Mapping and identification of hotspot areas for biodiversity and Ecosystem Services in cork oak woodlands of southern Portugal

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(Front cover: cork oak montado in Alentejo, Southern Portugal. Photo credit: M.Bugalho)

DISSERTATION TOPIC:

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ABSTRACT:

Cork oak woodlands or *montados* are ecosystems of high conservation and socio-economic importance. The present work aimed at 1) identifying and mapping biodiversity and Ecosystem Services in main area of distribution of cork oak *montado* in Southern Portugal 2) assessing how the distribution of these conservation values relates with the distribution of the network of classified areas and 3) assessing how the distribution of identified conservation values relates with the area of cork oak *montado* under forest certification. I mapped biodiversity values (presence of species of amphibians, reptiles and threatened birds) and Ecosystem Services (carbon storage and aquifer recharge rates) within the study area. For achieving this I used the open source Q-GIS 2.0.1. software together with the open access online geographic information system WebGIS Hotspot Areas for Biodiversity and Ecosystem Services (HABEaS: www.habeas-med.org). With the exception of Natura 2000 sites the distribution of Biodiversity and Ecosystem Services is largely not coincident with that of classified areas. In relation to forest certified areas, these are presently covering a significant area of cork oak *montados* where biodiversity values and Ecosystem Services overlap.

Keywords:

Conservation tools, *Quercus suber*, Forest certification, Payments for Ecosystem Services.

RESUMO:

Os montados são ecossistemas com valor socio-económico e ambiental elevados. Para além de albergarem diversas espécies de fauna e flora endémica ou ameaçada geram importantes serviços do ecosistema incluindo cortiça e produção animal mas também serviços culturais, armazenamento de carbono a longo termo ou regulação do ciclo hidrológico.

Os montados são considerados um tipo de habitat classificado no âmbito da rede Pan-Europeia de Conservação Natura2000. Encontram-se ainda varias áreas de montado integradas em zonas de protecção especial para aves ou sítios clasificados assim como localizadas em várias na rede nacional de áreas protegidas.

Para além destas formas de protecção, mais recentemente a certificação da gestão florestal foi aplicada aos montados visando a promoção de boas práticas de gestão e conservação destes ecossistemas.

Este trabalho teve como principal objectivo identificar numa área de estudo dominantemente de montado de sobreiro (Quercus suber) quais as zonas que 1) concentravam valores de biodiversidade elevada (nomeadamente avifauna ameaçada); 2) armazenavam níveis de carbono elevado; 3) se concentravam em áreas importante para recarga de aquíferos. Para além da identificação de áreas com importancia para a conservação da biodiversidade e serviços do ecosistema referidos, o trabalho visou ainda avaliar 4) em que áreas existe sobreposição de valores de biodiversidade e serviços do ecossistema (áreas “hotspot” para biodiversidade e serviços do ecossistema) e 5) de que maneira a actual rede de áreas classificadas e sob certificação de gestão florestal cobrem estas áreas “hotspot.”

A área de estudo situa-se no Sul de Portugal nas regiões do Tejo e Ribatejo cobrindo aproximadamente 500 mil hectares nos quais o sobreiro é a espécie florestal dominante.

Para responder aos objectivos acima listados foram utilizados dados de distribuição de avifauna e répteis ameaçados e de répteis e anfíbios endémicos à Península Ibérica. Para o mapeamento de serviços do ecossistema foram usados dados de carbono florestal e localização de aquíferos. Estes dados foram inseridos em Sistema de Informação Geográfica e analisados com recurso à ferramenta WebGIS HABEaS (www.habeas-med.org). Seguidamente identificaram-se as áreas geográficas que coincidiram com células espaciais com número de espécies de avifauna ameaçada acima da média, assim como valores de armazenamento de carbono ou taxas recarga de aquífero também acima da média para a região em causa. Finalmente identificaram-se as áreas que concentravam valores de

biodiversidade e serviços do ecosistema elevados e avaliou-se qual a percentagem destas áreas que está coberta pela Rede Natura 2000, rede de áreas protegidas ou sob sistema de gestão florestal certificada.

Com excepção dos sítios Natura 2000 de interesse comunitário a rede de áreas classificadas é geralmente pouco coincidente com áreas com valor para a conservação da biodiversidade e serviços do ecossistema. No entanto a área de montado sob gestão florestal certificada coincide em grande parte com os valores de conservação identificados.

Palavras-chave:

Ferramentas de conservação, *Quercus suber*, certificação florestal, Pagamentos por Serviços Ambientais.

Chapter 1: Introduction

1.1. Biodiversity and Ecosystem Services in forests

The continued growth of human populations and per capita consumption have resulted in unsustainable exploitation of Earth biological diversity, exacerbated by climate change, ocean acidification, and other anthropogenic environmental impacts. Effective conservation of biodiversity is essential for human survival and the maintenance of ecosystem processes (Rands *et al.,* 2010).

Forest biodiversity refers to all life forms found within forested areas and the ecological roles they perform. As such, forest biological diversity encompasses not just trees, but the multitude of plants, animals and micro-organisms that inhabit forest areas and their associated genetic diversity. It results from evolutionary processes over thousands and even millions of years which, in themselves, are driven by ecological forces such as climate, fire, competition and disturbance. Within specific forest ecosystems, the maintenance of ecological processes is dependent upon the maintenance of their biological diversity (Convention of Biological Diversity, 1995), which is globally decreasing at an alarming rate (Pereira *et al.,* 2010, Butchart *et al*., 2010). For example, the Living Planet Index (an index measuring mean population trend of vertebrate species) declined 31% over the last 40 years (Butchart *et al.,* 2010).

The Mediterranean Basin is one of the world's biodiversity "hotspots" (Myers *et al.,* 2000), hosting more than 25000 plant species, 50% of which are endemic to the region (Médail & Quézel, 1997) and a number of endangered or critically endangered vertebrates (Branco *et al.*, 2010). Human-induced changes are known to account for an important part of the variation in the components and dynamics of current biodiversity in the Mediterranean region (Blondel & Aronson, 1999; Lavorel *et al.*, 1998). An example is the cork oak (*Quercus suber*) woodlands. These are human-shaped ecosystems, typical of the western part of the Mediterranean Basin, which harbour important biodiversity values and generate relevant Ecosystem Services (Bugalho *et al.,* 2011-a).

Ecosystem Services (ES) are the benefits that humankind derives from ecosystems. In economic terms, ES can be defined as intangible commodities and, ecologically, as biophysical processes that contribute to production, to human wellbeing or value (Meijaard *et al.*, 2014).

Scientists have struggled to quantify ES using consistent, comparable approaches. ES have been quantified at different spatial and temporal scales, in relation to their supply or production, demand and consumption, and using a wide and heterogenic array of indicators or metrics (Nemec & Raudsepp-Hearne, 2013). Indicators or metrics can be quantity of a product extracted from forest ecosystems, such as the number of deer killed in a forest during a year (e.g. Raudsepp-Hearne, *et al.,* 2010), water quality data or equations linking production values to potential use or benefit to human populations (e. g. Chan *et al.*, 2006). The Millennium Ecosystem Assessment (MEA, 2005) analysed the state of the Earth ecosystems and provided summaries and guidelines for decision-makers. MEA reported 24 Ecosystem Services concluding that only 4 ES have shown improvement over the last 50 years, 15 are in serious decline, and 5 are in a stable state overall, but under threat in some parts of the world (MEA, 2014).

ES frequently trade-off, that is maximizing delivery of a particular ES results in decline of other ES. For example, there may be trade-offs between availability of water and carbon sequestration. Enhancing carbon sequestration can help to mitigate climate change, but it can also encourage the expansion of fast growing species with negative consequences for water supply and biodiversity (Chisholm, 2010; Caparrós *et al.,* 2010). Additionally, ES supply can be related with ES interactions, or ES responses to the same driver of change, such as human management (Bennet *et al*., 2009). In the case of carbon sequestration and water availability, both of these ES have unidirectional interaction (Engel *et al.,* 2005): provision of carbon affects provision of water but not vice-versa. In this case, afforestation can be the driver of change.

Over the past several decades, a rapidly expanding field of research known as biodiversity and ecosystem functioning has begun to quantify how the world's biological diversity can, as an independent variable, control ecological processes essential for the functioning of ecosystems (Cardinale *et al.,* 2011). There is now a consensus that worldwide biodiversity decline (Butchart *et al*. 2010) can affect ecosystem functioning and ES supply (Balvanera *et al.,* 2006; Cardinale *et al.*, 2011; Hooper *et al*., 2005; Naeem *et al*., 2009). Recent studies have supported this hypothesis (e.g. Isbell *et al*., 2011).

Understanding where biodiversity and ES are located within a landscape and identifying areas where biodiversity values and Ecosystem Services may geographically overlap will contribute to support conservation policies and tools.

1.1.2. Tools for conserving biodiversity and Ecosystem Services

1.1.2.1. Classified areas

Different tools have been developed for protecting biodiversity and associated ES. For example, the development of laws and geographical delimitation of "classified areas", usually restricting uses of the land aim to protect relevant biodiversity values. In Europe, Natura 2000 is an example. Natura 2000 is a pan-European Network of classified areas aiming to ensure the long-term survival of European most valuable and threatened species and habitats (European Commission, 2014). In Portugal, Natura 2000 was established by, and depends on, the Institute for Conservation of Nature and Forests (ICNF), of the Ministry of the Environment, Territory, and Regional Development. A duty of ICNF is to identify and monitor endangered habitats and species, as well as to promote adequate management of areas under Natura 2000 (Instituto da Conservação da Natureza e das Florestas, 2014). Natura 2000 includes the Special Protection Areas for Birds (SPABs), which identifies areas important for the conservation of bird species and are defined by the European Birds Directive, Council Directive 2009/147/EC on the conservation of wild birds, and Special Areas of Conservation (SACs), which are defined to protected habitats of conservation value in Europe and are designated by the Habitats Directive, Council Directive 1992/43/EEC on the Conservation of natural habitats and of wild fauna and flora.

Other classified areas in Portugal are covered by the national network of Protected Areas and include Nature Parks, Nature Reserves, Protected Landscapes and Natural Monuments.

Beyond classified areas, more recently there has been a focus on market based conservation tools. These tools are based on the idea that we currently witness an acceleration of the pace of degradation of valuable Ecosystem Services currently not transacted in markets, while market incentives (prices) convey our needs for food, energy, mobility, housing and other goods and services, without reflecting the value of biodiversity and ES which we usually benefit for free (Branco *et al.,* 2010). An example of a market based conservation tool is forest certification.

1.1.2.2. Forest Certification

Forest certification aims to promote the sustainable management and conservation of forest ecosystems by adding market value to products generated according to environmental and socio-economic principles (Auld *et al.*, 2008; Gomez-Zamalloa *et al.,* 2011). It integrates both sustainable forest management and biodiversity protection, whereas, earlier, these goals were separated in different regulations and different geographical areas (Pappila, 2013). Success of forest certification also relies on the willingness of a growing number of consumers to pay more for sustainably generated products (Auld *et al*., 2008). Forest certification has generated multiple debates. Some authors consider that certification has generated considerable interest as a means to achieve improved environmental and social outcomes in forests and forest landscapes (Auld *et al.*, 2008). Indeed certification may help buyers of a market commodity to distinguish different types of products or services according to whether or not they have desirable features (Pagiola & Ruthenberg, 2002). Other authors have criticized viability and achievement of forest certification (e.g. Romero *et al.,* 2013; Visseren-Hamakers & Pattberg, 2013; Meijaard *et al.*, 2011) because of insufficient demand for multiple services, high biophysical service complexity, and elevated monitoring costs that indicate that opportunities for large-scale commercial viability of certified forest Ecosystem Services are limited (Meijaard *et al.*, 2011). Other authors (e.g. Ulybina & Fennell, 2013) suggest that behind certification there are commercial drivers, which in combination with the lack of social controls, may let through not always desirable forestry practices under certification schemes.

The most expanded forest certification programs are the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) (Third-Party Forest Certification in British Columbia, 2013). In the present work we concentrate in areas under FSC forest certification which predominantly cover (over 90%) the cork oak *montado*, which is the ecosystem addressed in the present thesis.

The Forest Stewardship Council certification (FSC) is the first working example of a certification body, founded in 1993 by environmental Non-Governmental Organizations (NGOs), retailers and private foundations (Meijaard *et al.*, 2014). FSC is based on a flexible standard of forest management covering issues that include land tenure, use rights and responsibilities, rights of indigenous peoples, and biodiversity conservation, among others (Auld, *et al.,* 2008). The process is voluntary and conducted at the request of landowners, based on an independent audit of landholder management practices. FSC specifies 10 principles defining Responsible Forest Management which are global and applied in any forest worldwide (Branco *et al.*, 2010; Auld *et al* 2008). These 10 principles are: 1: Compliance with laws and FSC Principles; 2: Tenure and use rights and responsibilities; 3: Indigenous peoples' rights; 4: Community relations and worker's rights; 5: Benefits from the forest; 6: Environmental impact; 7: Management plan; 8: Monitoring and assessment; 9: Maintenance of high conservation value forests; 10: Plantations.

Forest biodiversity and ES values are addressed under Principle 6 that states that ''forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes'' and Principle 9 that states that "Management activities in high conservation value forests shall maintain or enhance the attributes which define such forests. Decisions regarding high conservation value forests shall always be considered in the context of a precautionary approach" (FSC, 2014). High Conservation Value Area (HCVA) is a concept defined under Principle 9 as an area containing one or more of the following 6 "high conservation attributes" (HCV Resource Network, 2014): 1: Areas containing globally, regionally or nationally significant concentrations of biodiversity values; 2: Areas containing globally, regionally or nationally significant large landscape-level areas where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance; 3: Areas that are in or contain rare, threatened or endangered ecosystems; 4: Areas that provide basic Ecosystem Services in critical situations; 5: Areas fundamental to meeting basic needs of local communities; 6: Areas critical to traditional cultural identity of local communities. The HCVA concept has been extended and applied beyond the context of forest certification such as conservation planning or landscape management. HCVA is an international standard that is regionally adopted through a process of stakeholder consultation and public participation. In Portugal, HCVA national interpretation involved public participation and discussion among stakeholders including environmental NGOs, universities, forest and biodiversity public administration, farmer and forest landowner associations and other entities (Branco *et al.*, 2010)..

Presently, the area of forests under FSC certification cover approximately 184 million ha (FSC, 2014). Although monitoring studies are relatively scarce, FSC certification has been shown to affect positively biodiversity conservation, both in tropical (Azevedo-Ramos *et al.,* 2006) and temperate forests (Elbakidze *et al.,* 2011). However, less is known for Mediterranean type forests. Currently there are 4 million ha of Mediterranean forests certified under FSC (Dias *et al*., 2013) including cork woodlands (Berrahmouni *et al*., 2009). In Portugal, the country with the largest area of cork oak woodlands (approximately 716 thousand ha) certified area reached 100 thousand ha in 2013 (FSC Portugal, 2014).

Although forest certification is aimed at management standards of producing wood and non-wood forest products there are now attempts of several organizations to develop certification systems that may also explicitly address certification of forest ES, such as pollination, flood buffering or carbon storage (FSC, 2010; WWF, 2011). Together with other financial mechanisms such as tax incentives, certification is intended to reward forest managers providing environmental services when adopting certified management standards. Given the multiple societal demands on forest ecosystems, certification of Forest ES is a logical progression from timber certification (FSC, 2012). Although, so far, certification of forest ES has been unsuccessful due to insufficient demand for maintaining a market of certification of forest ES (Meijaard *et al*., 2014).

1.1.2.3. Payments for Environmental Services

Payments for Environmental Services (PES) is a relatively novel market conservation tool which aims generating economic incentives to landowners that adopt good management practices favouring the conservation of biodiversity and ES (Branco *et al.*, 2010). PES are part of a new and more direct conservation paradigm, explicitly recognizing the need to bridge the interests of landowners and outsiders (Wunder, 2005). PES are increasingly being applied worldwide (Daily & Matson, 2008) aiming at mitigating ecosystem mismanagement, loss of biodiversity, and the reduction of ES such as carbon sequestration and storage or water provision (Bennett & Balvanera, 2007). PES are indeed transactions that reward individuals or communities for undertaking actions that increase the levels of desired ES (Gundimeda & Wätzold, 2010). According to Wunder & Wertz-Kanounnikoff (2009), the most novel and persuasive feature of PES lies in its "businesslike" conditional payment form, which differs from traditional conservation projects. The core idea consists in beneficiaries of ES making direct contractual payments to local land managers in return for adopting land and resource uses that secure ecosystem conservation and restoration (Wunder, 2007). On the other hand, as explained in Wunder (2005), if a price has to be paid for ecosystem degradation, then ecosystem degradation may be integrated as a cost in decision-making as a compensation. Thus, incentives are created for both investing in ecosystem conservation and refraining from degrading ecosystems. For instance, by setting aside an area for forest conservation farmers may positively impact the provision of certain ES (*e.g.* biodiversity protection, water quality), but at a cost of decreasing crop productivity (Ribas *et al.,* 2011). Service users must then compensate service providers for their behavioural change and the consequent increase in services supply (Figure 1).

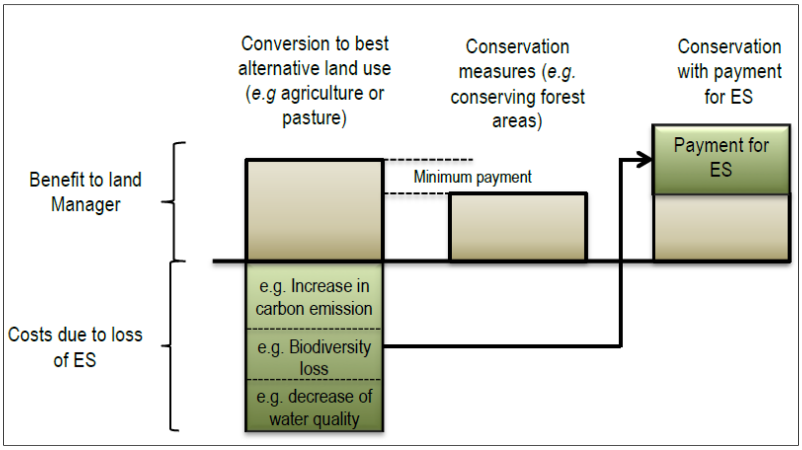

Figure 1: The logic of PES (Ribas, 2011, adapted from Pagiola & Platais, 2007; Engel *et al.,* 2008; Arriagada & Perrings, 2009).

The payments for ES can be direct or indirect (Tallis *et al.,* 2008) and of 3 different types (Powell & White, 2001; Johnson *et al.*, 2002, Wunder & Wertz-Kanounnikoff, 2009):

1. Public payment mechanisms: involve public agencies purchasing services. These arrangements can be based on market or quasi-market prices, frequently using extra-market payment mechanisms such as bonds, tax revenues, or user fees and may be subsidized. Payments generally go directly to the landowner (Robbins, 2005).

2. Trading Schemes: trading schemes consist of heavily regulated industries that can trade credits below a predetermined cap. In order for this scheme to function, a strong regulatory system with enforcement capacity must exist so that this system can operate (Robbins, 2005). There are also voluntary markets that work through companies or organizations that seek to reduce their carbon footprints and therefore are motivated to engage in the voluntary market. Such companies or organizations aim to enhance their brands, to anticipate emerging regulation as a result of stakeholder and/or shareholder pressure or other reasons, and, according to Wendland *et al.* (2010), are growing.

3. Self-Organized Private Deals: they are negotiated business-to-business or business-to-community and government organizations are not normally involved (Robbins, 2005). In this scheme, individual beneficiaries of ES contact directly with providers of those services. Voluntary markets are also a category of private PES (Forest Trends, The Katoomba Group & UNEP, 2008).

In addition, ES can be sold as a package (Bundle Ecosystem Services). In other words, biodiversity conservation, provision of clean water by water catchment, carbon sequestration or storage and other ES can be sold together rather than individually (Branco *et al.*, 2010). Bundled services can be seen as (Landell-Mills & Porras, 2002): *merged bundles* in which ES are sold together and cannot be subdivided for sales to separate purchasers. This kind of service bundling is an adequate strategy only when the same buyer has several simultaneous service interests (Wunder & Wertz-Kanounnikoff, 2009); and as s*hopping basket bundles in which* purchasers can acquire specific services on their own or as part of a package and land stewards can sell different services to different buyers (Wunder & Wertz-Kanounnikoff (2009).

One example of a global PES scheme is the United Nations Program for Reduction Emission from Deforestation and Degradation (REDD+). REDD+ aims to mitigate carbon emissions in developing countries of the southern hemisphere through the provision of financial incentives reducing the rate of forest clearing and degradation (Bugalho *et al.,* 2011-a). It offers an additional source of financing to support sustainable forest management and to boost their development plans and poverty-reduction strategies. In the case of many developed countries, REDD+ seems to be an attractive option to achieve part of their reduction targets through investments in developing countries (Kanninen *et al.,* 2010). Although several PES schemes are still in a pilot phase these mechanism has been widely applied in developed countries (Baylis *et al*. 2008).

1.1.2.4. Other market conservation tools

Other conservation tools that have been implemented to favor good ecosystem management practices are, for example, the Agro-environmental schemes (AES) of the European Union Common Agricultural Policy (CAP). AES are based on monetary compensation to farmers (Kleijn & Sutherland, 2003) and consist on a set of programs and subsidies of direct payments to farmers, and subsidizing of agricultural exports which aim to protect biodiversity by reducing the negative effects of agriculture (e.g. reductions in the use of pesticides and/or fertilizers) and promoting environmentally friendly practices including traditional farming.

1.2. The *montado* ecosystem

Cork oak woodlands, also named *montados in Portugal* are silvopastoral systems characterized by a relatively scattered tree cover (60–100 trees/ha) dominated by the evergreen oaks cork oak (*Quercus suber),* and holm oak (*Quercus rotundifolia*). *Montados* occur in the warmer parts of the humid and sub humid western Mediterranean Basin, covering approximately 1.5 million ha in Europe and 1 million ha in North Africa (Pausas *et al*., 2009; Bugalho *et al.,* 2011-a). In Portugal, *montados* cover approximately 1.1 million ha (cork and holm oak), dominating in the South of the country, with approximately 716 thousand ha of cork oak and 350 thousand ha of holm oak (Invéntario Florestal Nacional, 2007).

In some regions these species are mixed with other tree species such as maritime (*Pinus pinaster)* and umbrella (*Pinus pinea*) pine. Under the tree canopy pastures and agricultural crops (clover, wheat, barley, oats) are common, and usually implemented in a rotation scheme that includes fallows (Pinto-Correia, 1993; Lourenço *et al*., 1998). Shifting rotation in *montados* creates an ever-changing mosaic of land uses and of habitat types of high conservation value (Diaz *et al.,* 1997; Carrión *et al* 2000; de Miguel 1999).

A diversity of shrub species also occurs (e.g., *Cistus* spp*., Erica* spp*., Lavandula* spp*.,* and *Ulex* spp.) (Lourenço *et al.*, 1998; Pinto-Correia & Mascarenhas, 1999, Bugalho *et al.* 2009). The human and ecological systems are integrated in *montados,* a feature typical of the Mediterranean Basin where ecosystems have been shaped by humans for more than 10 000 years (Blondel *et al*. 2010).

