ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE,
conf.int=TRUE, data=data1)
```

#Wilcoxon rank sum test with continuity correction

data: CONTIG_MN by CERTIFICATION

W = 533.5, p-value = 0.07832

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-1.226614e-05 2.081725e-02

sample estimates:

difference in location

0.007192217

10.4 Results of statistics Mann–Whitney U test for all landscape metrics in class 1 from RStudio

 # 10.4.1 PLAND Mann–Whitney U test

wilcox.test(PLAND ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: PLAND by CERTIFICATION

W = 94, p-value = 0.3578

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-2.941157 5.882282

sample estimates:

difference in location

2.510859

 # 10.4.2 ED Mann–Whitney U test

wilcox.test(ED ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: ED by CERTIFICATION

W = 85.5, p-value = 0.6465

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-249554.4 543722.9

sample estimates:

difference in location

106951.9

 # 10.4.3 PARA_MN Mann–Whitney U test

wilcox.test(PARA_MN ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: PARA_MN by CERTIFICATION

W = 46, p-value = 0.07185

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-4.000000e+06 1.061684e-05

sample estimates:

difference in location

-2e+06

 # 10.4.4 CONTIG_MN Mann–Whitney U test

wilcox.test(CONTIG_MN ~ CERTIFICATION, mu=0, alt="two.sided", correct=TRUE, paired=FALSE, conf.int=TRUE, data=data1)

#Wilcoxon rank sum test with continuity correction

data: CONTIG_MN by CERTIFICATION

W = 110.5, p-value = 0.05314

alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:

-7.894231e-05 1.667422e-01

sample estimates:

difference in location

0.08324467