1.2.1. Ecosystem Services of cork oak *montados*

Cork oak *montados* are exploited for forestry, agriculture and grazing. These ecosystems generate cereal crops, cork, charcoal, game, honey, meat and dairy products (Pereira & Fonseca, 2003; Bugalho *et al.,* 2009). The main source of income in cork oak *montados* however is cork production. Cork is a non-timber forest product, 70 % of which is used to make wine bottle stoppers (Bugalho *et al.*, 2011-a). Portugal is the world's largest cork producer, with 49.6 % of the world production (Mendes & Graça, 2009). Cork has been harvested since very old times, probably even before the 4th century BC (Aronson *et al.,* 2009) but only gained commercial importance after the 18th century, with an increasing need for cork bottle stoppers that accompanied the expansion of the trade in bottled wine at that time (Bugalho *et al.,* 2011-a). From the 19th century onwards, there was a sustained effort to expand the existing areal extent of cork oak lands (most notably in the Iberian Peninsula) in direct response to the increasing value of cork in international markets (Bugalho *et al.,* 2009). Currently cork is manually harvested from living trees once every 9-12 years. *Montados* generate other Ecosystem Services such as cultural, supporting or regulating services (Table 1) including long term carbon storage or regulation of the water cycle.

Table 1: Ecosystem Services generated by *montados* as modified from Berrahmouni *et al.* (2009).

Service	Description	Examples
Provisioning	Products obtained from ecosystems	Food, fodder, firewood, cork, other non-timber products
Cultural	Non material benefits obtained from ecosystems	Cultural heritage (landscape amenity), recreation, tourism
Regulating	Benefits obtained from regulation of ES	Soil conservation, water retention, watershed protection, erosion control, fire risk prevention, carbon storage
Supporting	Services necessary for the production of all other ES	Soil formation, nutrient cycling, primary production

1.2.1.1. Long term carbon storage

As with old-growth forests (Luyssaert *et al*., 2008), cork oak *montados* accumulate and maintain carbon stocks for long periods. They play a role in carbon storage as the long-lived oak trees act as long term reserves of carbon (they can live up to hundreds of years). Also, cork is harvested without killing the trees with negligible effects on the ecosystem carbon balance (Pereira, unpublished). Thus, through adequate management, *montados* can promote carbon storage over very long periods (Branco *et al.,* 2010). Although cork oak is a slow growth tree this species may sequester carbon amounts similar to other oak species and ecosystems. For example, it has been shown that a *montado* with an average tree cover of 30% may sequester up to 140 g/m^2year which is a value similar to those obtained in North American deciduous oak woodlands (Pereira *et al*., 2007). .

1.2.1.2. Quality and availability of water

Well managed and conserved forests promote infiltration of rain water, prevent soil erosion and contribute to regulate the water cycle (Cardinale *et al.,* 2011). This is particularly important in areas where water is scarce and is likely to become scarcer in forecasted scenarios of climate change such as the Iberian Peninsula (Schröter *et al.* 2005). Cork and holm oak *montados* cover a large area of the Iberian Peninsula and therefore may play an important role in regulation of water cycle in these regions, restricting water loss (Pausas *et al.,* 2009). Oak tree roots extract nutrients from deep soil layers and transform it in organic matter in the photosynthesis process. Nutrients are returned to soil as organic matter when leaves fall off and accumulate on its surface. High organic matter content enhances water infiltration and decreases rainfall loss in surface runoffs (Rego *et al*., 2008). In the Iberian Peninsula, *montados* are situated within watersheds associated with impoundments used for irrigation or located over aquifers. An example of this is the Tagus-Sado aquifer system, the major groundwater unit of the Iberian Peninsula. This is a multi-layer system, the deepest and most productive aquifer in the region, being a unique source of water supply for drinking, agricultural and industrial supply (Ribeiro & Cunha, 2010). Approximately 40% of this aquifer is covered by cork oak (Bugalho *et al.* 2011-a; Branco *et al.,* 2010), therefore, forest management practices in the cork oak covering this aquifer will potentially affect the quality and quantity of water recharging this aquifer.

1.2.2. Biodiversity of *montados*

In the Mediterranean Basin human-mediated disturbances such as forest clearance (including fire use) and livestock grazing have favored habitat heterogeneity and biodiversity at local and regional levels, creating a multiplicity of ecotones (Blondel, 2006). Within the Mediterranean Basin the *montado* ecosystem harbors important biodiversity values. In these ecosystems species composition depends both on environmental and anthropogenic factors (Pereira & Da Fonseca, 2003; Bugalho *et al.,* 2011-a). Cork oak *montados* support a high diversity of species of birds, mammals, amphibians and reptiles, many of which are endemic to the Iberian Peninsula. *Montados* are also a key habitat for several migratory and overwintering birds (Diaz *et al.,* 1997). The variety of bird species occurring in *montados* is relatively high as compared with other ecosystems (Araújo *et al.,*1996). A reason for this is that habitat conditions in *montados* allow for the coexistence of species typically from forested areas simultaneously with species common from open agricultural areas or shrubland areas (Diaz *et al*., 1997; Branco *et al.,* 2010). Mismanagement and land abandonment (partially caused by devaluation and lower demand of cork) may lead to shrub encroachment, increased risk of wildfire and loss of habitat heterogeneity in *montados*. Shrub encroachment reduces grassland diversity in *montados* and may degrade some of the services generated by these ecosystems (Bugalho *et al.,* 2011). This is especially risky when considering wildfires, as shrub encroachment is often of native, flammable shrubs, such as *Cistus* spp. increasing the risk of severe wildfires (Joffre *et al.,* 1999). In some regions overgrazing can also be threat. Although the maintenance of grazing and small scale grazing-excluded areas increases habitat heterogeneity and plant and invertebrate diversity of *montados* (Bugalho *et al.,* 2011-b), overgrazing can lead to oak regeneration failure and loss of ecological sustainability of the system (Bugalho *et al*., 2011-a). Other management problems in *montados* include the general use of wide plows, disc harrows, and scarifiers. This heavy machinery unselectively destroys young trees and may damage roots and weaken established trees (Bugalho *et al*., 2009). Indeed, in dry sites or during droughts, trees become more dependent on their extensive superficial root system to survive and thus become more susceptible to the effects of heavy farm machinery. Tree weakness, in turn, may induce pests and fungal diseases that have attacked open *montados* and related systems in the last twenty years (Bugalho *et al*., 2009). The maintenance of a healthy oak canopy is not only essential to assure cork production but to ensure oak regeneration and the ecological sustainability of the system (Caldeira *et al.*, 2014). Finding proper incentives to good management practices in cork oak ecosystems will contribute to the conservation of such socio-economic and biodiversity rich ecosystem.

1.3. Aims of the study

My aims with the present study were to identify and map areas in *montados* of Southern Portugal:

- harboring important biodiversity values;
- generating carbon storage and water-related Ecosystem Services;
- where biodiversity values and Ecosystem Services overlap geographically (hotspot areas for biodiversity and Ecosystem Services);
- presently covered by classified areas and FSC certification and which concentrate areas important for the conservation of biodiversity and Ecosystem Services.

Chapter 2: Materials and Methods

2.1. Study area and data

The study area is located in southern Portugal, in the provinces of Ribatejo and Alentejo. It comprises the watersheds of Rivers Tagus and Sado (Figure 2-a and b), an area that corresponds to the largest and continuous cork oak cover of approximately 500 thousand ha (Branco *et al.*, 2010).

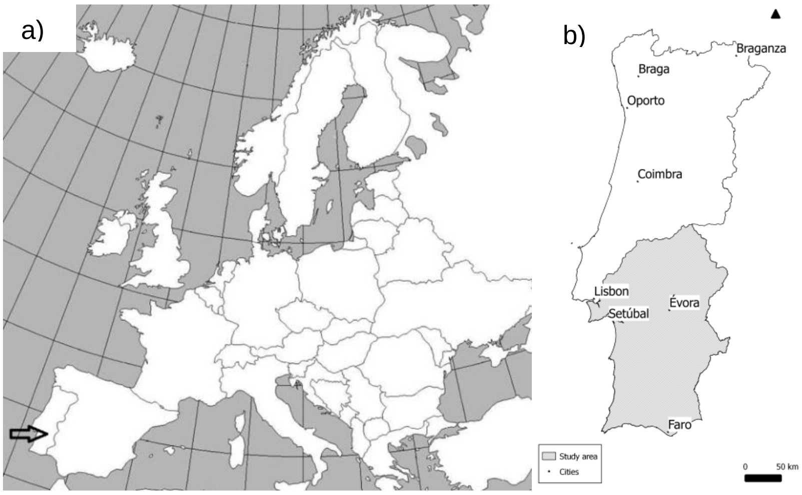

Figure 2-a; Location of Portugal in Europe (modified from plazadehistoria.wordpress.com); 2-b: Study area in Portugal.

Data on the distribution of cork oak *montados* was taken from HABEaS project, modified from the National Forest Inventory (Autoridade Florestal Nacional, 2010). Protected Areas of Portugal (PAs) distribution was obtained from the Institute for the Conservation of Nature and Forests (Instituto da Conservaçao da Natureza, 2014). Areas related with Natura2000 network (SPABs and SACs) were obtained from the European Environment Agency (www.eea.europa.eu). The source of information for area under FSC certification was taken form FSC Portugal (www.fscportugal.com).

Data for biodiversity was taken from 1) the national biodiversity surveys carried out by Equipa Atlas (2008) for occurrences of breeding non marine birds and 2) from Loureiro *et al.* (2008) for the distribution of reptiles and amphibians that spend part of their life cycle in *montados*. Both bird and reptiles and amphibians data were obtained in a 10km x 10km grid scale. Above ground carbon storage in *montados* was collected from the National Forest Inventory (Autoridade Florestal Nacional, 2010). Data on aquifer location and aquifer water recharge rates was collected from Almeida *et al.,* (2000).

All data have been adapted from the original vector coverage into a raster map. For the areas under different conservation categories (PAs, SPABs, SACs and FSC certified), cells were classified according to the proportion of the cell area occupied by a conservation category (less than 2%, 2 to 5%, 5 to 10%, 10 to 20% and more than 20% of the grid-cell area). The use of thresholds is common when dealing with protection networks and species distributional data at different spatial scales (e.g. Araújo *et al.,* 2007).

Data on *montado* cover was obtained from HABEaS project in a 500 x 500 m grid (modified form Autoridade Florestal Nacional, 2010) and transposed to a 10 x 10 km UTM grid, following the Food and Agriculture Organization of the United Nations (FAO) which defines Mediterranean and other Forest areas as "areas with a tree canopy projection equal or above 10%" (FAO, 2006). Thus, I selected those cells within the grid which had cork oak cover equal or above 10%. In other words, I took the 10 x 10 km UTM grid used in national biodiversity surveys and defined the study area as the set of cells with canopy projection of cork oak ≥10 % (Figures 3-a and b). Furthermore, using data from HABeAS project initially taken from the Forest National Inventory, I identified those areas where cork oak was dominant. This area corresponded to the northwestern part of the study area (Figure 4). (For consulting original dataset please see *Appendix I: original dataset*).

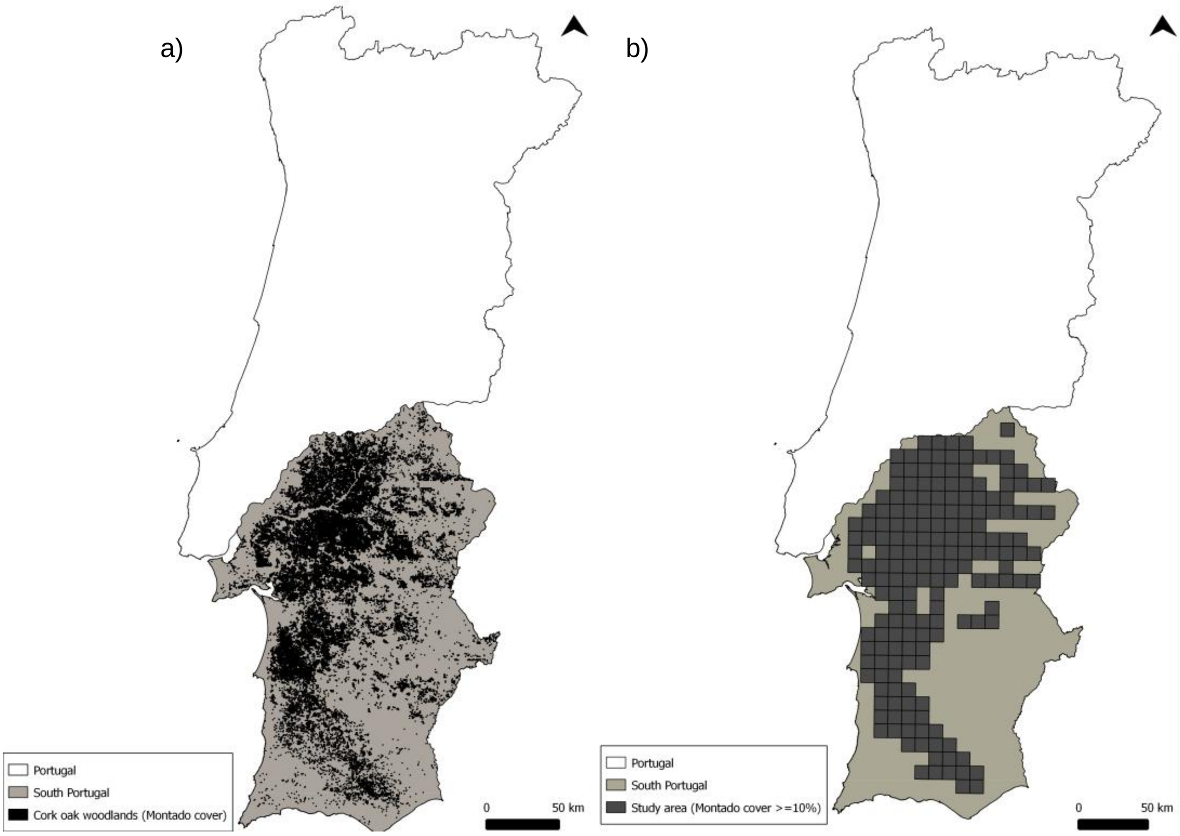

Figure 3-a: Vector coverage of *montados* in South Portugal; 3-b: Study area in the 10x10 km UTM grid.

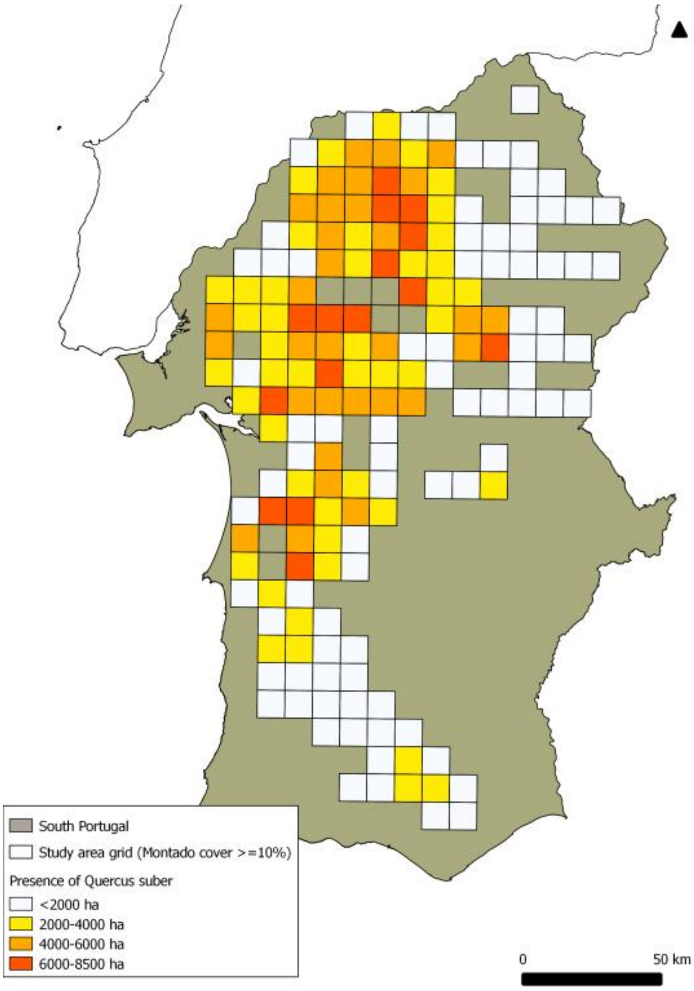

Figure 4: Cells within study area where cork oak cover is dominant.

The study area is moderately hilly with a mean altitude of 178 m whose values range between 0 and 1019 m above the sea level. The climate is typically Mediterranean, with a hot and dry summer and a rainy and mild winter. The mean annual temperatures range between 15 and 18 ºC and precipitation between 600 and 800 mm/year (Instituto Português do Mar e da Atmosfera, 2013). The dominant forest cover in the area are cork (*Quercus suber*) and holm oak (*Q. rotundifolia*), interspaced with maritime pine (*Pinus pinaster*), stone pine (*Pinus pinea*) and blue gum (*Eucalyptus globulus*) plantations (Dias *et al*., 2013). Species such as *Quercus rotundifolia, Pinus pinea, Pinus pinaster* and *Eucalyptus globulus* are widely dispersed in the study area occurring in the 69%, 75%, 60% and 91% of the cells, respectively. *Eucalyptus globulus* and *Pinus pinaster,* although widely distributed, are dominant in only 15% and 3% of the forested area, respectively (Figures 4 and 5). *Quercus rotundifolia* is more localized in the southern and eastern parts of the study area and generally less represented in areas where *Quercus suber* dominates (Figures 4 and 5).

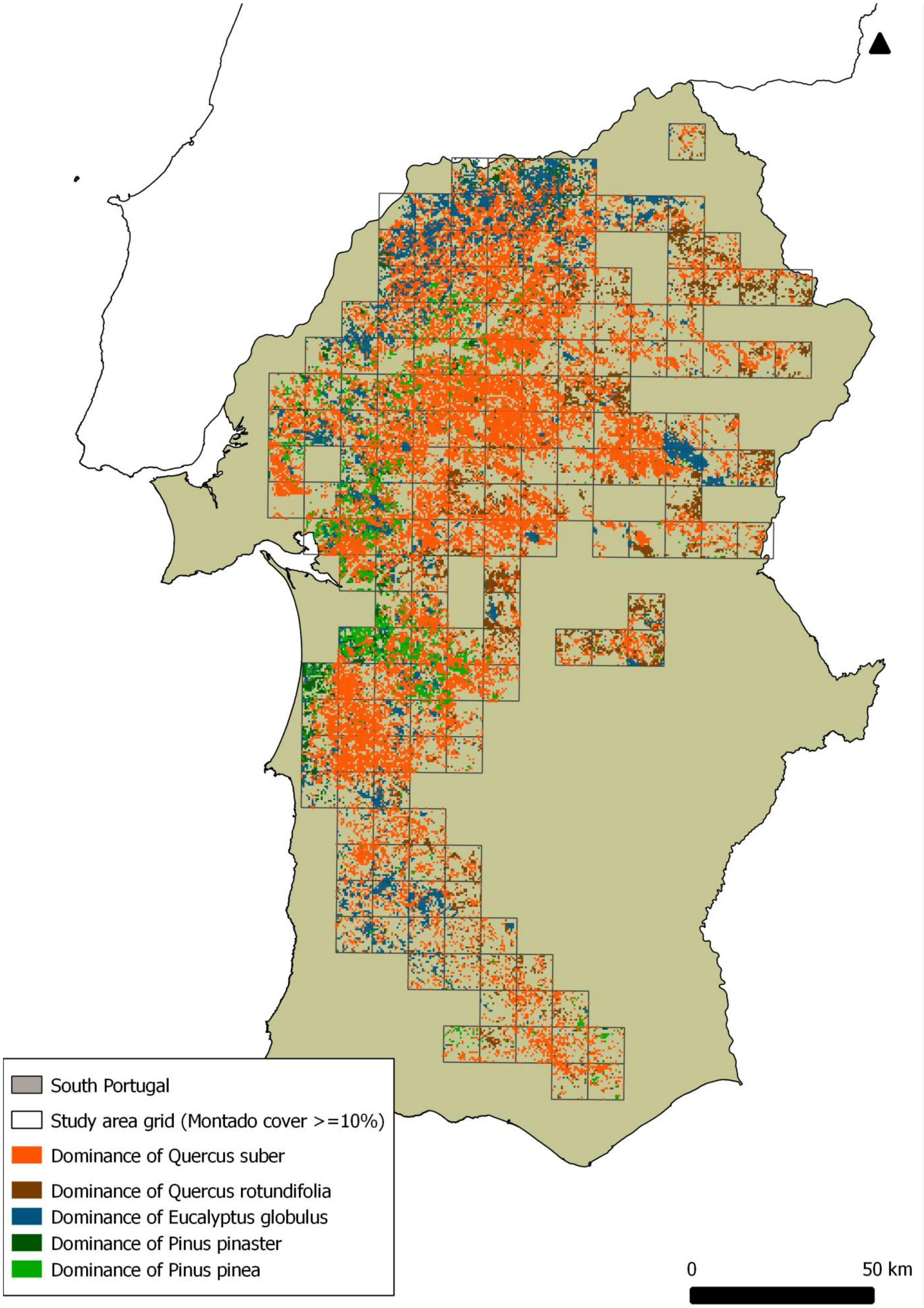

Figure 5: Distribution of lands dominated by *Quercus suber, Quercus rotundifolia, Eucalyptus globulus, Pinus pinaster* and *Pinus pinea* in the study area.

Thus *Quercus suber* is the most abundant species in the study area followed by *Eucalyptus globulus, Quercus rotundifolia, Pinus pinea and Pinus pinaster* (Figure 6 and Table 2).

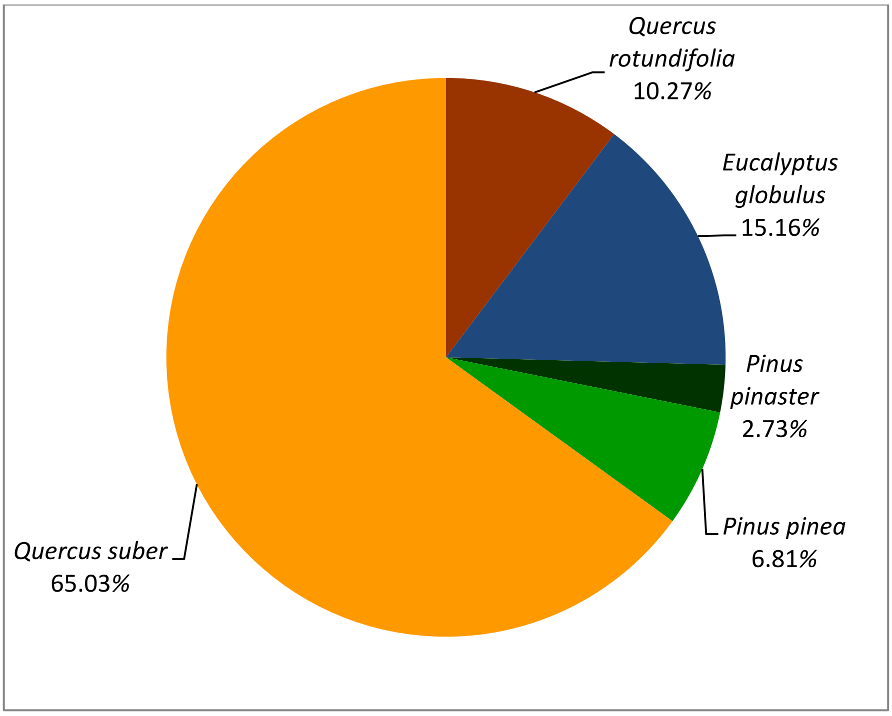

Figure 6: Percentage of the study area in which each of the 4 tree species occurring in the study area are dominant. Data from the National Forest Inventory (Autoridade Florestal Nacional, 2010).

Table 2: Percentage of study area grid cells in which each of the species occurs, and in which each species has the widest distribution, not considering *Quercus suber*.

% of cells	*Quercus rotundifolia*	*Eucalyptus globulus*	*Pinus pinaster*	*Pinus pinea*	*Quercus suber*
Species ocurrence	69.44	91.11	60	75	100
Species dominance	41.11	37.77	2.22	18.89	-

Relationships among other species occurring in the study area can be seen in *Appendix II: Other species analysis.*

There are different classified areas occurring in the study area including Protected Areas (PAs), Special Protection Areas for Birds (SPABs) and Special Areas of Conservation (SACs) (Figure 7). The area under Forest Stewardship Council (FSC) certification is also considerable (Figure 7).

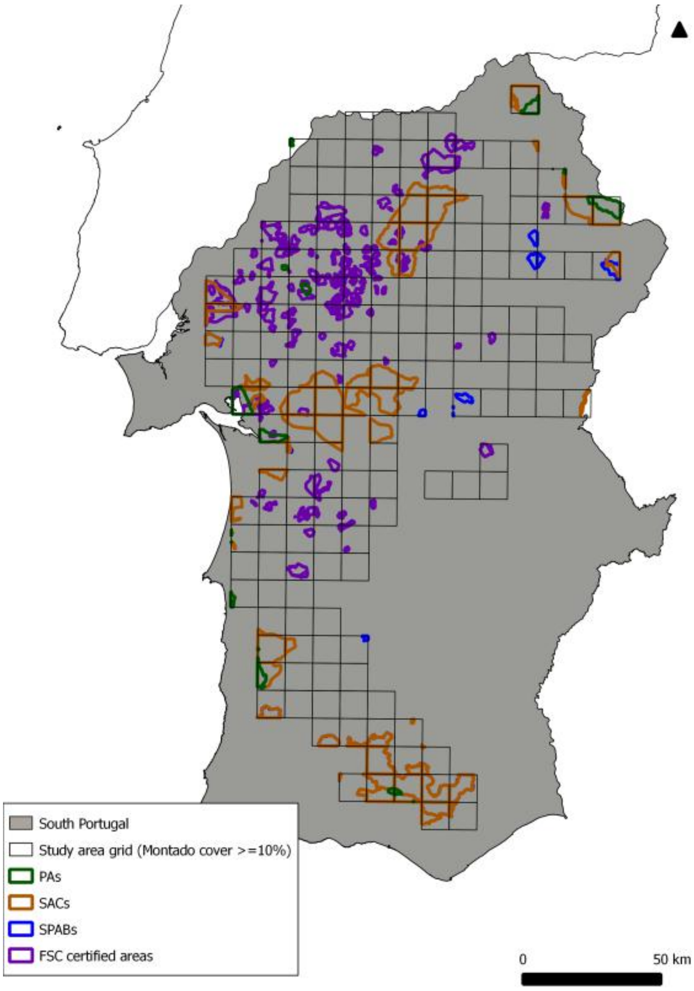

Figure 7: Delimitation of different conservation strategies in the study area: Protected Areas of Portugal (PAs) from the Institute for Conservation of Nature and Forests; Special Protection Areas for Birds (SPABs) and Special Areas of Conservation (SACs) from the European Environmental Agency; FSC certified areas from FSC Portugal.

2.2. The HCVA framework

The High Conservation Value Areas (HCVA) framework (www.hcvnetwork.org) was used to compile information on biodiversity and Ecosystem Services of the study area. HCVAs are those areas where forest biodiversity or Ecosystem Services (ES) are of significance or critical importance (Jennings *et al.*, 2003). HCVA is an international standard that is regionally and nationally adapted through a process of stakeholder public participation (Branco *et al*. 2010). In Portugal, public participation involved Forest and Nature Conservation public administration entities, landowner associations, environmental NGOs, Universities, research groups and other entities (www.fscportugal.org). In this thesis hotspot areas for biodiversity and ES are considered those areas where biodiversity values and Ecosystem Services overlap geographically (e.g. Anderson *et al*., 2009; Chan *et al.,* 2006; Egoh *et al.,* 2008; Nelson *et al.*, 2009; Onaindia *et al.*, 2012). Data on biodiversity and ES attributes were considered as below, following the Portuguese interpretation of HCVA. For biodiversity:

- Total species richness: number of threatened birds, amphibians and reptiles occurring in a cell of the study area;
- Bird richness: number of threatened bird species occurring in a cell of the study area;

- Richness of amphibians and reptiles: number of amphibians and reptiles occurring in a cell of the study area.

Data on Ecosystem Services was:

- Above ground carbon storage: forest biomass(not considering soil carbon storage);
- Location of aquifers and their water recharge rates (water catchment).

Cells in study areas were classified according to percentiles of occurrence of biodiversity (number of species) and Ecosystem Services (tons of carbon storage/ha and mm/year of water recharge rates) attributes of that cell.

We then identified those areas (cells) where biodiversity and Ecosystem Services were spatially coincident in the study area: hotspot areas for biodiversity and Ecosystem Services (Branco *et al.*, 2010; Egoh *et al.,* 2008; Onaindia *et al*., 2012) using two combinations of biodiversity values and Ecosystem Services:

- Biodiversity as total species richness, carbon storage higher than 83.25 ton CO_2 eq/ha and location of aquifer and water recharge rates above 175 mm/year.
- Biodiversity as bird richness, carbon storage higher than 83.25 ton CO_2 eq/ha and location of aquifer and water recharge rates above 175 mm/year.

Considered values for carbon storage and water recharge rates are average values for above ground carbon storage and aquifer water recharge rates estimated for the cork oak *montado* in the study area and as defined in HABEaS (www.habeas-med.org). HABEaS is a WebGIS tool developed by a partnership among the Mediterranean program of the World Wide Fund for Nature (WWF), a global non-governmental organization on nature conservation, the University of Lisbon (School of Agriculture, Centre for Applied Ecology) and Faunalia, a consultancy company on open-source GIS software. This tool uses the High Conservation Value Concept (www.hcvnetwork.org) to integrate biodiversity and Ecosystem Services data from different sources and assess the conservation value of different areas. We used bird diversity (Equipa Atlas, 2008) as a surrogate for overall biodiversity as it has been done in other works (e.g. Burgas *et al.,* 2014; Gregory *et al.,* 2003; Lindenmayer *et al.*, 2000; Schulze *et al.,* 2004).

Reptiles and amphibians were excluded from the analysis as, comparatively to birds, there was a very low number of identified species in the study area. Detailed data on biodiversity can be consulted in *Appendix I: Original dataset and Appendix III: Species catalogue.*

The study area was classified according to values of biodiversity an Ecosystem Services attributes using the percentiles 25, 50 and 75, (values under which there are the 25, 50 or 75% of the sample units, respectively, in our case 10x10 km UTM cells) as thresholds for number of species occurring in the study area as well as values of carbon storage and aquifer water recharge rates. HCVAs cells can then be defined according to the percentile of each conservation attribute observed. We also identified those cells for which conservation attributes had values above average. Detailed data on carbon storage and location of aquifers and their recharge rates can be consulted in *Appendix I: Original dataset*.

Chapter 3: Results

3.1. Location of High Conservation Value Areas

3.1.1. Biodiversity

Within the study area there were 179 cells (out of 180 cells) where at least 4 species of threatened birds, amphibians and reptiles were present. These cells were classified as having biodiversity value. The number of species (threatened birds amphibians and reptiles per individual cell) in the study area varied between 0 (one cell) and 18 (6 cells). The most represented species were the birds *Oenanthe hispanica* and *Burhinus oedicnemus* which occurred in 89 and 87 cells respectively. The cells with a higher number of species were concentrated in the northeast part of the study area (Figure 8-a). In contrast, most of biodiversity cells occurring in percentile 25 were located in the northwest part of the study area where cork oak cover is dominant. The average number of species (threatened birds amphibians and reptiles) per cell was 6, ranging between 0 and 18 species. Cells with a number of species above the average tended to be concentrated in the eastern part of cork oak distribution (Figure 8-b).

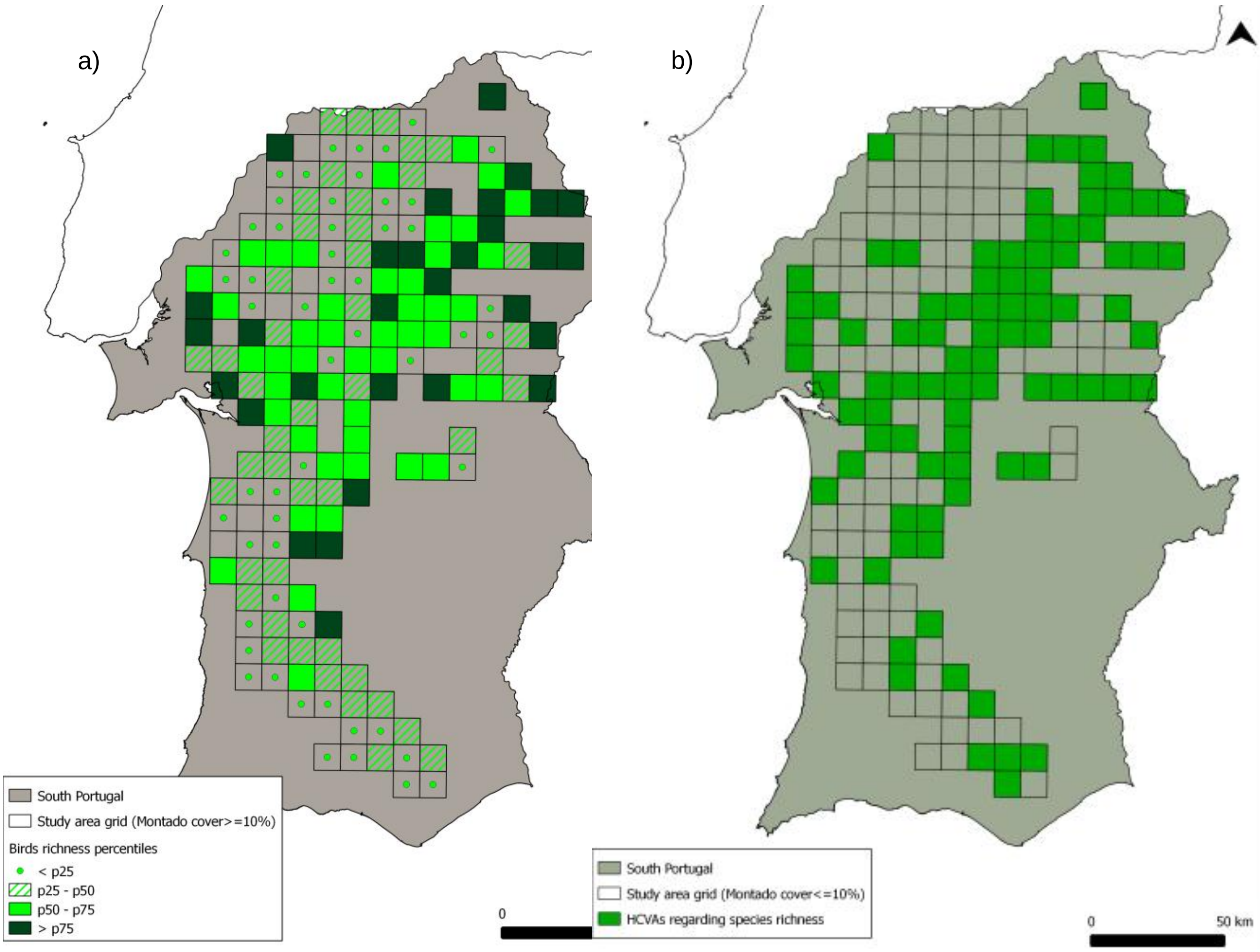

Figure 8-a: Classification of the study area grid cells according to the percentiles of species richness. pX = percentile X. Percentile X is the value under which there are located the X% of the total measurements (in this case species richness per cell). p25 = 4 species; p50 = 6 species; p75 = 8 species; 8-b: Classification of cells as HCVAs considering occurrence of species per cell above average value of total species richness (6 species per cell).

Threatened bird species occurred in 175 cells in the study area. These cells were evenly distributed, although slightly concentrated in the central part of the study area (Figure 9-a and b). The group of threatened bird species include species such as *Ardeola ralloides* (Critically Endangered), *Circus cyaneus* (Critically Endangered), *Emberiza schoeniclus* (Vulnerable), *Fulica cristata* (Critically Endagered), *Locustells luscinioides* (Vulnerable) and *Pterocles orientalis* (Endangered). These species were only present in single cells in the study area. These cells may thus be considered as key priority areas for the conservation of these species. In contrast, there were species occurring in more than 50% of the cells. Examples are: *Oenanthe hispanica* (Vulnerable), *Burhinus oedicnemus* (Vulnerable), and *Circus pygargus* (Endagered). The average number of threatened birds per cell in the study area was 3 with121 cells with more than 3 threatened bird species (Figure 9-b).

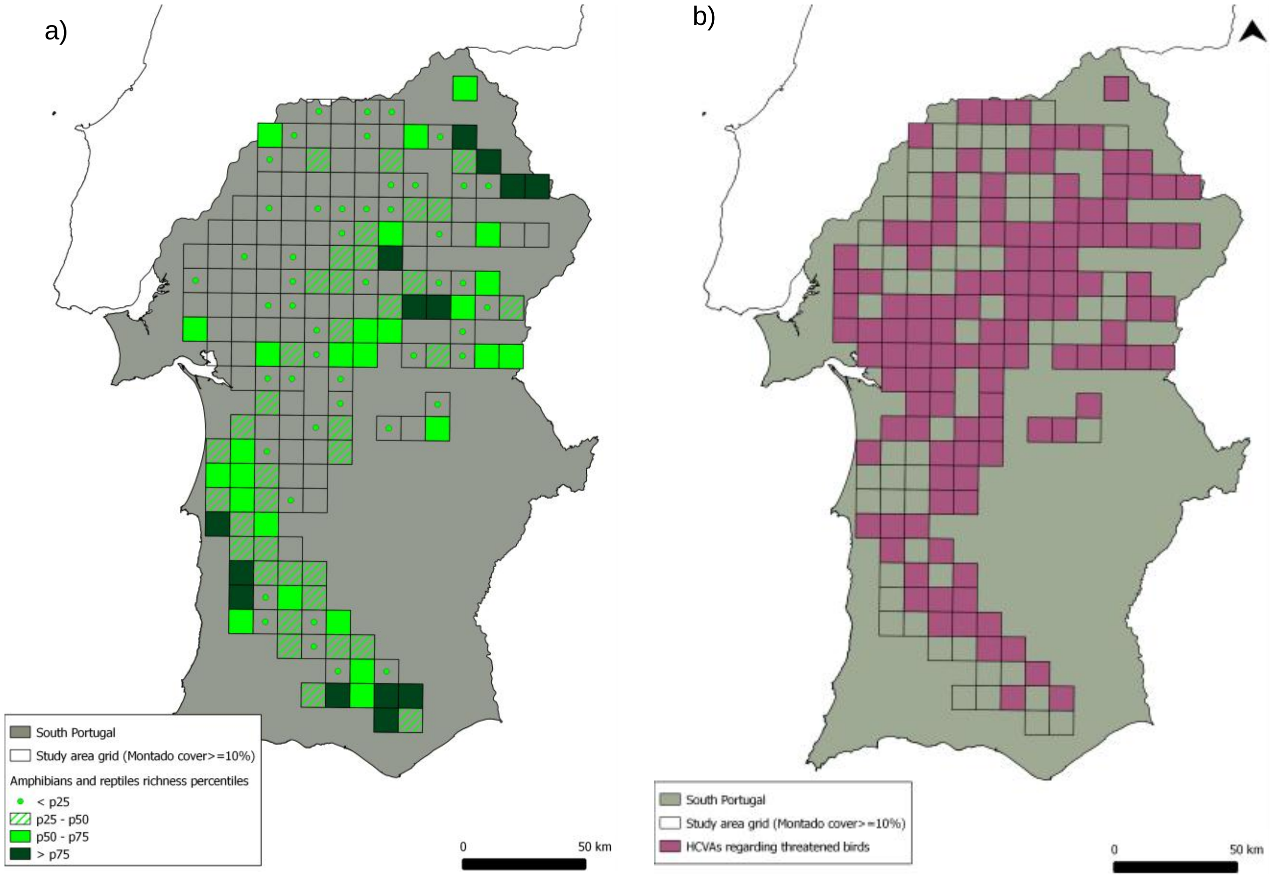

Figure 9-a: Classification of the study area grid cells according to the percentiles of threatened birds' richness. pX = percentile X. Percentile X is the value under which there are located the X% of the total measurements (in this case birds richness per cell). p25 = 3 species; p50 = 5 species; p75 = 7 species; 9-b: Distribution of HCVAs regarding the average value of threatened birds among the study area grid (3 species of threatened birds per cell).

The number of endemic and threatened amphibians and reptiles per individual cell in the study area varied between 0 and 7 (only one cell with 7 species). Most of these cells tended to be concentrated in the northeast and south part of the study area (Figure 10-a). The distribution of reptiles tends to be grouped in the northeast and southwest of the study area, while that of amphibians and birds was more randomly distributed; there were 4 cells located in the west part of the study area where endemic reptiles and amphibians occur but with no occurrence of threatened birds (*Appendix I: Original dataset*). The most abundant endemic species of reptiles and amphibians were *Alytes cisternasii* (amphibian, Least Concern), *Lissotriton boscai* (amphibian, Least Concern), present in 99 and 68 of the study area cells respectively. The scarcest were *Rana iberica* (amphibian, Least Concern) and *Lacerta schreiberi* (reptile, Least Concern) only present in 7 and 3 cells respectively. Although scarce in the South, both species are common in the north of Portugal. Regarding occurrence of threatened reptiles, *Emys orbicularis* (Endangered, present in 15 cells) is the most widespread reptile species and *Vipera latasti* (Vulnerable, in 7 cells) the less widespread reptile species. The average number of endemic amphibians and reptiles per cell in the study area is 2. Cells containing more than 2 endemic sspecies of amphibians and reptiles are randomly distributed within the study area (Figure 10-b).

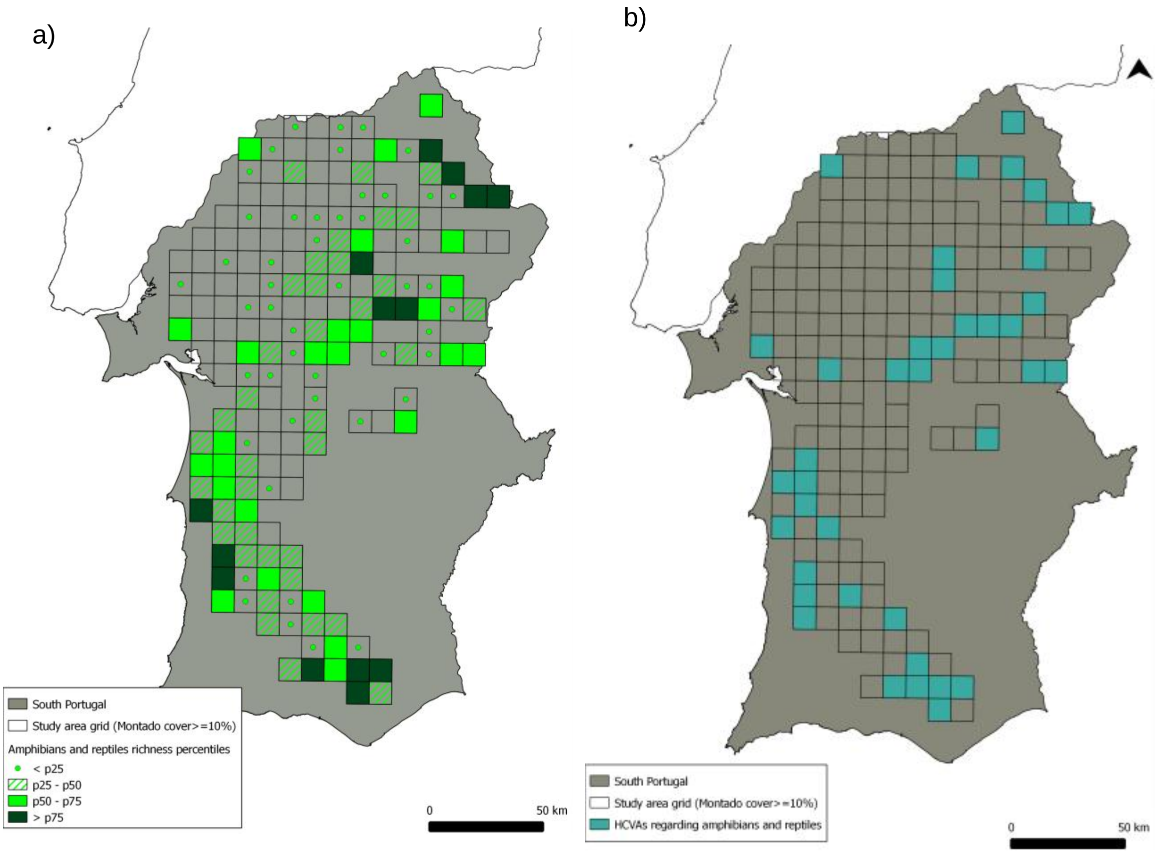

Figure 10-a: Classification of the study area grid cells according to the percentiles of amphibians and reptiles richness. pX = percentile X. Percentile X is the value under which there are located the X% of the total measurements (in this case amphibians and reptiles richness per cell). p25 = 3 species; p50 = 5 species; p75 = 7 species; 10-b: Distribution of HCVAs regarding the average value of reptiles and amphibians among the study area grid (2 species per cell).

3.1.2. Ecosystem Services

The higher levels of carbon storage of *montados* are concentrated in the west part of the study area (Figure 11-a). This is an area concentrating higher cork oak cover and possibly a higher number of trees/ha. The average value of carbon storage in the study area due to cork oak is 83.25 ton eq CO_2/ha. Approximately 50% of the cells in the study area have a carbon storage equal or above this value (Figure 11-b).

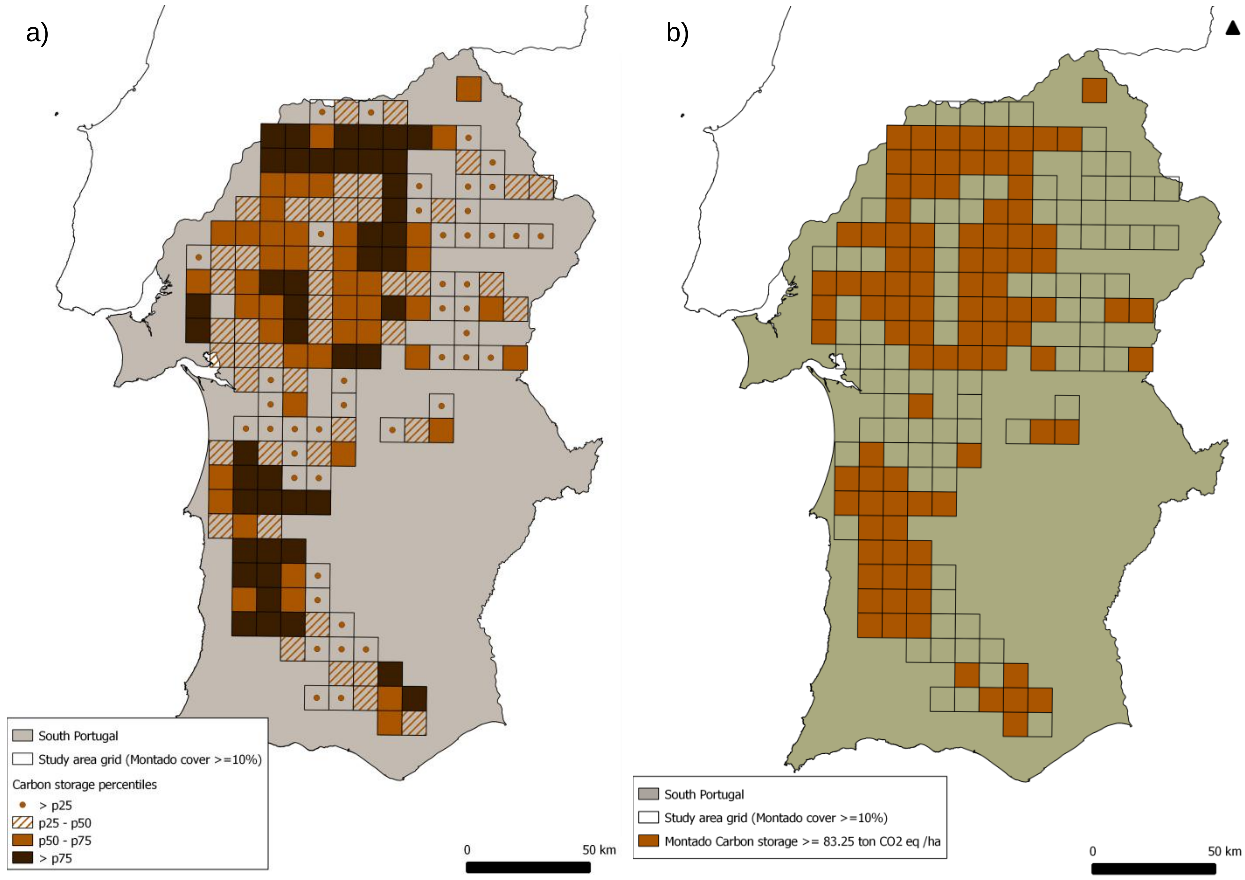

Figure 11-a: Classification of the study area grid cells according to the percentiles of carbon storage due to *montados*. pX = percentile X. Percentile X is the value under which there are located the X% of the total measurements (in this case ton CO_2 eq/ha per cell). p25 = 80.40 ton CO_2 eq/ha; p50 = 83.74 ton CO_2 eq/ha; p75 = 86.30 ton CO_2 eq/ha; 11-b: Distribution of cells in the study area with carbon storage due to *montados* equal or above 83.25 ton eq CO_2/ha.

In relation to water related services the study area includes the most important aquifer of the Iberian Peninsula: the Tagus-Sado aquifer system (Branco *et al.* 2010). Approximately 40% of this area is covered by cork oak *montado* (Branco *et al.* 2010). This region is concentrated in the northern part of the study area (Figures 12-a and b). The average aquifer water recharge rate of the Tagus-Sado system is 175 mm/year. There were 35 cells (19% of study area) in the study area with water recharge rates equal or above that value (Figures 12-a and b).

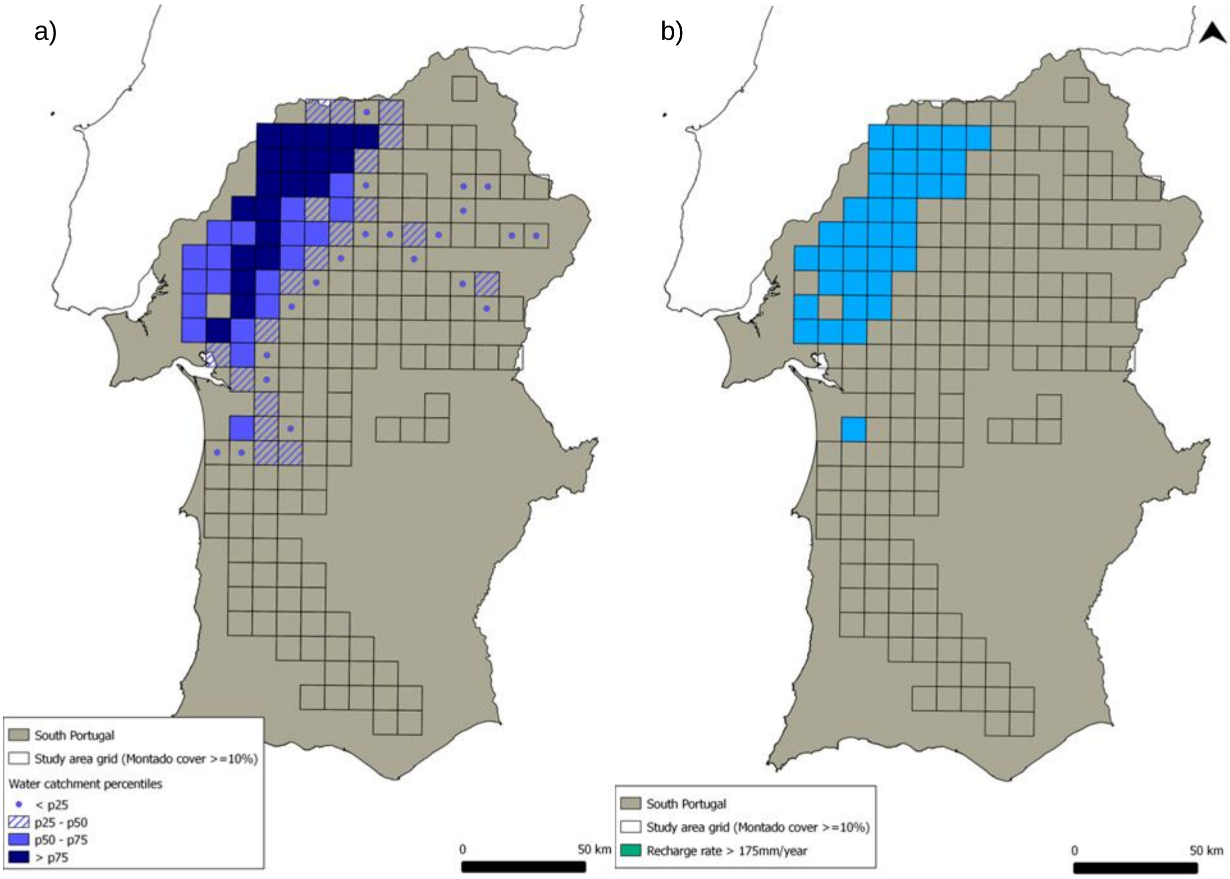

Figure 12-a: Classification of the study area grid cells according to the percentiles of aquifer recharge rates (recharge rates). pX = percentile X. Percentile X is the value under which there are located the X% of the total measurements (in this case water echarge rates). p25 = 62.77 mm/year; p50 = 156.18 mm/year; p75 = 204.98 mm/year; 12-b: Cells in study area with recharge rates equal or above 175 mm/year.

3.2. Hotspot areas for biodiversity and Ecosystem Services (ES)

To identify areas concentrating biodiversity and Ecosystem Services values in the study area we overlapped GIS layers of estimated conservation attributes. Areas concentrating high biodiversity and high carbon storage in *montados* were concentrated in the central part of study area (Figure 13-a). These areas could be defined as carbon-biodiversity rich areas. Similar analysis for areas concentrating high biodiversity and high water recharge rates showed a limited number of cells overlapping with aquifer location, in the northern part of the study area (Figure 13-b). These areas could be defined as water-biodiversity rich areas (Figure 14).

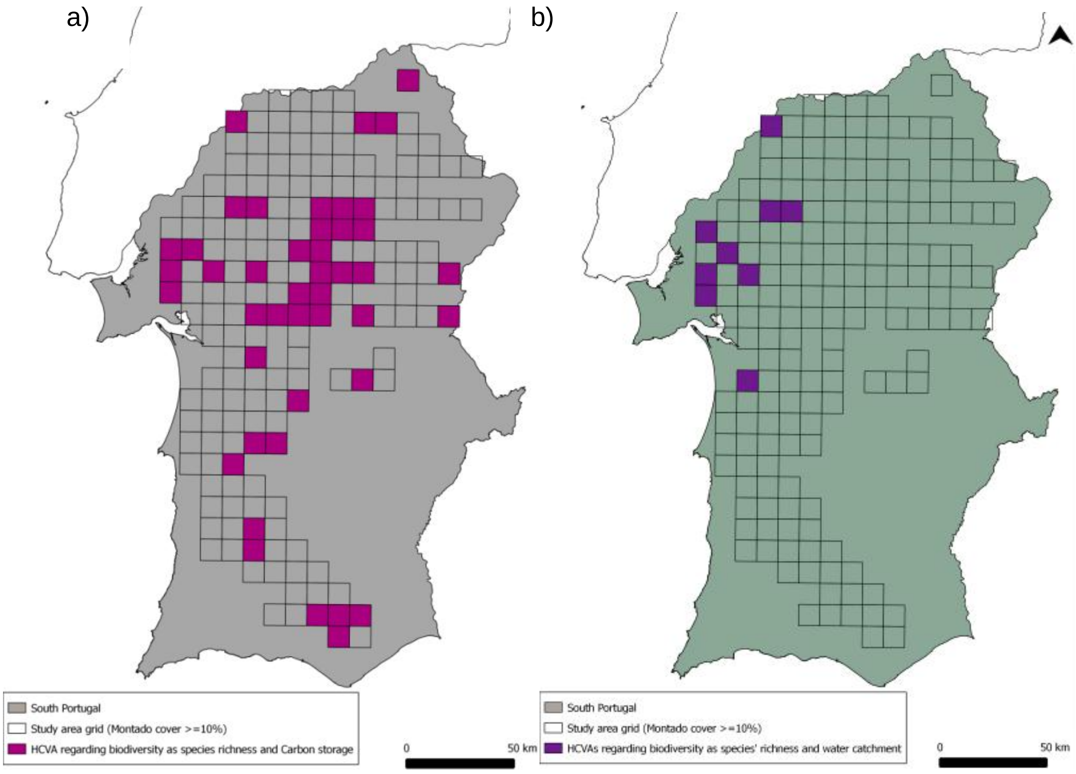

Figure 13-a: HCVAs regarding biodiversity as species richness and carbon storage among the study area grid; 13-b: HCVAs regarding biodiversity as species richness and water catchment rates among the study area grid.

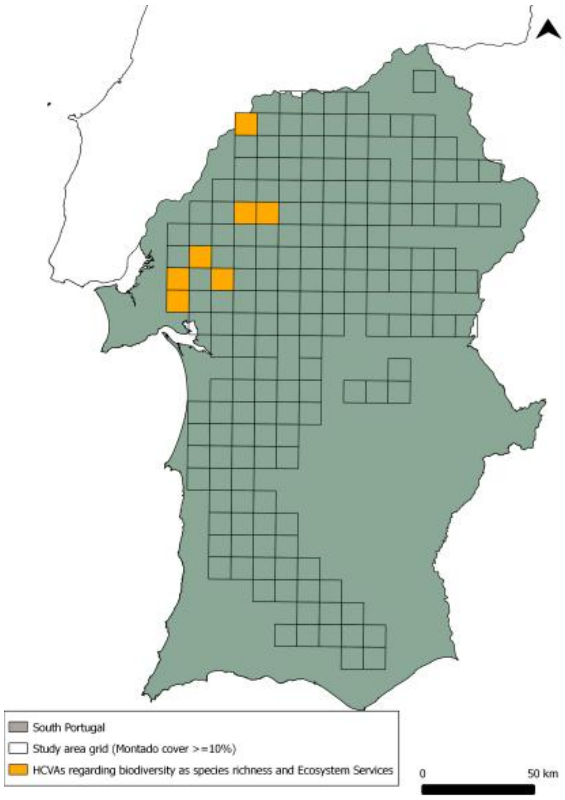

Figure 14: HCVAs resulting from overlapping biodiversity as species richness, carbon storage and water catchment.

Similarly we can identify *montado* “hotspot areas” that concentrate threatened bird species and are carbon rich (Figure 15-a) or have high aquifer water recharge rates (Figure 15-b) or both (Figure 16).

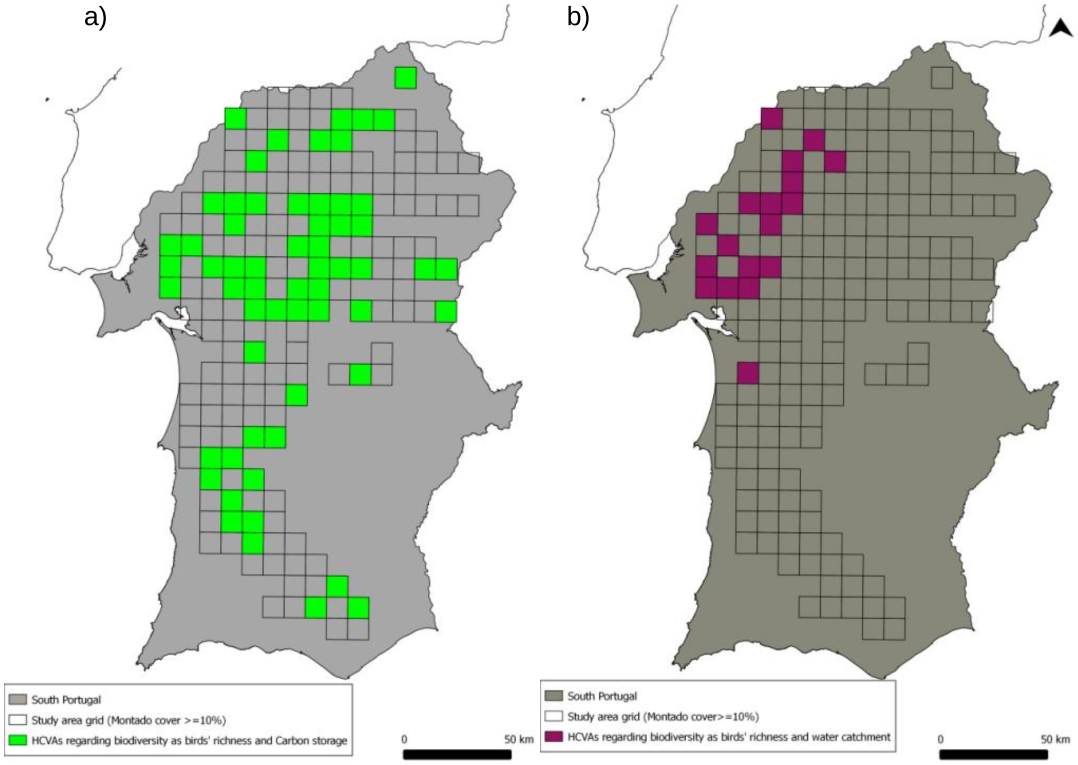

Figure 15-a: HCVAs regarding biodiversity as threatened birds' richness and carbon storage among the study area grid; 15-b: HCVAs regarding biodiversity as threatened birds' richness and water catchment rates among the study area grid.

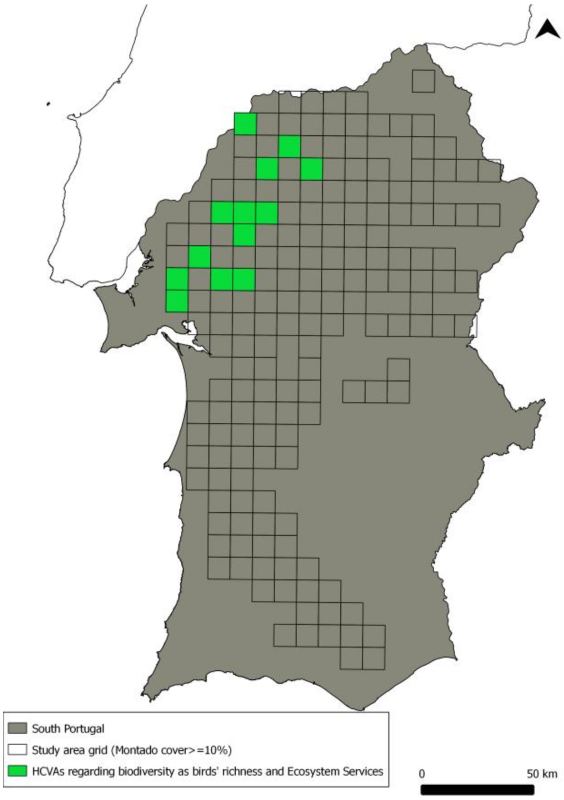

Figure 16: HCVAs resulting from overlapping biodiversity as threatened birds' richness, carbon storage and water catchment.

As expected, cells of high water recharge rates had a restricted distribution, overlapping with aquifer location, while for carbon storage these cells were more widely distributed across the study area.

3.3. Relationship between High Conservation Value Areas, classified areas and areas under FSC certification

There was not a major geographical overlap between areas defined as of High Conservation Value (HCVAs) and the distribution of classified areas (Tables 3 to 5). The majority of the area classified as of conservation value, either because it concentrated biodiversity or Ecosystem Services attributes, was mostly not covered by classified areas. For example, Protected Areas, or areas for Special Protection of Birds included a relatively low proportion of HCVA cells (Tables 3 and 4). There was only one exception to this relating with the occurrence of endemic species of amphibians and reptiles. Approximately half of the cells containing endemic reptiles and amphibians were located under Special Areas of Conservation (SAC) (Table 5). SACs, a strategy implemented under the Natura 2000 network, is very extensive in the study area which may partially contribute to explain the results. Generally, distribution of classified areas did not overlap with identified HCVAs cells.

Table 3: Percentage of HCVAs inside cells with more than 10%, less than 10% and 0% of the area included in the network of Protected Areas of Portugal (PAs).

% Protected Areas in cells	>10 %	0-10%	0%
HCVAs regarding species richness	4.60	6.90	88.51
HCVAs regarding birds richness	33.33	6.61	60.06
HCVAs regarding amphibians and reptiles richness	7.50	20.00	72.50
HCVAs regarding carbon storage	1.85	7.41	90.74
HCVAs regarding water catchment	0.00	8.57	91.43
HCVAs regarding biodiversity as species richness and Ecosystem Services	0.00	14.29	85.71
HCVAs regarding biodiversity as birds richness and Ecosystem Services	0.00	23.08	76.92

Table 4: Percentage of HCVAs inside cells with more than 10%, less than 10% and 0% of the area included in the network of Special Protection Areas for Birds (SPABs).

% Special Protection Areas for Birds in cells	>10 %	0-10%	0%
HCVAs regarding species richness	13.79	9.20	77.01
HCVAs regarding birds richness	9.92	8.26	81.82
HCVAs regarding amphibians and reptiles richness	17.50	10.00	72.50
HCVAs regarding carbon storage	8.33	4.63	87.04
HCVAs regarding water catchment	5.71	11.43	82.86
HCVAs regarding biodiversity as species richness and Ecosystem Services	14.29	28.57	57.14
HCVAs regarding biodiversity as birds richness and Ecosystem Services	7.69	15.38	76.92

Table 5: Percentage of HCVAs inside cells with more than 10% and less than 10% and 0% of the area included in the network of Special Areas of Conservation (SACs).

% Special Areas of Conservation in cells	>10 %	0-10%	0%
HCVAs regarding species richness	27.59	12.64	59.77
HCVAs regarding birds richness	28.10	11.57	60.33
HCVAs regarding amphibians and reptiles richness	37.50	15.00	47.50
HCVAs regarding carbon storage	28.70	7.41	63.89
HCVAs regarding water catchment	14.29	8.57	77.14
HCVAs regarding biodiversity as species richness and Ecosystem Services	14.29	14.29	71.43
HCVAs regarding biodiversity as birds richness and Ecosystem Services	15.38	7.69	76.92

In relation to forest certification, results were slightly different from those obtained for classified areas. Forest Stewardship Council (FSC) certified areas have expanded recently in the cork oak *montado* and presently cover approximately 100 thousand ha (FSC Portugal, 2014). When comparing areas under FSC certification with identified HCVA areas, results show different trends. Indeed HCVAs regarding 1) water catchment, 2) Threatened bird richness and ES (carbon storage and aquifer recharge rates) and 3) HCVAs regarding species richness and ES were more abundant in FSC certified cells (74%, 69% and 57% of the HCVAs respectively) (Table 6). HCVA were also more abundant in cells having over 10% of FSC certified area. These results suggest that presently FSC certification in *montado* is covering a relatively high number of identified HCVA areas.

Table 6: Percentage of HCVAs inside cells with more than 10%, less than 10% and 0% of the area certified by the Stewardship Council (FSC certified areas).

% Forest Stewardship Council certified areas in cells	>10 %	0-10%	0%
HCVAs regarding species richness	11.49	20.69	67.82
HCVAs regarding birds richness	16.53	21.49	61.98
HCVAs regarding amphibians and reptiles richness	2.50	15.00	82.50
HCVAs regarding carbon storage	18.52	25.93	55.56
HCVAs regarding water catchment	42.86	31.43	25.71
HCVAs regarding biodiversity as species richness and Ecosystem Services	42.86	14.29	42.86
HCVAs regarding biodiversity as birds richness and Ecosystem Services	46.15	23.08	30.77

Chapter 4: Discussion

4.1. Mapping biodiversity and Ecosystem Services: potentials and challenges

Mapping of biodiversity values and Ecosystem Services (ES) is necessary to better inform conservation policies. Since the supply and demand of ES may differ geographically (Fisher *et al.,* 2009; Bastian *et al.,* 2012), spatially explicit units are needed to quantify ES (Troy & Wilson, 2006). Mapping ES is a useful tool to identify priority conservation areas and support decision-making processes.

Recent studies have mapped the supply of multiple ES, at global (e.g. Naidoo *et al.,* 2008), continental (e.g. Schulp *et al.,* 2012), national (e.g. Egoh *et al*., 2008, Bateman *et al*., 2011) or sub-national (e.g. Nelson *et al*., 2009; Raudsepp-Hearne *et al*., 2010, Willemen *et al*., 2010) scales. However, the lack of homogeneity in methods to quantify ES, challenges the possibility of comparing values and so conservation management planning. Each case has its own criteria and is limited by the available data. Different metrics have been proposed. Using standardized frameworks to quantify biodiversity and ES facilitates comparisons of conservation values (Crossman *et al*., 2013; Martínez-Harms & Balvanera, 2012; Eppink *et al.*, 2012; Meas *et al.*, 2012).

In the present work the High Conservation Value (HCVA) framework was used (www.hcvnetwork.org) together with WebGIS Habeas tool (www.habeas-med.org) to compile information and identify biodiversity and ES values in the cork oak *montado* of southern Portugal, but it can be applied to any forest ecosystem. Additionally, the HCVA framework integrates public participation processes which increases its transparency, people commitment and social benefits of using it for conservation purposes (Nordström *et al.* 2010). Addressing the interests of people is crucial in any conservation program.

When using HCVA for assessing the extension of spatial overlap of biodiversity and ES, it is frequently necessary to deal with different geographical scales. For example, in the present work, for the GIS analysis there was the need to unify different data sources into a standardized 10 x 10 km grid, which may have implied loss of data resolution. This may have happened when using data from the smaller 500m x 500m grid of the National Forest Inventory for identifying areas where *Quercus suber* is a dominant *species* and the distribution of those areas with that of classified areas or areas under FSC certification. Issues regarding the scale of analysis may be challenging when mapping biodiversity and ES.

4.2. Biodiversity and Ecosystem Services of cork oak *montados*

The present work identified the occurrence of 49 threatened bird species in the study area (see *Appendix I: Original dataset*). Birds are usually seen as good biodiversity surrogates, although this may vary in a case by case basis. For example, an increase or decrease in the number of bird species in an area may be related to other factors rather than proportional improvement or deterioration of their habitats and associated flora (Newton, 2004). Changes in bird populations may be related to variations of seasonal agricultural cultivation and harvest or increased nest predation (Newton, 2004). Also, a high number of species may not necessarily mean high conservation value as, for example, when dealing with species of common birds (Duelli & Obrist, 1998). In the present study, both conservation status (threatened bird species) and occurrence were considered. Additionally a number of endemic and threatened species of reptiles and amphibians were also identified in the study area, which increases the robustness of using data on threatened bird distribution as a surrogate for biodiversity.

Beyond biodiversity, the present work also mapped important areas for carbon storage and water related Ecosystem Services in the cork oak *montado* study area. This implies considering a broader concept of conservation, rather than biodiversity *per se* when identifying areas of conservation value, which strengthens the classification of HCVAs and contributes with further information for decision making processes involving biodiversity values together with ES assessments.

In the case of carbon storage, identification of areas harbouring high levels of carbon may provide funding opportunities for conservation of cork oak *montados* in the future. Ecosystems with high tree canopies tend to form bigger carbon stocks (e.g. Bonan, 2008; Dixon *et al.*, 1994; Houghton *et al.*, 1993; Nepstad *et al.*, 1999). Although *montados* have not high tree densities they may nevertheless store significant amounts of carbon in their above ground biomass. Carbon storage due to the cork oak *montado* is more than half (approximately 67%, see *Appendix II: Other species analysis*) of the total amount of carbon stored by the different tree species in the study area. Long term carbon storage is an important ecosystem service of cork oak *montados*. Well managed *montados* may accumulate carbon for very long periods (cork oak trees can live up to hundreds of years), which means long term reserves of carbon. Since a main threat to *montados* and carbon stocks is wildfire, management for prevention of severe wildfires must be a priority in the cork oak ecosystem. A well-managed *montado* should maintain a healthy canopy cover and a non-continuous coverage of shrubs which increase the risk of severe wildfires.

The study area has also a potential for water related Ecosystem Services (the Tagus-Sado aquifer, the biggest of the Iberian Peninsula). Cork oak *montados* cover approximately 40% of the area above this aquifer (Bugalho *et al.*, 2011; Branco *et al.*, 2010). Well managed *montados* promote the infiltration of rain water and prevent soil erosion, contributing, as other forest ecosystems, to water cycle regulation. This is essential in areas where water is scarce, as it is the case of southern Portugal. It makes *montados* of southern Portugal a relevant area for possible implementation of water-Payment Ecosystem Services (PES) schemes. Water-PES schemes have been implemented in different regions, such as in Bolivia's Los Negros valley, where farmers are currently paid to protect 2774 ha of a watershed containing the threatened cloud-forest habitat of 11 species of migratory birds (Asquith *et al.*, 2008). Nevertheless, for better implementation of water- PES schemes, more research linking the effects of forest management practices on water dynamics is needed particularly for *montados* (Bugalho *et al.,* 2011). Another specific issue in relation to water-related PES schemes, is that service customers cannot choose among service suppliers (Meijaard *et al*., 2014). This is because of the location-specific character of watershed protection services which means that targeted providers are unchangeable: typically there is little scope for choosing between alternative watershed providers (e.g. landowners) and potential impacts on biodiversity may play no role in location choices (the opposite that happens with carbon supply).

4.3. Overlapping areas of biodiversity and Ecosystem Services in *montados*

There are different studies (e.g. Onaindia *et al.*, 2012; Raudsepp-Heane *et al.*, 2010; Nelson *et al.*, 2009) where researchers mapped biodiversity and different Ecosystem Services and found significant overlap among biodiversity and ES. In our study area, however, the most valuable areas for biodiversity did not coincide with those most valuable for the Ecosystem Services analysed. These results are in agreement with results found for forest ecosystems elsewhere (e.g. Anderson *et al*., 2009; Chan *et al.,* 2006; Egoh *et al.,* 2008, in Britain, Central Coast ecoregion of California and in south Africa respectively). For example, in the present work, the higher water aquifer recharge rates were limited to the Tagus-Sado. Although occurrence of threatened birds species and high carbon storage levels had an even distribution within the study area, only 60 cells (from the 121 and 108 cells containing threatened birds species and high carbon storage, respectively) overlapped. This means that the area covered by these 60 cells could potentially be used to implement water-biodiversity PES schemes, that is, areas where incentives could be found to promote management practices favoring water and biodiversity conservation. The results of the present thesis also suggest that there are not general patterns of congruence in ES and biodiversity in the *montados* of southern Portugal. Consequently, priority areas may need to be identified and mapped on a case by case analysis. In such cases, it may be useful quantifying local conditions using a smaller scale of analysis. Neverthelss, although a general distribution pattern of biodiversity and ES cannot be assumed at the scale used in present work, results suggest potential locations of broader HCVA areas that could then be further examined at finer scales. As location of such areas may vary depending on ES and biodiversity values being considered, conservation strategies may vary accordingly. For example, a conservation strategy aimed at protecting water catchments would not necessarily be targeting areas of high biodiversity or carbon storage. Identifying areas where biodiversity and ES overlap will contribute to identify priority areas for implementing Payment for Ecosystem Services schemes. For example, eventual PES schemes in montados based on financial compensation for landowners to maintain good management practices will favor not only the maintenance of carbon stocks but also the conservation of the *montado* itself, which is an important habitat for different threatened bird species. Thus, selecting areas where biodiversity and ES overlap increases the likelihood of positive outputs of PES conservation strategy, as funding directed for a particular ES may also favor biodiversity conservation. For example, a recent WWF conservation initiative– the Green Heart of Cork (GHoC) project (2014) is a novel approach aiming to implement a PES-like scheme in cork oak *montados*. Under this initiative, WWF is seeking donors willing to compensate landowners that commit to forest certification and implement sustainable management practices in their estates. The GHoC inititive uses information generated by HABEaS and HCVA framework to identify areas concentrating biodiversity and ES and thus more appealing for conservation donor investments.

4.4. Relationship between HCVAs, classified areas and areas under FSC certification in the *montados* of southern Portugal

In this study the distribution of classified areas (network of Protected Areas Natura 2000) was compared with the distribution of High Conservation Value Areas (HCVA) in the *montados* of southern Portugal. Classified areas do not cover the majority of identified HCVAs. Indeed, the results suggested a low degree of overlap between cells with high percentages of protected areas and cells classified as HCVAs. In other words, biodiversity and ES value of protected areas was not higher inside classified areas comparatively with non-classified areas. These results agree with those of other authors (e.g. Auld *et al.,* 2008; Convention on Biological Diversity, 2010) who found that protected areas, although a cornerstone of conservation strategies, have been insufficient to prevent the deterioration of Ecosystem Services and biodiversity loss. Other conservation schemes and strategies, such as PES schemes discussed above, in complement with protected areas and proper identification of areas important for biodiversity and ES may generate more effective conservation outputs.

HCVA areas were also compared with areas under FSC certification. FSC certification aims to promote the sustainable management of forest ecosystems. Under FSC certification landowners are required to identify HCVA areas within their properties. Several of HCVA areas were identified for certification aims using the HCVA framework. Thus, it is not surprising that a high proportion of HCVA areas identified in present study are also areas under FSC certification.

4.5. Potential of Payments for Ecosystem Services (PES) schemes in *montados* of southern Portugal

Land use is sustainable when, over generations, it supports the natural regulatory functions of ecosystems (biotic, abiotic) while allowing profitable economic activities and providing an environment that enhances the physical and mental well-being of the people who live in it (Barrett, 1992). As discussed above, *montado* ecosystems, when managed sustainably, provide several Ecosystem Services. Many of the ES generated by *montados* are ecologically important and do not have an associated economic value. Since a major challenge that *montado* ecosystems are facing nowadays is mismanagement or even outward abandonment (Bugalho *et al.*, 2011), financial incentives to landowners for maintaining biodiversity and ES of *montados* may contribute to their sustainable management and economic viability. Promoting sustainable management practices, using different conservation strategies such as Protected Areas in complement with FSC certification of HCVA areas may strongly contribute for the conservation of *montados*.

Payment for Ecosystem Services (PES) schemes may generate positive benefits for the conservation of biodiversity and also improve human well-being (Donald & Evans, 2006; Tallis *et al.*, 2008; Warren *et al*., 2008). PES is a conservation tool well adapted to human-shaped, managed, ecosystems (Bugalho *et al.* 2011-a), PES schemes in *montados* must favor sustainable management practices such as maintaining effective levels of oak regeneration, clearance of shrub understory in long rotational periods, maintenance of uneven age classes of trees and avoidance of overgrazing

(Bugalho *et al*. 2011-a, Rey Benayas *et al.,* 2008). These practices will potentially minimize some of the threats *montados* are facing nowadays.

Main challenge for PES implementation is that many of these mechanisms are still in pilot stages and some not well structured yet (Ribas, 2011). Also, standard homogeneous methods are needed to quantify ES. The variety of ES quantification methods makes trade of ecosystem service difficult as markets require certainty and clarity around the products being traded, both in the supply- side and in the demand-side (Crossman *et al.*, 2013). In accordance with this idea, there are recent initiatives aiming to measure the flows of services from ecosystems into economic and other human activity (European Commission *et al.,* 2012). Initiatives, such as the Ecosystem Market place platform were created (Ecosystem Market place platform, 2014) to disseminate successful cases of PES and provide information on how to build a revolutionary new economy that will pay for, and invest in ES. The Ecosystem Market place platform provides detailed information and follows the various trading ES markets related to water, carbon and biodiversity conservation. Other initiatives such as Ecosystem Services Partnership (WWF & Ecosystem Services Partnership, 2014), also aim to enhance communication, coordination and cooperation around trading of ES, to build a strong network of individuals and organizations around this topic.

Proposing PES is only possible if there is a demand for this ES. In other words, it is necessary to know who would be willing to pay for maintaining *montado* biodiversity and ES. Some authors (e.g. Wunder & Wertz-Kanounnikoff, 2009) defend that PES will only pay for the subset of services that present externalities, and among the subset of Ecosystem Services that present externalities, only those truly threatened will attract potential buyers since otherwise there would not be an incentive to pay. Moreover, there will only be payments for those ES that are most valuable, with the condition that the ES buyer willingness to pay exceeds the ES seller willingness to accept. However there may be important with no specific demand which may “lose” and eventual commercial competition with other ES. To avoid this, there are examples of integrated ES trade or selling of bundling services (see Introduction): when multiple services are provided from a single landscape, providers may try to combine services at a relevant scale so as to increase financial viability (Deal *et al.*, 2012; Wendland *et al.,* 2010). Developing markets for combined Ecosystem Services may reduce the inconveniences due to the focus on a single ES.

In relation to biodiversity conservation it faces the particular challenge that, in spite of its general appreciation, willingness to pay directly for biodiversity conservation has remained quite limited. The services provided by biodiversity are multiple, including pollination, genetic reservoirs, or existence values. Yet, most of these services (or their declining levels over time) are intangible (Wunder & Wertz-Kanounnikoff, 2009) while the benefits of activities that might harm it are measurable. As an example, economic benefit of preserving biodiversity conservation have to be profitable in relation to other land-use alternatives, such as logging. As a consequence it might be more difficult to target biodiversity buyers than in the case for other ES.

Encouragement of certain ES in detriment of others may lead to suboptimal outcomes (Caparrós *et al.* 2010). To avoid this, it is necessary to understand the relationships and mechanisms behind among multiple ES (Bennett *et al.*, 2009). An approach (Nelson *et al.*, 2009) is to model the trade-offs between different Ecosystem Services and biodiversity conservation and provide information on linkages of biodiversity and ES for supporting management decisions. For example, a factory may pay for polluting the water of a near-by river (giving those quantities to a land owner whose practices favor the clean water retention), then it may also be required to pay for damaging the biodiversity, even though biodiversity conservation is not an ES that he is making direct use of and has less “direct” demand. Other questions to be posed are: Is it possible to consider all the ES involved in an ecosystem? How many ES is necessary to consider? The more ES are considered the more likely is to favor an ES is detrimental to other ES. Considering several ES makes the decision making process practically unworkable. Finding the “equilibrium point” is an issue that needs further experiences and research. In our study case, considering biodiversity conservation, aquifer recharge and carbon storage seems adequate when assessing HCVA areas in the *montado* of southern Portugal. Indeed, applying sustainable management practices in *montado* is likely to favor biodiversity conservation, carbon storage and water quality contributing to the conservation of the whole ecosystem itself.

There are also issues of scale involved when considering multiple ES. For example, to benefit a certain ES a larger extension of land may be needed (e.g. maintenance of wildlife corridors). Therefore, providing PES incentives will only work for larger geographical scales. When land is fragmented into relatively small private properties, as in several areas of *montado* in Portugal, negotiation should be made with land-owner associations that are contributing for the maintenance of particular ES. An agreement among several stakeholders could be harder than when with a single decision maker represented in an landowner association, for example (Davis *et al.*, 2001). Multiple-owner planning is often the case in regions and countries where private forestry is prevalent, as it is the case of Portugal (Martins & Borges 2007). In Portugal, a number of Associations of cork oak producers occur. These associations frequently include large tracts of cork areas land under their management. This can be used to maximize benefits of sustainable management such as reducing cost of certification or implementing potential PES schemes over larger areas. There have been several case studies dealing with multiple stakeholder negotiations to find common agreements (Sheppard & Meitner, 2005; Mendoza & Prabhu, 2005, Nordström *et al.*, 2010; Kangas *et al.,* 2008; Pykäläinen *et al.,* 2007). This is essential when assessing which ES may be included in PES schemes.

For implementing a water-PES scheme in *montado*, for example, the procedure described by Fisher *et al.* (2010) for a pilot case in Tanzania could be followed. First, a feasibility had to be conducted for assessing the feasibility of a potential PES -water scheme in the basin (in our case would be the Tagus-Sado basin). Secondly, it would be necessary to assess income levels in the area and record opinions from people whose lives directly rely on the water flows as well as on timber and non-timber products (such as cork production in our study area) and engage with those individuals more likely to inform management decisions. Finally, there would be the need to collect funds from water users in the basin and allocate these funds to the various uses. This would include management practices benefiting forest (or cork oak *montado*) conservation and improvement of land management practices benefiting for example the conservation of threatened bird populations and water quality (e.g. avoid overgrazing and soil compaction, minimize use of herbicides and fertilizers).

4.6. Limitations of the present work and challenges for the future

The need for spatially explicit data for use in GIS analyses narrows data choices (Nemec & Raudsepp-Hearne, 2013). Identifying HCVAs in *montados* or other forest ecosystems will be always limited by data availability. For example, when assessing biodiversity values occurring in *montados*, it would have been interesting to include data related to plant communities. Considering more biodiversity attributes would lead to a more detailed, albeit more challenging, assessment of HCVAs. A balance needs to be achieved by working with reliable representative data. A mostly important aspect of the present work is that it cosubstantiates the use of a standard framework for identifying areas of conservation value in forest ecosystems such as the cork oak *montado*. From here, creativity, novel approaches and ambition may lead to the application of different conservation tools contributing to the conservation of forest ecosystems and of cork oak *montados* in particular.

Chapter 5: Summary of conclusions

The main conclusions of the present work can be summarized in the following:

- Mapping biodiversity and Ecosystem Services (ES) is a useful tool to identify priority areas for conservation and support conservation related decision-making processes;
- The High Conservation Value Areas framework is useful to standardize data collection and map biodiversity and Ecosystem Services;
- The High Conservation Value Areas framework can readily be applied in cork oak *montados* to identify priority areas for conservation.
- When using the HCVA framework the scales of data on biodiversity and Ecosystem Services are frequently different, which may be a challenge when mapping areas important for conservation;
- The present work shows that presently classified areas are not covering a high proportion of areas of cork oak *montados* important for the conservation of biodiversity and Ecosystem Services, such as carbon storage or aquifer water recharge rates. Forest certified areas, in contrast, cover a larger proportion of those important conservation areas;
- Identification and mapping of important areas for conservation in cork oak *montados* depends on the conservation attributes (biodiversity and Ecosystem Services) being considered and consequently location of these areas will vary according to chosen attributes;
- Identification of high conservation value areas (HCVA) in cork oak *montados* may contribute to implement alternative conservation tools, such as Payment for Ecosystem Services, in complement with other conservation strategies (e.g. protected areas) to promote the conservation of these important ecosystems.

Note: Part of the contents of the present thesis were used in the paper by Bugalho, M. N.; Brinas, B.; Dias, F. S. “Promoting the sustainable use and conservation of cork oak landscapes using the high conservation value forest framework” submitted to Agroforestry Systems and under reviewing (see *Appendix IV: Paper submitted to Agroforestry Systems*).

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Appendix I: Original dataset

I.I. Areas included in any traditional conservation strategy or FSC certification process in the study area:

I.I.I. Protected Areas of Portugal (PAs)

The area regulated by Decree-Law 142/2008 (24th July 2008) in the study area is 19751.75 ha (Instituto de Conservação da Natureza e das Florestas, 2014), which means the 1.10% of the grid. The distribution is shown in Figure 1-a and b. As we can see, most of the Protected Areas are located in the perimeter of our study area, since they are mainly in the perimeter of South Portugal.

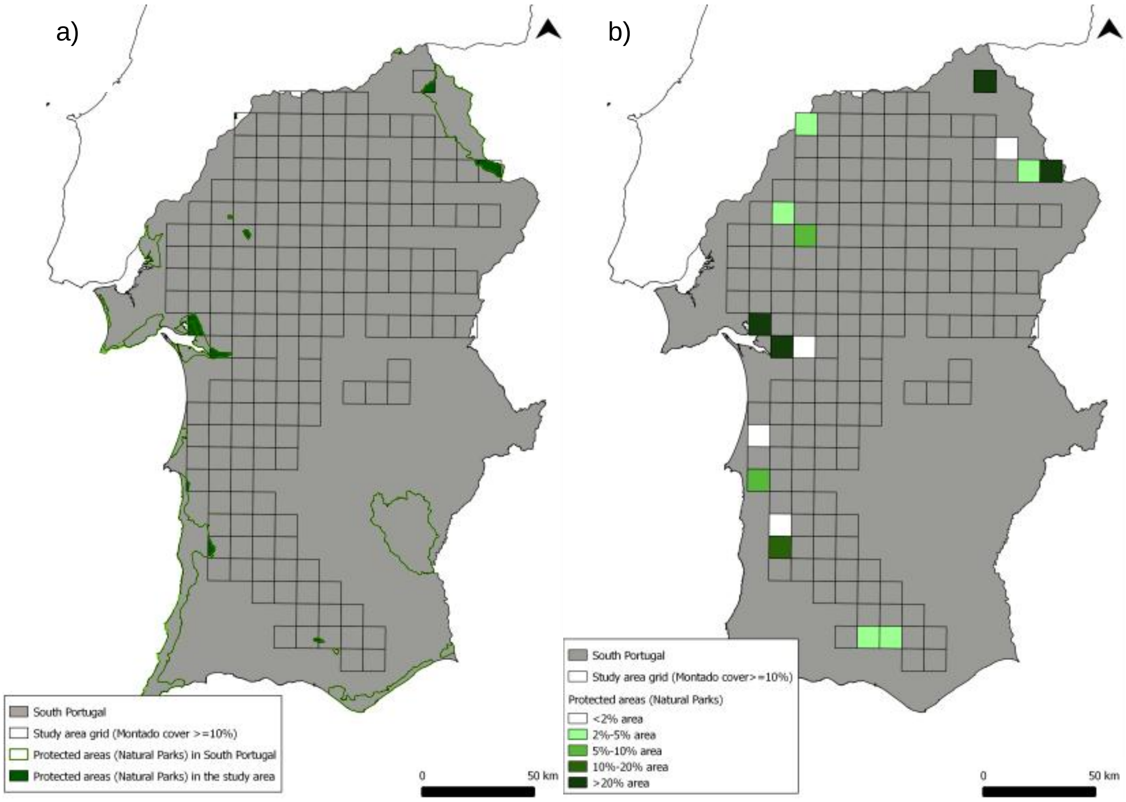


Figure 1-a: Vector coverage of Natural Parks distribution in South Portugal; 1-b: Raster map of Natural Parks' distribution in the study area, covering different proportions (2; 5; 10 and 20%) of the cell in the grid they are located in (darker colour means higher proportion).

I.I.II. Special Protection Areas for Birds (SPABs)

The area defined by the Birds Directive (Council Directive 2009/147/EC on the conservation of wild birds) of Natura 2000 Network inside our study area is 72883.82 ha, which means the 4.05% of the grid. The distribution is shown in Figure 2-a and b. The highest proportion of SPABs is located in the South of the study area.

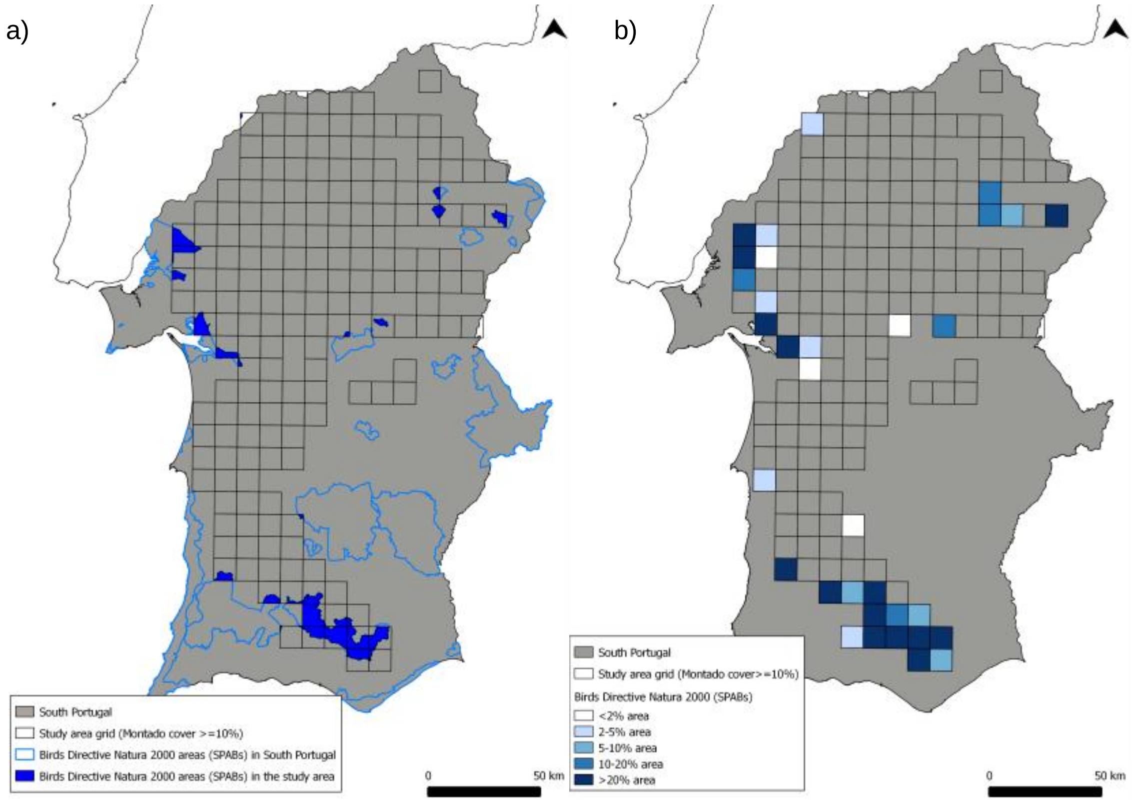


Figure 2-a: Vector coverage of Special Protection Areas for Birds' distribution in South Portugal; 2-b: Distribution of Special Protection Areas for Birds in the study area, covering different proportions (2; 5; 10 and 20%) of the grid's cell they are located in (darker colour means higher proportion).

I.I.III. Special Areas of Conservation (SACs)

The area defined by the Habitats Directive (Council Directive 1992/43/EEC on the Conservation of natural habitats and of wild fauna and flora) of Natura 2000 Network is 247336.20 ha, which means the 13.74% of the study area. The distribution of these areas is shown in Figures 3a) and b). It is quite homogeneously distributed in upper, central and lower part of the study area.

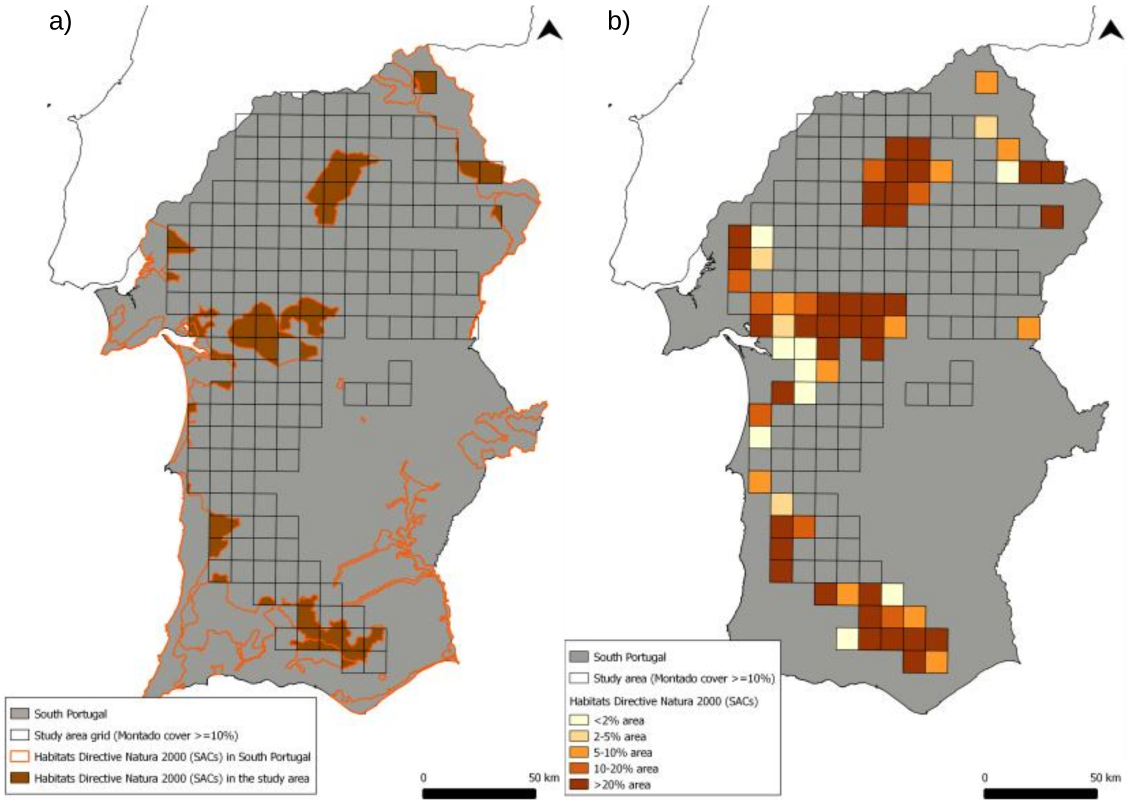


Figure 3-a: Vector coverage of Special Areas of Conservation's distribution in South Portugal; 3-b: Distribution of Special Areas of Conservation in the study area, covering different proportions (2; 5; 10 and 20%) of the grid's cell they are located in (darker colour means higher proportion).

I.I.IV. Forest Stewardship Council (FSC) certified areas

The area under FSC certification up to year 2014 is 95639.12 ha, which means the 5.32% of the study area. The distribution of these areas is shown in Figures 4-a and b. Most of the certified area of cork oak savannas is located in the northern part of the study area. According to *Dias et al.* (2013), socio-economic reasons may contribute to explain why the certification of cork oak savannas has initiated in this region. For example, it is in this region that the highest productivity of cork is attained, with values ranging between 114 and 145 kg/ha/year when the national averages are between 90.8 and 125.5 kg/ha/year (Autoridade Florestal Nacional 2010). Also the mean property size in this area is the highest in the country, being approximately 103 ha, whilst on the southern edge of the study area it is below 20 ha (Dias *et al*., 2013). Since FSC certification is a demanding and costly process that requires frequent monitoring and auditing (Marx and Cuypers 2010). The relatively high cork production that landowners may attain in this region helps to dilute the costs of forest certification and explain why certification has started here.

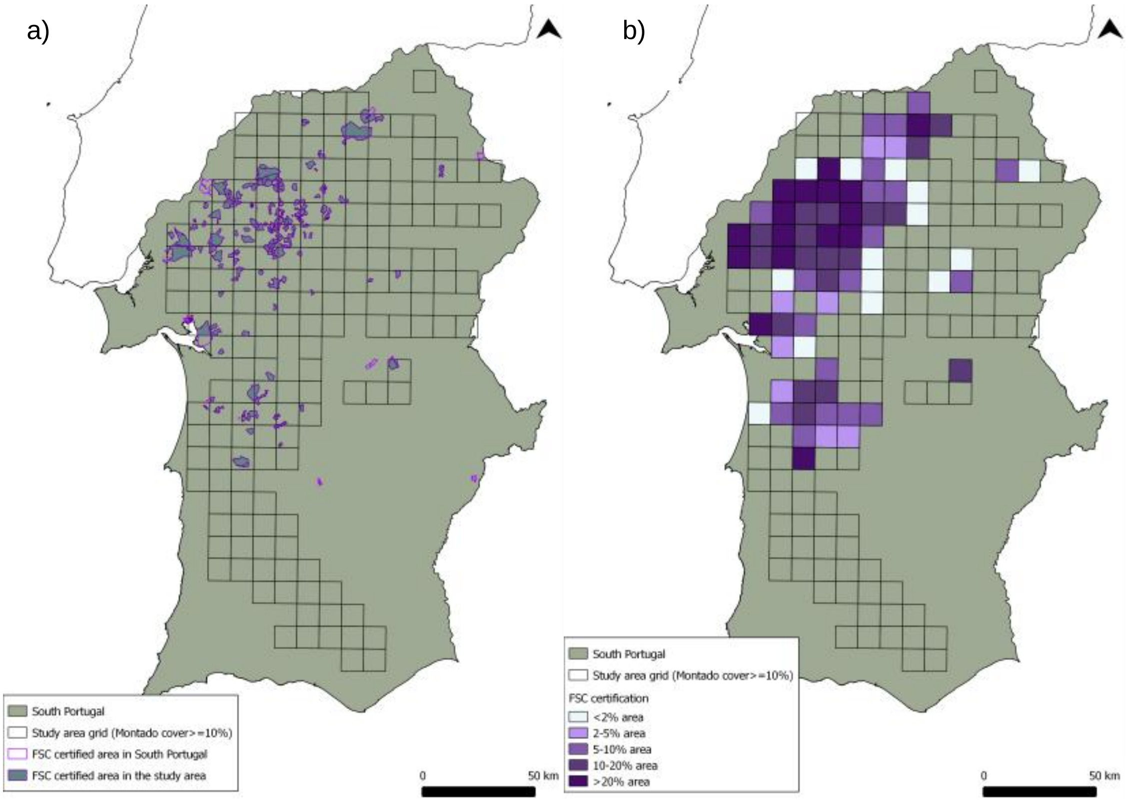


Figure 4-a: Vector coverage of FSC certified areas' distribution in South Portugal; 4-b: Distribution of FSC certified areas in the study area, covering different proportions (2; 5; 10 and 20%) of the grid's cell they are located in (darker colour means higher proportion).

I.I.V. Frequency distribution of traditional conservation strategies or FSC certified areas

The frequency distribution of traditional conservation strategies or FSC certified areas is shown in Figure 5 and in Table 1. SACs and FSC certified areas are the most abundant in the study area, although the area with not any special protection tool is the dominant.

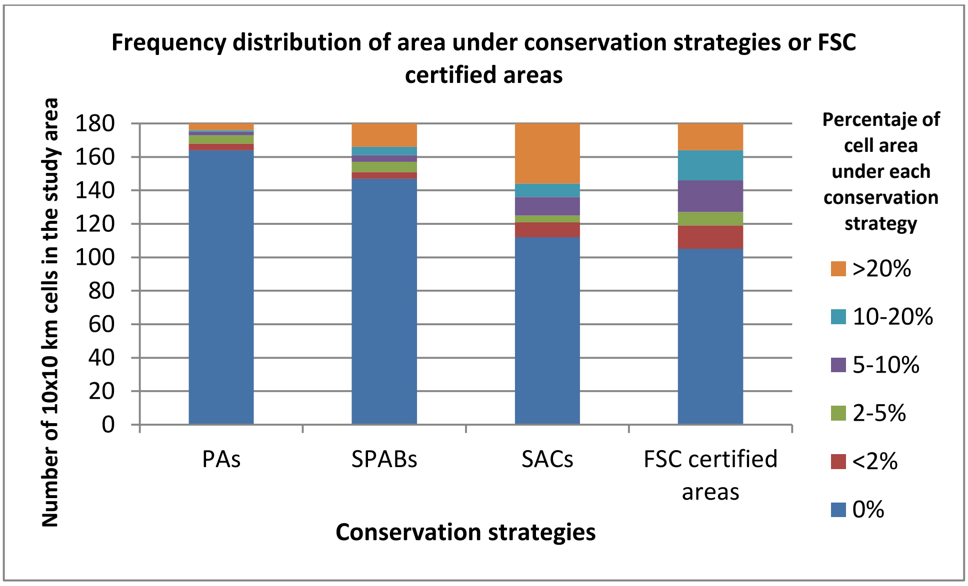


Figure 5: Graph showing the frequency distribution of the area under any conservation strategy per 10 x 10 km cell.

Table 1: Frequency distribution of the area under any conservation strategy per 10 x 10 km cell.

Percentage of cell area under each conservation strategy	PAs	SPABs	SACs	FSC certified areas
0%	164 cells	147 cells	112 cells	105 cells
<2%	4 cells	4 cells	9 cells	14 cells
2-5%	5 cells	6 cells	4 cells	8 cells
5-10%	2 cells	4 cells	11 cells	19 cells
10-20%	1 cell	5 cells	8 cells	18 cells
>20%	4 cells	14 cells	36 cells	16 cells

I.II. Biodiversity

The *Appendix III: Species Catalogue* includes a description of all the species involved in this study.

I.II.I. Threatened birds

45 threatened bird species were recorded in the study area, all of them included in the red Book of vertebrates of Portugal, with the following Conservation Status (Cabral *et al.,* 2006).

- Critically endangered (CR): faces an extremely high risk of extinction in the immediate future. There are 9 critically endangered birds in the study area.
- Endangered (EN): faces a high risk of extinction in the near future. There are 13 endangered birds in the study area.
- Vulnerable (VU): faces a considerable risk of extinction in the medium term. There are 23 vulnerable birds in the study area.

In Tables 2 and 3 and in Figures 6a), b), c) and d) we see the distribution and categorization of the threatened birds involved in this study.

Table 2: List all the bird species considered, their Conservation Status according to the Red Book of vertebrates of Portugal (Cabra e*t al.,* 2006), and the percentage of the study area in which they are located. CR=Critically endangered, EN=Endangered, VU=Vulnerable.

Scientific name	Common name	Conservation Status	% Study area
Accipiter gentilis	Northern goshawk	VU	3.33
Actitis hypoleucos	Common sandpiper	VU	32.78
Anas clypeata	Northern shoveler	EN	2.22
Anas strepera	Gadwall	VU	22.22
Aquila chrysaetos	Golden eagle	EN	1.11
Aquila fasciata	Bonelli's eagle	EN	17.78
Ardea purpurea	Purple heron	EN	14.44
Ardeola ralloides	Squacco heron	CR	0.56
Aythya ferina	Common pochard	EN	2.22
Burhinus oedicnemus	Eurasian stone-curlew	VU	48.33
Caprimulgus europaeus	European nightjar	VU	11.11
Caprimulgus ruficollis	Red-necked nightjar	VU	37.78
Chlidonias hybrida	Whiskered tern	CR	2.78

Table 2 (cont.): List all the bird species considered, their Conservation Status according to the Red Book of vertebrates of Portugal (Cabra *et al.,* 2006), and the percentage of the study area in which they are located. CR=Critically endangered, EN=Endangered, VU=Vulnerable.

Ciconia nigra	Black stork	VU	13.33
Circus aeruginosus	Western marsh harrier	VU	12.22
Circus cyaneus	Hen harrier	CR	0.56
Circus pygargus	Montagu’s harrier	EN	46.67
Clamator glandarius	Great spotted cuckoo	VU	27.78
Coracias garrulus	European roller	CR	4.44
Emberiza schoeniclus	Common reed bunting	VU	0.56
Falco naumanni	Lesser kestrel	VU	3.33
Falco peregrinus	Peregrine falcon	VU	1.67
Falco subbuteo	Eurasian hobby	VU	6.67
Fulica cristata	Red-knobbed coot	CR	0.56
Gallinago gallinago	Common snipe	CR	11.67
Glareola pratincola	Collared pratincole	VU	4.44
Ixobrychus minutus	Little bittern	VU	12.78
Locustella luscinioides	Savi’s warbler	VU	0.56
Milvus milvus	Red kite	CR	13.33
Neophron percnopterus	Egyptian vulture	EN	2.78
Netta rufina	Red-crested pochard	EN	2.78
Nycticorax nycticorax	Black-crowned night heron	EN	3.89
Oenanthe hispanica	Black-eared wheatear	VU	49.44
Otis tarda	Great bustard	EN	10.56
Pandion haliaetus	Western osprey	CR	2.78
Pernis apivorus	European honey buzzard	VU	17.78
Platalea leucorodia	Eurasian spoonbill	VU	9.44
Porphyrio porphyrio	Purple swamphen	VU	1.11
Pterocles orientalis	Black-bellied sandgrouse	EN	0.56
Sterna albifrons	Little tern	VU	4.44
Sterna hirundo	Common tern	EN	1.67
Sterna nilotica	Gull-billed tern	EN	4.44
Sylvia borin	Garden warbler	VU	1.67
Tetrax tetrax	Little bustard	VU	32.78
Tringa totanus	Common redshank	CR	5.00

Table 3: Percentage of study area in which each of the birds’ Conservation Status is.

Threatened birds’s Conservation Status	**% study area**
Critically endangered birds	33.89
Endangered birds	69.44
Vulnerable birds	94.44

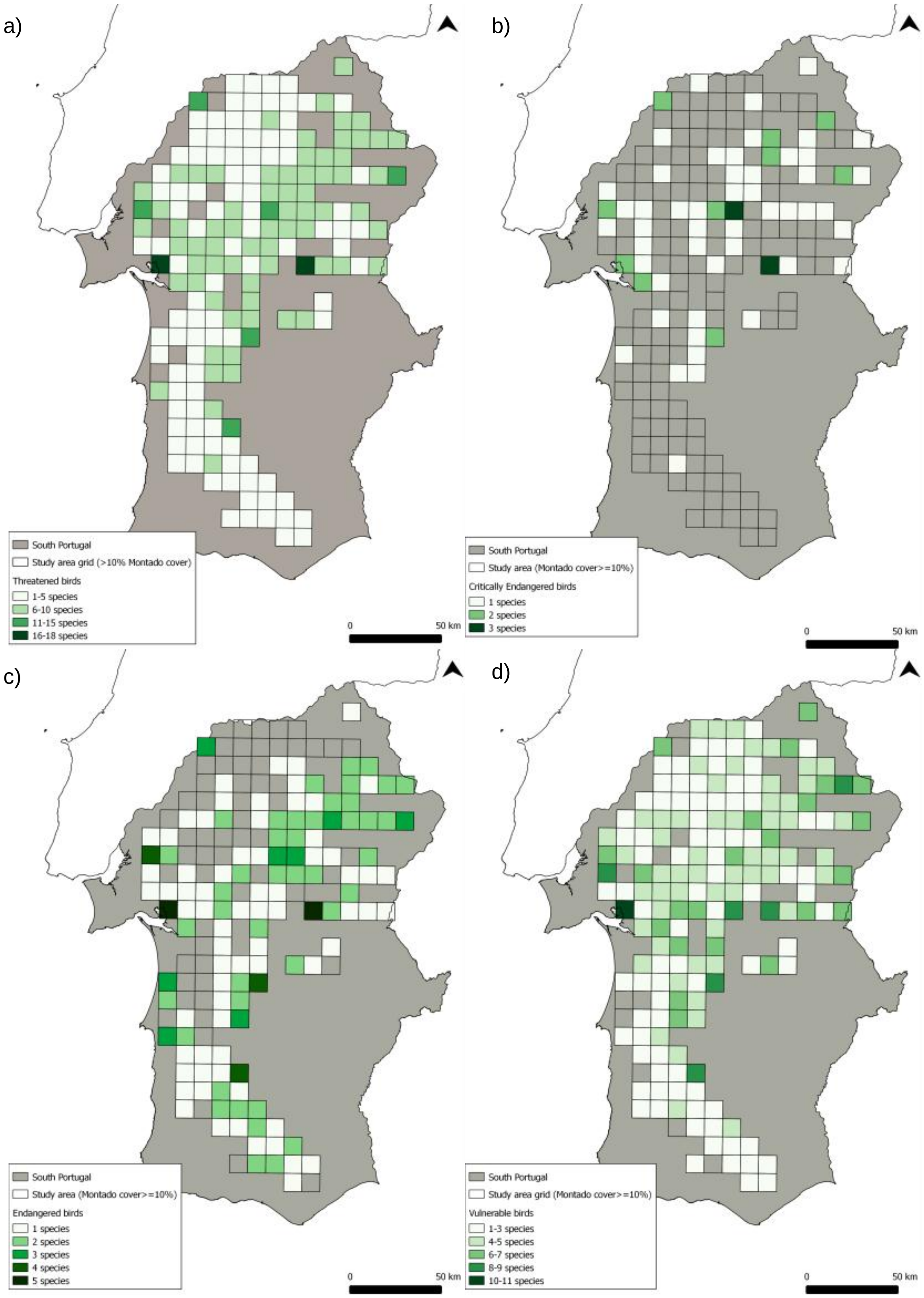


Figure 6-a: Classification of the study area grid cells according to the threatened birds' representation on each; 6-b, c and d: Distribution of the threatened birds regarding their Conservation Status (CR, EN, VU respectively). Darker color means higher number of species.

I.II.II. Threatened reptiles

There are 3 species of threatened reptiles in our study area, listed and categorized according to their Conservation Status and the percentage of the study area in which they are located in Table 4. They have a very scarce distribution (see Figure 7).

Table 4: List, Conservation Status and percentage in the study area where each of the threatened reptile species is.

Scientific name	Common name	Conservation Status	% Study area
Emys orbicularis	European pond turtle	Endangered	8.33
Hemydactilus turcicus	Mediterranean house gecko	Vulnerable	3.89
Vipera latasti	Lataste's Viper	Vulnerable	2.78

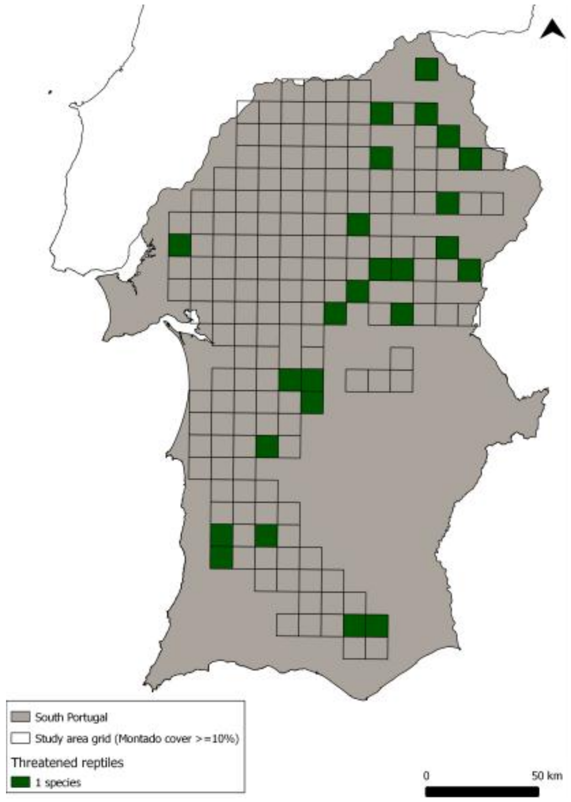


Figure 7: Distribution of threatened reptiles among the study area grid.

I.II.III. Endemic amphibians and reptiles

There are a total of 6 species of endemic amphibians (4 species) and reptiles (2 species), listed and categorized according to their Conservation Status and the percentage of the study area in which they are located in Table 5. They are distributed as it is shown in Figure 8.

Table 5: List, Conservation Status and percentage in the study area where each of the endemic amphibian and reptile species is.

Endemic amphibians			
Scientific name	**Common name**	**Conservation Status**	**% Study area**
Alytes cisternasii	Iberian midwife toad	LC	55
Discoglossus galganoi	Iberian painted frog	LC	27.78
Lissotriton boscai	Bosca's newt	LC	37.78
Rana iberica	Iberian frog	LC	1.67

Table 5 (cont.): List, Conservation Status and percentage in the study area where each of the endemic amphibian and reptile species is.

Endemic reptiles			
Scientific name	**Common name**	**Conservation Status**	**% Study area**
Chalcides bedriagai	Bedriaga's skink	LC	6.67
Lacerta schreiberi	Schreiber's green lizard	LC	3.89

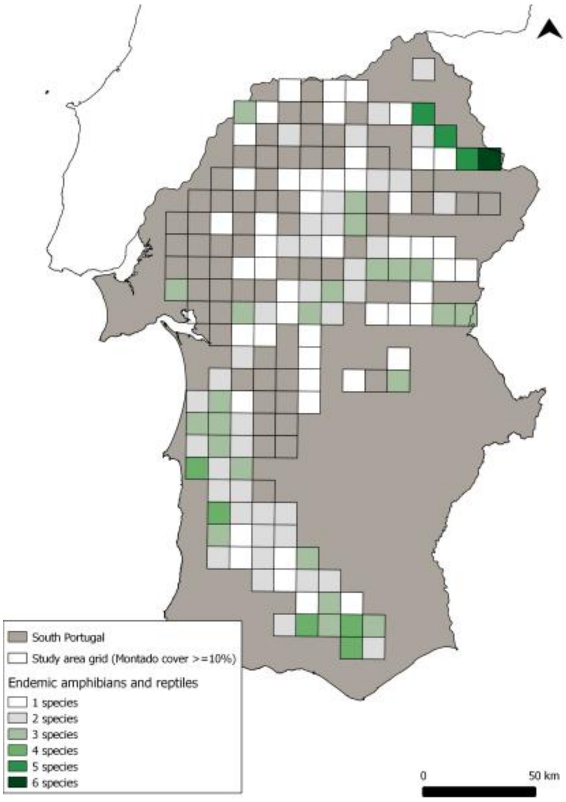


Figure 8: Distribution of endemic amphibians and reptile species among the study area grid. Darker colour means higher number of species.

I.III. Carbon storage

I.III.I. *Quercus suber*

The average Carbon storage due to *Quercus suber* (cork oak, main tree of the *montado* systems we are studying in this work) in the lands of the study area where this tree species is dominant is of 83.25 ton CO_2 eq/ha, reaching a maximum value of 87.88 ton CO_2 eq/ha and a minimum of 65.02 ton CO_2 eq/ha. In Table 6 we can see the percentage of the study area that has each of the ranges of Carbon storage due to *montados* that are represented in Figure 9.

Table 6: Proportion of study area on each range of Carbon storage

Carbon storage (ton CO_2 eq/ha)	% Study area
< 80	22.78%
80 – 83.25	22.78%
83.25 – 86	25.55%
>86	28.89%

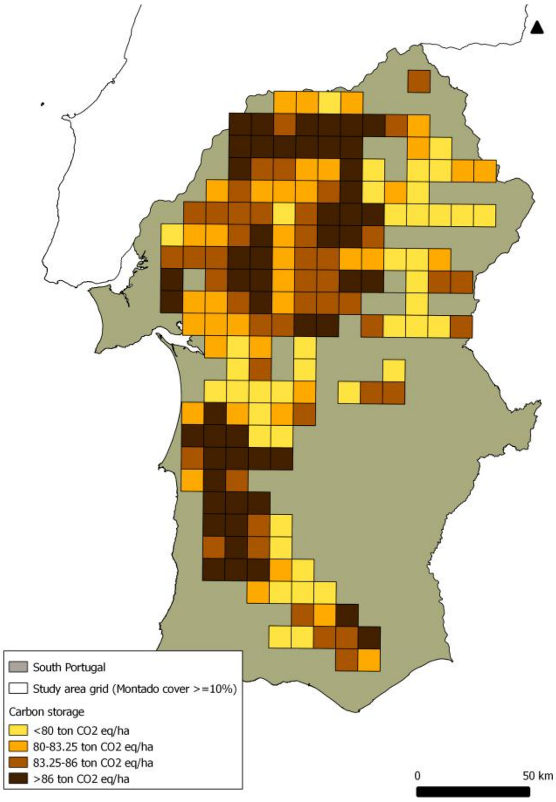
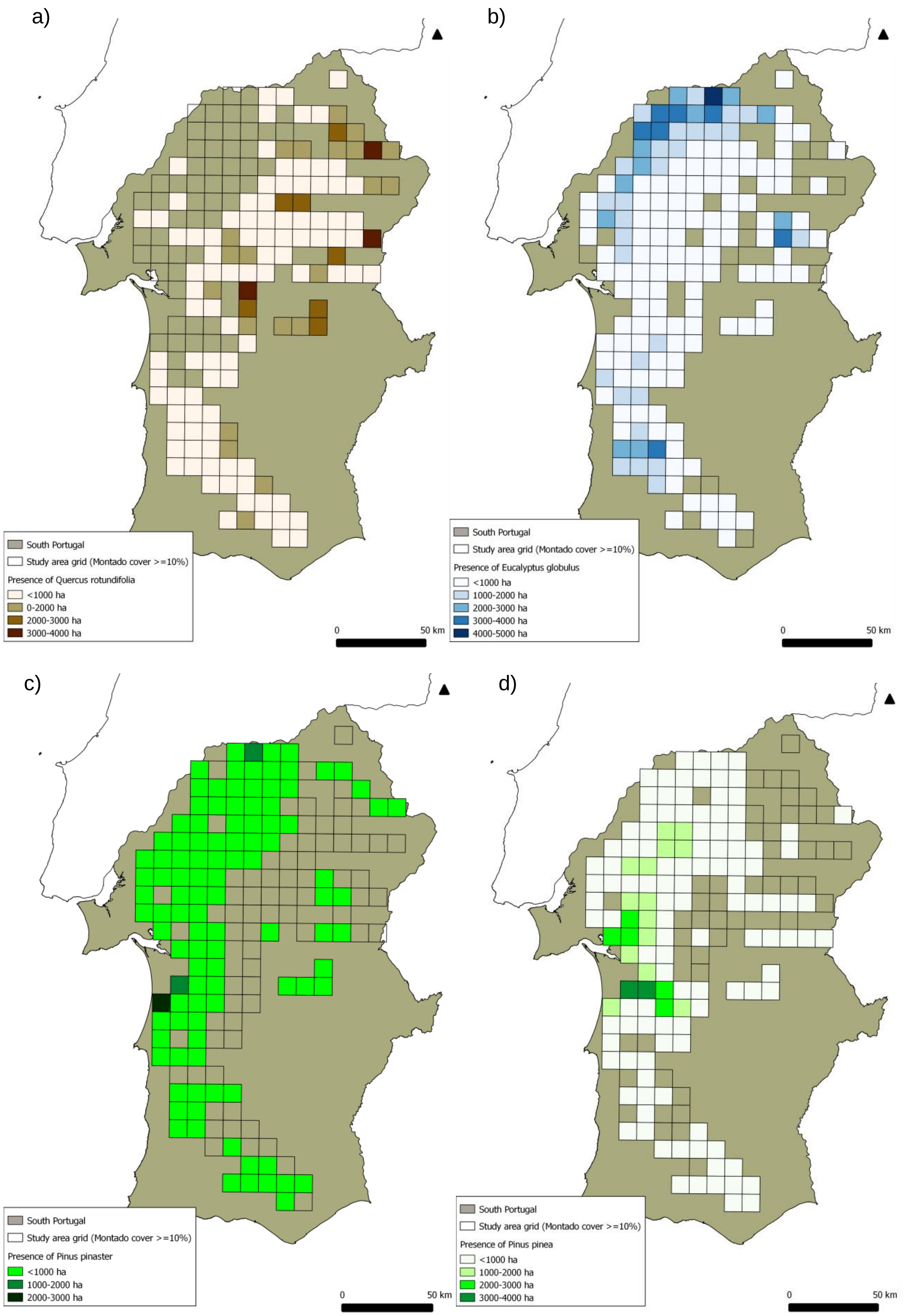


Figure 9: Carbon storage's levels among the study area grid. Darker color means higher level of Carbon storage.

I.III.II. Other species

The Carbon storage due to lands where other tree species are dominant in the study area (*Quercus rotundifolia*, *Eucalyptus globulus*, *Pinus pinaster* and *Pinus pinea*) for each of the 180 cells is represented in Figure 10-a, b, c and d.



Figures 10-a, b, c and d: Area occupied by lands with dominance of *Quercus rotundifolia, Eucalyptus globulus, Pinus pinaster* and *Pinus pinea* respectively in the study area.

I.IV. Water recharge

It is estimated that aquifers are below the 56.11% of the study area (see Figure 11-a). The average water recharge rate in the study area is of 133.32 mm/year, reaching a maximum value of 258.17 mm/year and a minimum of 0.78 mm/year. The 56.11% of the study area is not considered to contribute to the aquifers recharge (See Table 8). The recharge rates' distribution is represented in Figure 11-b.

Table 8: Percentage of the study area with each range of water recharge rates.

RAQ (mm/year)	% Study area
0	56.11
0-100	15,00
100-175	9.45
175-250	18.33
>250	1.11

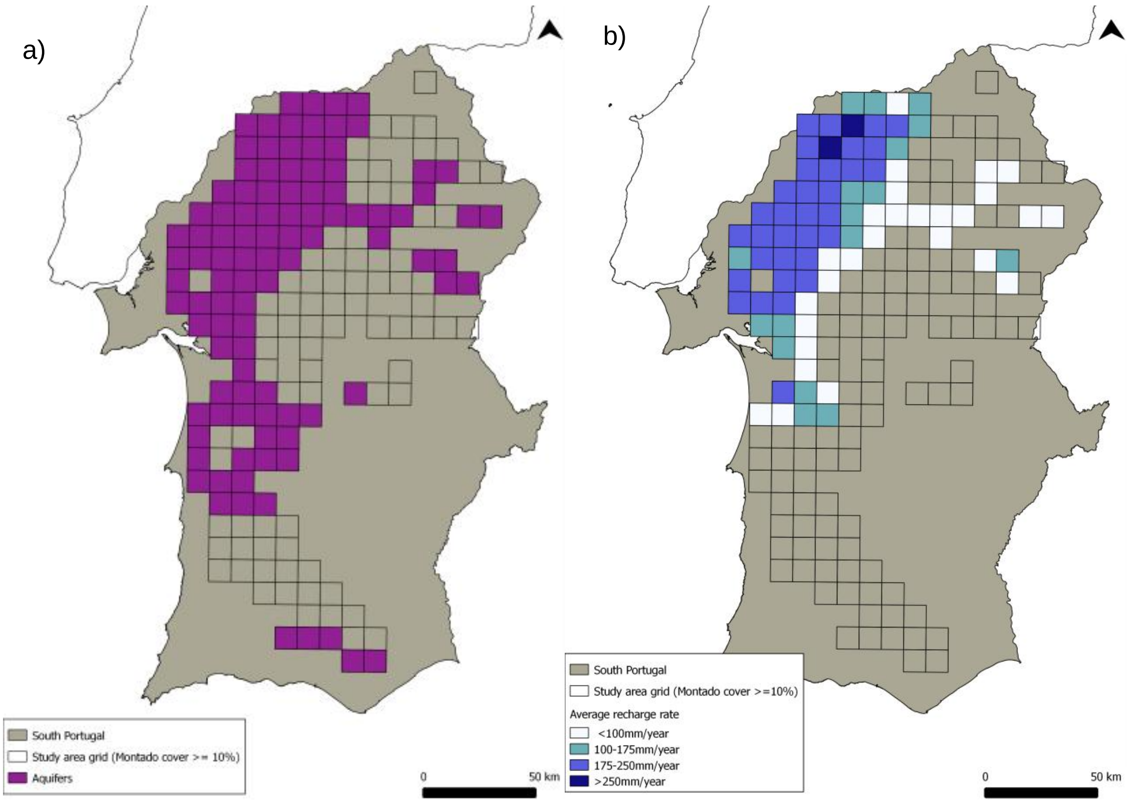


Figure 11-a and b: Distribution of the aquifers and recharge rates respectively among the study area grid. Darker color means higher recharge rate in Figure 14.

Appendix II: Other species analysis

Quercus rotundifolia, Pinus pinea, Pinus pinaster and *Eucalyptus globulus* are widely dispersed in the study area grid (in 69.44%, 75%, 60% and 91.11% of the study area grid cells respectively). It is especially noticeable this spreader distribution in *Eucalyptus globulus* and *Pinus pinaster,* that, while being dominant in the 15.16% and 2.73% of the forested area (relative low presence), they are present in the 91.11% and 60% of the study area grid cells respectively, representing the widest forested areas (after *Quercus suber*) in the 37.78% and 2.22% of them (68 and 4 grids respectively).

Quercus rotundifolia is more localized in the southern and eastern parts of the study area, concurring with those with less recharge rates and generally less representation of lands where *Quercus suber* dominates. Its distribution is more grouped, being the species with wider distribution per cell in the 41.11% of the study area grid cells (total of 74), while occurring in the 69.44%; this means that it is the most abundant species in the 59.20% of the cells it is located. *Eucalyptus globulus* and *Pinus sps* are more concentrated in the opposite parts.

Figure 1-a, b, c and d represent the abundance of lands with *Quercus rotundifolia, Eucalyptus globulus, Pinus pinaster* and *Pinus pinea* as the dominant species respectively, with a distinction between the study area grid, and the cells classified as HCVAs regarding threateed birds richness and carbon storage due to *montados* in that grid.

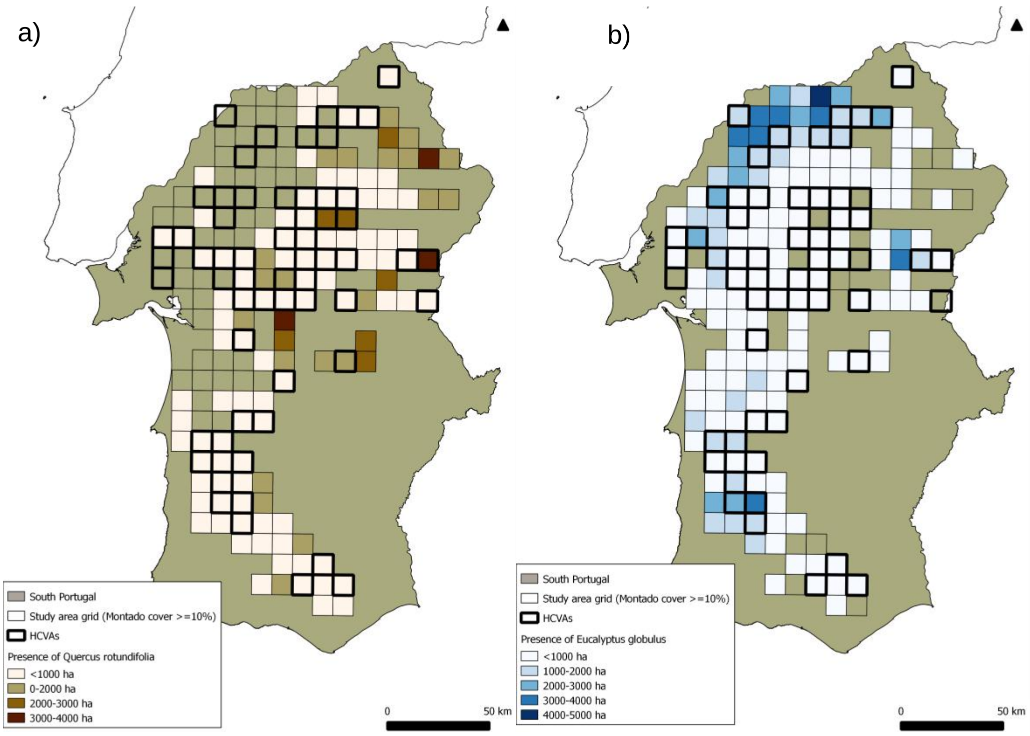


Figure 1-a and b: Area occupied by lands with dominance of *Quercus rotundifolia* and *Eucalyptus globulus* respectively in the study area, and limits HCVAs according to threatened birds' richness and carbon storage due to *montados*.

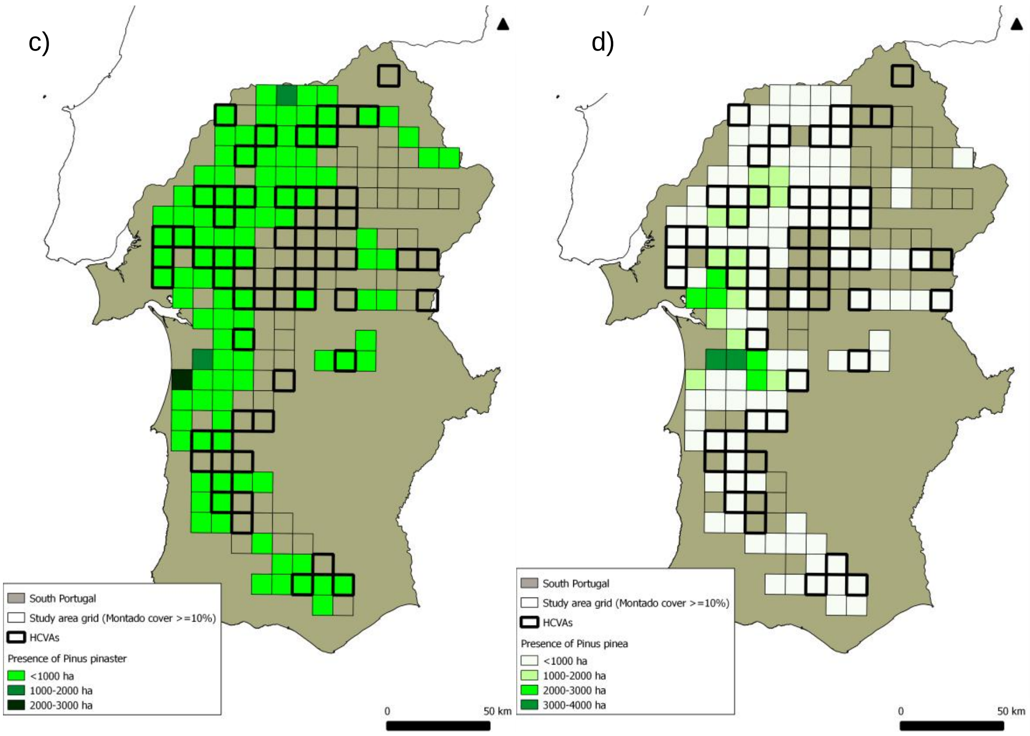


Figure 1-c and d: Area occupied by lands with dominance of *Pinus pinaster* and *Pinus pinea* respectively in the study area, and limits HCVAs according to threatened birds' richness and carbon storage due to *montados*.

The presence of the tree species classified by their belonging to a HCVA (the one that considers birds' biodiversity and carbon storage due to *montados*) is the one represented in Table 1.

Table 1: Percentage of the HCVA and non-HCVA cells in which each of the species occurs.

	Quercus rotundifolia	***Eucalyptus globulus***	***Pinus pinaster***	***Pinus pinea***	***Quercus suber***
% in HCVA	76.67	91.67	51.67	75.00	100.00
% in non-HCVA	65.83	90.83	64.17	75.00	100.00

On one hand, *Quercus rotundifolia,* is the species with a higher difference in representation comparing the grid cells inside of the area classified as HCVA according to threatened bird species and Carbon storage due to *montado* and the area outside (from a 76.67% inside to 65.83% outside the HCVA). This means that, although areas dominated by *Quercus rotundifolia* might not be generally concentrated in the same part as *Quercus suber*, they both provide very nice conditions for the threatened birds involved in this study.

On the other hand, *Pinus pinaster* is the only species that decrease its representation in areas inside the HCVA from the areas outside (from 51.67% inside to 64.17% outside the HCVA); also, *Pinus pinaster* is the species that less representation has in the study area. This means that, conversely to what happens with *Quercus rotundifolia, Pinus pinaster* might be more located in other kind of lands, coexisting less with cork oak *montados* and not providing as good conditions for threatened birds included in this study.

The total amount of carbon storage in the study area (18000 km^2) due to the 5 species we are considering is 70415730.9 tons of CO_2 equivalents, (see in Table 2 the quantity related to each tree species). The contribution of *Quercus rotundifolia, Eucalyptus globulus, Pinus pinaster* and *Pinus pinea* (dominant in the 34.97% of the forested area) to the whole amount of carbon storage in the study area is of 23523293 ton CO_2 eq/ha, representing the 33.4% of the total.

Table 2: Species contribution to carbon storage in the study area

Species	Carbon storage (ton CO_2 eq)	% of total carbon storage
Quercus rotundifolia	3994589	5.67
Eucalyptus globulus	11772610	16.72
Pinus pinaster	2607918	3.70
Pinus pinea	5148176	7.31
Quercus suber	46892437.9	66.59

Most of the studied species have a proportional relation between their Carbon storage rates and the land in which they are dominant among the study area. The only exception to this is *Quercus rotundifolia,* which is dominant in the 10.27 % of the land, providing with the 5.67% of the Carbon. This might be due not to the lack of coexistence between cork oak and holm oak *montados,* but to the low density of *Quercus rotundifolia* lands.

Each species' relative contribution for the total amount of carbon storage classified the area they belong to (HCVA or non-HCVA) is represented in Figure 2. *Eucalyptus globulus* and *Quercus rotundifolia* remain more or less in a constant proportion between HCVAs and non-HCVAs, while *Pinus sps'* contribution decrease in HCVA at the same time that *Quercus suber's* increases.

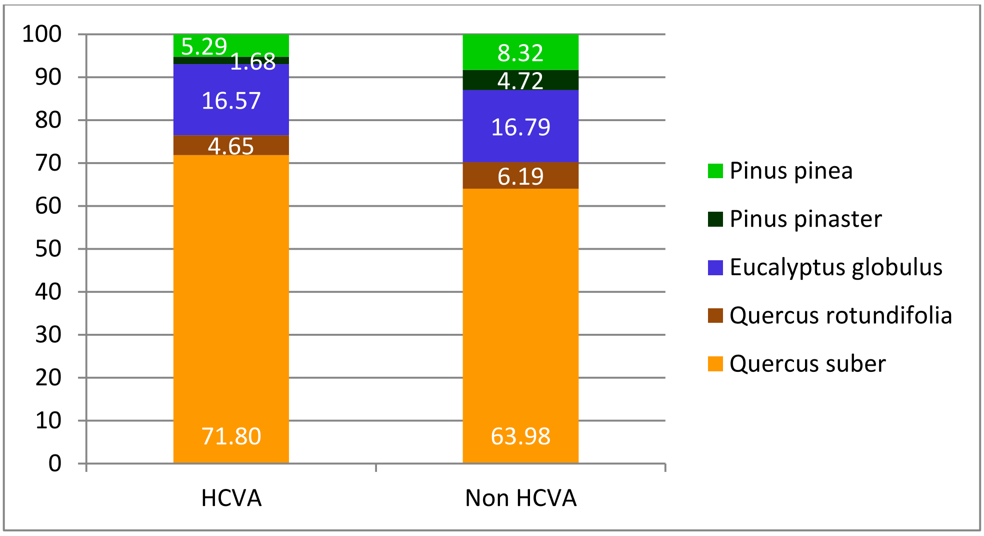


Figure 1: Relative contribution (in percentage) of each tree species to the total amount of carbon storage in and out the HCVA considered.

Pinus sps are the ones with a higher difference of Carbon storage in and out the HCVA (from 6.97% inside to 13.04% outside the HCVA). They are the less widely spread too, and are more grouped in the cells not classified as HCVA under our criteria. It seems the threatened birds involved in this study prefer oak-dominated lands

Appendix III: Species catalogue

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- *Alytes cisternasii*
- *Discoglossus galganoi*
- *Lissotriton boscai*
- *Rana iberica*

1.2. Reptiles

- *Chalcides bedriagai*
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- *Ardea purpurea*
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- *Vipera latasti*
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- *Ixobrychus minutus*
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- *Pernis apivorus*
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- *Sterna albifrons*
- *Sterna hirundo*
- *Sterna nilotica*
- *Sylvia borin*
- *Tetrax tetrax*
- *Tringa totanus*

1. Endemic species

1.1. Amphibians

Scientific name
Alytes cisternasii
Common name
Iberian midwife toad
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
LC-Least Concern
Key to species identification
Plump body. Visible eardrum. Fourth finger much shorter than second.

Scientific name
Discoglossus galganoi
Common name
Iberian painted frog
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
LC-Least Concern
Key to species identification
Pupil with an upside down droplet shape. Different colors and patterns depending on individuals.

Scientific name
Lissotriton boscai
Common name
Bosca's newt
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
LC-Least Concern
Key to species identification
Reddish belly with thick rounded black spots on the sides.

Scientific name
Rana iberica
Common name
Iberian frog
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
LC-Least Concern
Key to species identification
Eardrum separated from the eye. Heavily black dotted throat.

1.2. Reptiles

Scientific name
Chalcides bedriagai
Common name
Bedriaga's skink
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
LC-Least Concern
Key to species identification
Reduced members with five fingers.

Scientific name

Lacerta schreiberi

Common name

Schreiber's green lizard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

LC-Least Concern

Key to species identification

Short wide head. Tail twice longer than body length. Blue neck in males in the mating season.

2. Threatened species

2.1. Birds

Scientific name

Accipiter gentilis

Common name

Northern goshawk

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Rounded tail vertex. Bluish above, white and grey variegated below. Wingspan from 93 to 127 cm.

Scientific name

Actitis hypoleucos

Common name

Common sandpiper

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Short neck and legs. Upper parts with brown tones and lower whitish. Wingspan from 32 to 35 cm.

Scientific name

Anas clypeata

Common name

Northern shoveler

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Shovel-shaped peak. Wingspan from 73 to 82 cm.

Scientific name

Anas strepera

Common name

Gadwall

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Black or dark brown peak. Wingspan from 78 to 90 cm.

Scientific name

Aquila chrysaetos

Common name

Golden eagle

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN- Endangered

Key to species identification

Dark brown, with clearer nape. Tail as long as wingspan, from 190 to 225 cm.

Scientific name

Aquila fasciata

Common name

Bonelli's eagle

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN- Endangered

Key to species identification

Dark brown on upper parts, clearer on lower parts with mottled belly. Wingspan from 142 to 175 cm.

Scientific name

Ardea purpurea

Common name

Purple heron

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN- Endangered

Key to species identification

Brownish colors and black line in the long neck and head. Long and thin peak. Wingspan up to 1.5 m.

Scientific name

Ardeola ralloides

Common name

Squacco heron

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

CR-Critically endangered

Key to species identification

Long hair-like feathers on the head. Brown back and white breast and belly. Wingspan from 80 to 92 cm.

Scientific name

Aythya ferina

Common name

Common pochard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Blue band in the peak. Males with brown head and neck in mating season. Wingspan from 67 to 75 cm.

Scientific name
Burhinus oedicnemus
Common name
Eurasian stone-curlew
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
Big yellow eye. Long yellow legs to walk and run. Wingspan from 76 to 88 cm.

Scientific name
Caprimulgus europaeus
Common name
European nightjar
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
White grey and black molted body. White band on each side of the throat. Wingspan from 52 to 59 cm.

Scientific name
Caprimulgus ruficollis
Common name
Red-necked nightjar
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
Grey, reddish and brown body. Brown gold necklace that surrounds the neck. Wingspan from 65 to 68 cm.

Scientific name
Chlidonias hybrida
Common name
Whiskered tern
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
CR-Critically endangered
Key to species identification
Dark red peak. Greyish with a black hood. Wingspan from 80 to 95 cm.

Scientific name
Ciconia nigra
Common name
Black stork
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
Long red peak and black head, neck and upper parts. White belly. Wingspan from 145 to 155 cm.

Scientific name

Circus aeruginosus

Common name

Western marsh harrier

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Long and rounded wings and tail. Wingspan from 115 to 130 cm.

Scientific name

Circus cyaneus

Common name

Hen harrier

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

CR-Critically endangered

Key to species identification

Black wing extremes. Wingspan from 97 to 118 cm.

Scientific name

Circus pygargus

Common name

Montagu's harrier

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Equal size to *Circus cyaenus*, but bigger black wing extremes and black bands in secondary wings.

Scientific name

Clamator glandarius

Common name

Great spotted cuckoo

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Tapered wings and crest. Young with reddish primary wings. Wingspan from 60 to 70 cm.

Scientific name

Coracias garrulus

Common name

European roller

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

CR-Critically endangered

Key to species identification

Head and peak relatively big. Reddish brown back, bluish body. Wingspan from 52-58 cm.

Scientific name

Emberiza schoeniclus

Common name

Common reed bunting

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Male with a white necklace in mating season. Wingspan from 21 to 28 cm.

Scientific name

Falco naumanni

Common name

Lesser kestrel

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Male grey head, uniform brown upper parts. Black flight feathers. Wingspan from 60 to 67 cm.

Scientific name

Falco peregrinus

Common name

Peregrine falcon

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Bluish grey pointy wings and back. Long thin and round tail. Wingspan from 80 to 120 cm.

Scientific name

Falco subbuteo

Common name

Eurasian hobby

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Pointed and long wings. Medium and squared tail. Reddish thighs. Wingspan from 70 to 84 cm.

Scientific name

Fulica cristata

Common name

Red-knobbed coot

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

CR-Critically endangered

Key to species identification

Red bumps on the top of the white peak with gusset. Black body and blue legs. Wingspan from 75 to 85 cm.

Scientific name ***Gallinago gallinago*** Common name **Common snipe** Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006) **CR-Critically endangered** Key to species identification Long peak, slightly curved downwards. Wingspan from 39 to 45 cm.	
Scientific name ***Glareola pratincola*** Common name **Collared pratincole** Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006) **VU-Vulnerable** Key to species identification Black necklace. Head and back sandy brown. White throat and belly. Wingspan from 60 to 70 cm.	
Scientific name ***Ixobrychus minutus*** Common name **Little bittern** Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006) **VU-Vulnerable** Key to species identification Darker upper parts and speckled downer parts. Wingspan from 50 to 55 cm.	
Scientific name ***Locustella luscinioides*** Common name **Savi's warbler** Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006) **VU-Vulnerable** Key to species identification Strong tail. Wingspan from 18 to 21 cm.	
Scientific name ***Milvus milvus*** Common name **Red kite** Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006) **CR-Critically endangered** Key to species identification Forked tail that is reddish in the upper part, and clearer in the lower. Wingspan from 140 to 165 cm.	

Scientific name

Neophron percnopterus

Common name

Egyptian vulture

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Yellow face and legs, white body with black wing extremes. Wingspan from 150 to 160 cm.

Scientific name

Netta rufina

Common name

Red-crested pochard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Big white band along the wing. Big orange head and red peak in males. Wingspan from 85 to 92 cm.

Scientific name

Nycticorax nycticorax

Common name

Black-crowned night heron

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Intense red eyes. White throat, breast and lower parts. Wingspan from 105 to 110 cm.

Scientific name

Oenanthe hispanica

Common name

Black-eared wheatear

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Ochre head and breast, with a black mask, wings and tip of the tail. Wingspan from 25 to 27 cm.

Scientific name

Otis tarda

Common name

Great bustard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Thick legs with no posterior finger and big heavy body. Wingspan from 2.2. to 2.5 m.

Scientific name

Pandion haliaetus

Common name

Western osprey

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

CR-Critically endangered

Key to species identification

Black and white, with curved claws. Black ocular band. Wingspan from 152 to 167 cm.

Scientific name

Pernis apivorus

Common name

European honey buzzard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Similar to *Falco peregrinus*, but with longer tail and wings. Wingspan from 110 to 132 cm.

Scientific name

Platalea leucorodia

Common name

Eurasian spoonbill

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Long black peak with shovel-shaped yellow tip. Wingspan from 120 to 135 cm.

Scientific name

Porphyrio porphyrio

Common name

Purple swamphen

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Dark blue, clearer in throat and chest. Red peak (with gusset), eyes and legs. Wingspan from 90 to 100 cm.

Scientific name

Pterocles orientalis

Common name

Black-bellied sandgrouse

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Male with orange throat and a black mark in the middle. Wingspan from 120 to 140 cm.

Scientific name

Sterna albifrons

Common name

Little tern

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

White forehead. Short and forked tail. Wingspan from 51 to 56 cm.

Scientific name

Sterna hirundo

Common name

Common tern

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Red thin and sharpened peak with black extremes and red legs. Wingspan from 70 to 80 cm.

Scientific name

Sterna nilotica

Common name

Gull-billed tern

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

EN-Endangered

Key to species identification

Black legs and peak. Shorter tail than *Sterna hirundo.* Wingspan from 100 to 115 cm.

Scientific name

Sylvia borin

Common name

Garden warbler

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Short peak and pale ocular ring. Grey legs. Wingspan from 20 to 24.5 cm.

Scientific name

Tetrax tetrax

Common name

Little bustard

Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)

VU-Vulnerable

Key to species identification

Males with characteristic black and white patters around the neck. Wingspan from 90 to 110 cm.

Scientific name
Tringa totanus
Common name
Common redshank
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
CR-Critically endangered
Key to species identification
Orange peak base and legs. Wingspan from 47 to 53 cm.

2.3. Reptiles

Scientific name
Emys orbicularis
Common name
European pond turtle
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
EN-Endangered
Key to species identification
Members with visible fingers, blackish carapace with a yellow design.

Scientific name
Hemydactilus turcicus
Common name
Mediterranean house gecko
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
Flat body, short and tight head. Translucent appearance. Reverse with transversal black bands.

Scientific name
Vipera latasti
Common name
Lataste's Viper
Conservation status according to the red book of vertebrates of Portugal (Cabral et al. 2006)
VU-Vulnerable
Key to species identification
Very high muzzle, covered dorsally by five or six scales.

Appendix IV: Paper submitted to *Agroforestry Systems*

Promoting the sustainable use and conservation of cork oak landscapes using the high conservation value forest framework

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Abstract

Cork oak ecosystems are silvo-pastoral systems, typical of the western Mediterranean Basin. When well managed, these ecosystems provide relevant ecosystem services and biodiversity conservation. In the northern part of the Mediterranean Basin, cork oak areas are mainly privately owned and a source of income to landowners, chiefly through cork and livestock production. Sustainable use is essential to maintain the ecological sustainability and socio-economic viability of these ecosystems. Biodiversity conservation and non-provisioning ecosystem services may generate additional incentives promoting sustainable use and conservation of cork oak ecosystems, but require adequate mapping and identification. The High Conservation Value Forest (HCVF) framework allows systematic inventory of biodiversity and non-provisioning ecosystem services in forest ecosystems. The High Nature Value Farmland (HNVF), a concept emphasizing the importance of non-intensive agricultural ecosystems for the conservation of biodiversity, can possibly be coupled with HCVF to promote sustainable use and conservation of silvo-pastoral systems. Here we describe and exemplify the application of HCVF to the cork oak landscape of southern Portugal and suggest potential synergies between HCVF and HNVF.

Keywords: silvo-pastoral systems, *montados*, *dehesas*, forest management

Introduction

Cork oak (*Quercus suber* L.) ecosystems occupy 2.5 million ha in the western Mediterranean Basin both in North Africa (Algeria, Morocco and Tunisia) and Europe (Portugal, Spain, France and Italy) (Aronson et al 2009). They can have a closer or more open oak canopy being structurally similar to forest or savannah type ecosystems, respectively. The typical silvo-pastoral system, called *montado* in Portugal and *dehesa* in Spain, has a relatively low density of trees and an undercover of diverse shrub and grassland species (Diaz et al. 1997; Aronson et al. 2009). Dominant uses are cork and livestock production, frequently complemented with big and small game hunting and agricultural crops (Bugalho et al. 2009; Ferraz de Oliveira 2013). Cork oak ecosystems have considerable conservation value harboring several threatened and endemic vertebrate species (Diaz et al. 1997, Bugalho et al. 2011) and are a classified habitat under the pan-European network of protected areas Natura2000 (Berrahmouni et al. 2009). There have been different revisions on the importance of these ecosystems for the conservation of biodiversity (Diaz and Pulido 1997; Joffre and Rambal 1999; Bugalho et al 2011-a) although few addressing the non-provisioning ecosystem services (sensu MEA 2005) delivered by these systems (Berrahmouni et al 2009, Branco et al. 2010, Bugalho et al. 2011- a). Cork oak ecosystems are human-shaped, socio-ecological systems that can only be maintained if properly managed. This means maintaining a sustainable oak cover, with adequate oak regeneration, trees distributed over different age classes and shrubs cleared over long-term rotation cycles and maintenance of open grassland areas within the shrub matrix to favor biodiversity (Rey-Benayas et al. 2008; Bugalho et al 2011-b; Santana et al. 2012). Mismanagement, including abandonment, endangers the ecological sustainability and consequently the socio-economic sustainability of the ecosystem. Over-use, namely over-grazing, can cause oak regeneration failure, induce even age class structure of the oak cover with a dominance of old trees and a simplified undercover with absence of shrubs (Pulido et al. 2001; Plieninger et al.

2003). Conversely, lack of management can lead to shrub encroachment, increased risk of severe wildfires and loss of habitat heterogeneity and the tree canopy. In particular, the species diverse grasslands (Diaz-Villa et al. 2003) can be lost to the dominant shrub cover. The system may even fall under a cycle of arrested succession, in which fire and shrub encroachment hinder ecological succession and woodland formation (Acacio et al 2007).

In Europe, cork oak ecosystems have the largest area of distribution in Iberian Peninsula, where they are mainly privately owned. Cork, a non-timber forest product harvested between 9 and 12 years without felling the trees, is the main source of income to cork oak landowners. Maintaining a healthy oak canopy is not only essential to assure cork production but to ensure oak regeneration and the ecological sustainability of the system (Caldeira et. al. 2014). The socio-economic and ecological components are closed interlinked in cork oak ecosystems. Ecological collapse will lead to the economic failure of the system and vice-versa. Economic incentives, based on valuation of biodiversity and ecosystem services, may complement cork and other provisioning services returns, contributing to the sustainable use and conservation of cork oak ecosystems. For example, compensating landowners for assuring biodiversity conservation and delivering of non-provisioning services (sensu MEA 2005) is the basis of mechanisms such as payment for ecosystem services (PES) (Wunder 2005; Engels et al 2008). However, implementation of such mechanisms requires systematic inventory and mapping of areas important for the conservation of biodiversity and ecosystem services.

The High Conservation Value Forest (HCVF) is an international standardized framework used to systematically identify biodiversity and ecosystem services delivered by forest ecosystems that can be applied to cork oak ecosystems (Branco et al. 2010). While HCVF can target the forest management component of the silvo-pastoral systems, other conceptualized tools, such as the High Natural Value Farmland (HNVF), aim the farming component. HNVF is a concept that encapsulates the value of non-intensive agricultural ecosystems for the conservation of biodiversity. In agro-forestry or silvo-pastoral systems such as cork oak ecosystems, HCVF and HNVF can potentially be used together to promote sustainable use and biodiversity conservation of cork oak ecosystems.

In the present work we 1) describe and exemplify the use of HCVF framework to identify and map cork oak landscape areas in southern Portugal concentrating biodiversity values and ecosystem services 2) discuss how HCVF can be used to promote the sustainable use of cork oak ecosystems and 3) suggest how HCVF and HNVF could be used together towards the conservation of cork oak ecosystems.

The High Conservation Value Forest framework

The HCVF framework was developed under the Forest Stewardship Council (FSC) certification. FSC is a voluntary forest certification scheme which aims to promote the responsible management of the world´s forests. Approximately 148 million ha (3.7% of the world productive forests) are certified under FSC. This area includes 150 thousand ha of cork oak in Portugal Spain and Italy (www.fsc.org). By adhering to FSC certification forest landowners and managers have to comply with third party audited forest management practices respecting environmental and socio-economic standards (Auld et al. 2008). Timber and non-timber forest products (e.g. cork) originated from certified forests are identified with a certification logo and sold with added market value, generating an economic incentive to responsible forest management (Auld et al. 2008).

HCVF is covered by one of the FSC environmentally related principles: Principle #9 “Maintenance of high conservation value forests” (www.fsc.org), which requires landowners to “maintain or enhance the High Conservation Value attributes” (HCVs) identified within their properties. HCV attributes cover biodiversity values and ecosystem services, including cultural services, identified at a particular forest management unit. HCV attributes also explicitly address the “human needs of local people whose subsistence depends directly on forest resources” and recognizes the importance of active management for maintaining or enhancing HCV attributes (www.hcvnetwork.org). HCVF, therefore, moves beyond conservation based on biodiversity values *per se* and away from conservation “fortress conservation” approaches.

Another relevant issue is that HCVF is an international standard adapted to the national and regional specificities through public interpretation of HCV attributes by multiple stakeholders. These “HCVF national interpretations” increase the power and legitimacy of HCVF as a conservation tool. In Portugal, for example, HCVF public interpretation implied thoroughly discussion with farmer and forest associations, public administration bodies, including the National forest administration and Nature Conservation administration, non-governmental environmental organizations, research entities and forest private companies (www.fscportugal.org).

Although HCVF was first developed under the FSC certification it has now been applied independently of forest certification and extended to other aims such as land-use and conservation planning, advocacy, or for developing of responsible purchasing investment policies in forest and non-forest ecosystems (www.hcvnetwork.org).

The High Conservation Value Attributes

There are six High Conservation Value attributes (HCVs) (Table 1). High Conservation Value attribute - 1 (HCV1) is related to biodiversity values and imply assessing an area for its potential to host “significant concentration of biodiversity values”, such as endemic or endangered species. HCV1 is divided into HCV1.1 Protected Areas: which recognizes the importance of a particular forest management unit to be included or contain a classified area; HCV1.2 Threatened and Endangered Species: which assumes that these species are particularly vulnerable and that an area containing threatened species has high conservation value; HCV1.3 Endemic Species: which considers vulnerability of species with restricted ranges of geographical distribution and HCV1.4 Critical Areas for Temporal Use: which encompasses seasonally important habitat types or ecosystems such as breeding sites, migration routes or forest areas with seasonal concentration of species. HCV 2 evaluates if an area is part of a “nationally significant large landscape-level” region hosting viable populations of most species, recognizing that maintenance of large and continuous (not fragmented) areas of particular ecosystems at the landscape level are particularly important for biodiversity conservation. HCV3 assesses if an area contains “rare, threatened or endangered ecosystems”, such as classified and rare habitat types. HCVA4 is related to ecosystem services and evaluates if an area “provides basic ecosystem services” and is further divided into HCV4.1 “Forest areas critical for water catchments” enhancing the importance of an area to prevent water flooding, controlling stream flow or regulate water quality; HCV4.2 “Forest areas critical to erosion control”, which refers to control of soil erosion, landslides or downstream sedimentation and HCV 4.3 “Forest areas providing barriers to destructive fire” which enhances the importance of particular areas to prevent severe and destructive wildfires. A further attribute presently under discussion and falling within HCV4 relates to the importance of forest ecosystems for carbon storage and sequestration. Finally, attributes relevant to the “human dimension” of conservation are HCV5 and HCV6. HCV5 considers the importance of a particular area to meet the “basic needs of subsistence and health of local communities” namely getting essential benefits such as food, fodder or medicines from these areas. HCV6 Implies considering the relevance of an area for the “traditional and cultural identity” of the local community, such as the presence of sacred sites (Table 1).

By explicitly listing ecosystem services and including “human needs” attributes into its framework HCVF also relates to the Millennium Ecosystem Assessment framework for classification of ecosystem services (MEA 2005). For example, HCV4 attributes can be categorized as “regulatory ecosystem services” whilst

HCV5 and HCV6 relate to “provisioning ecosystem services” and “cultural ecosystem services”, respectively (sensu MEA 2005).

Applying HCVF to cork oak landscapes: biodiversity and carbon storage

We used the WebGIS HABEaS (Hotspot Areas for Biodiversity and Ecosystem Services) (www.habeas-med.org, Branco et al. 2010) to identify HCV attributes in the main area of cork oak distribution in Portugal. This is area covers approximately 500,000 ha located in the water basin of rivers Tagus and Sado (Figure 1). The WebGIS HABEaS, a joint project from the University of Lisbon, Portugal, the Mediterranean Program of the World Wide Fund for Nature (WWF), a global non-governmental conservation organization, and Faunalia a GIS open-source company, integrates information on HCV attributes on biodiversity and ecosystem services in Portugal. These data were gathered from publicly available information. For example, biodiversity data on bird distribution was gathered from the Portuguese Atlas on Bird Distribution (Equipa Atlas 2008) and data on distribution of cork oak and forest biomass collected from the Portuguese Forest Inventory (Autoridade Florestal Nacional 2010).

We used a HCV ecosystem services attribute (carbon storage) and a HCV biodiversity attribute (occurrence of threatened bird species) in the study area. Carbon storage data refers to biomass of cork oak trees only, not including information on other stocks of carbon such as the soil (www.habeas-med.org). For biodiversity, we used data on the distribution of threatened bird species (“vulnerable”, “endangered” or “critically endangered”) as classified in the red book for vertebrate species in Portugal (Cabral et al. 2005). Distribution data is based on a 10 km x 10 km grid as used in the Portuguese Atlas for the Distribution of Bird Species (Equipa Atlas 2008). We determined the number of threatened bird species occurring in the cell, as classed by percentiles and this information was overlapped with data on cork oak distribution (Figure 2). Similarly, we computed information on cork oak carbon storage in the study area as classed into different percentiles (Figure 3).

Finally, by overlapping the HCV attribute layers on biodiversity and carbon storage, we identified those areas of cork oak with high numbers of threatened bird species and of high carbon storage (Figure 4).

How can HCVF promote the conservation of cork oak landscapes?

HCVF framework, coupled with the HABEaS WebGIS tool, allows identification and mapping of areas concentrating biodiversity and ecosystem services values in a standard and systematic way. As exemplified above, we identified areas within cork oak landscapes concentrating high levels of biodiversity and carbon storage. Although we only used a biodiversity and an ecosystem service attribute the approach allows identification of sites concentrating multiple combinations of biodiversity values and ecosystem services. Presently, HABEaS generates geographical information on biodiversity HCV attributes: distribution of threatened and endemic vertebrate species, classified areas (e.g. network of protected areas, Natura2000), priority habitats and areas of seasonal importance for vertebrates; for ecosystem services HCV attributes HABEaS provides information on: location of main aquifers and water recharge rates and carbon storage. Attributes related to protection against soil erosion and mitigation of severe forest wildfires are being incorporated into the WebGIS.

Identification of areas important for the conservation of biodiversity and ecosystem services within cork oak landscapes can then be used to set up mechanisms promoting forest sustainable use and conservation in those areas. Information provided by HABEaS, for example, has been used by Forest Landowner Associations in Portugal to identify priority areas for conservation within their properties as required by FSC certification. Also, the WWF conservation initiative Green Heart of Cork (GHoC) project (http://awsassets.panda.org/downloads/ghocenglish.pdf), which aims to promote sustainable use of cork oak landscapes by seeking donors willing to compensate landowners that commit to forest certification, uses information generated by HABEaS to identify areas concentrating biodiversity and ecosystem services and thus more appealing to conservation donor investments.

Can High Conservation Value Forest and High Natural Value Farmland be used together towards the conservation of cork oak landscapes?

High Natural Value Farmland systems (HNVF) are low-input, extensive farming systems which generate habitat hosting species of conservation concern (EEA 2004). In Europe, for example, much of the biodiversity values depend on the maintenance and conservation of these low-input farming systems (Kleijn et al. 2009). More than 50% of Europe's most highly valued biotopes occur on low-intensity farmland (Bignal and McKacken 1994) and over 20% of the European countryside qualifies as HNVF (Pointereau et al. 2007). Abandonment, mismanagement and loss of these systems will imply loss of habitat and of species of conservation value. Recognizing the importance of HNVF systems for the conservation of biodiversity is essential to allow integration of these systems into nature conservation policies and grant access to agri-environment and other conservation supporting schemes (EEA 2004).

Cork and holm oak (*Q. rotundifolia* L.) silvo-pastoral systems of the Iberian Peninsula, *montados* and *dehesas*, qualify as HNVF systems (EEA 2004; Pointereau et al. 2007; Pinto-Correia and Carvalho-Ribeiro 2012). Other HNVF systems include semi-natural grasslands, steppes and extensive cereal fields for example (Pointereau et al. 2007, Flores et al. 2014). Incorporating HNVF information into a HCVF WebGIS database, such as HABEaS, may further increment conservation opportunities by specifically addressing the farming and agricultural component of cork oak ecosystems. Using such coupled approach will potentially diversify sources of funding directed to the conservation of these systems. We suggest that further research is critically needed to assess how HCVF and HNVF could be used in synergistically for securing private and public funding promoting the sustainable use and conservation of cork oak landscapes.

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Figure legends

Figure 1. Distribution of cork oak in the study area

Figure 2. Distribution of threatened bird species in the study area. All cells with at least 10% of cork oak were considered in the analysis. Legend indicates cells classified according to percentile of species occurrence.

Figure 3. Distribution of carbon storage in the study area. All cells with at least 10% of cork oak were considered in the analysis. Legend indicates cells classified according to percentile of carbon storage levels.

Figure 4. Distribution of areas important for the conservation of threatened birds and concentrating high carbon storage in the study area.

Figure 1

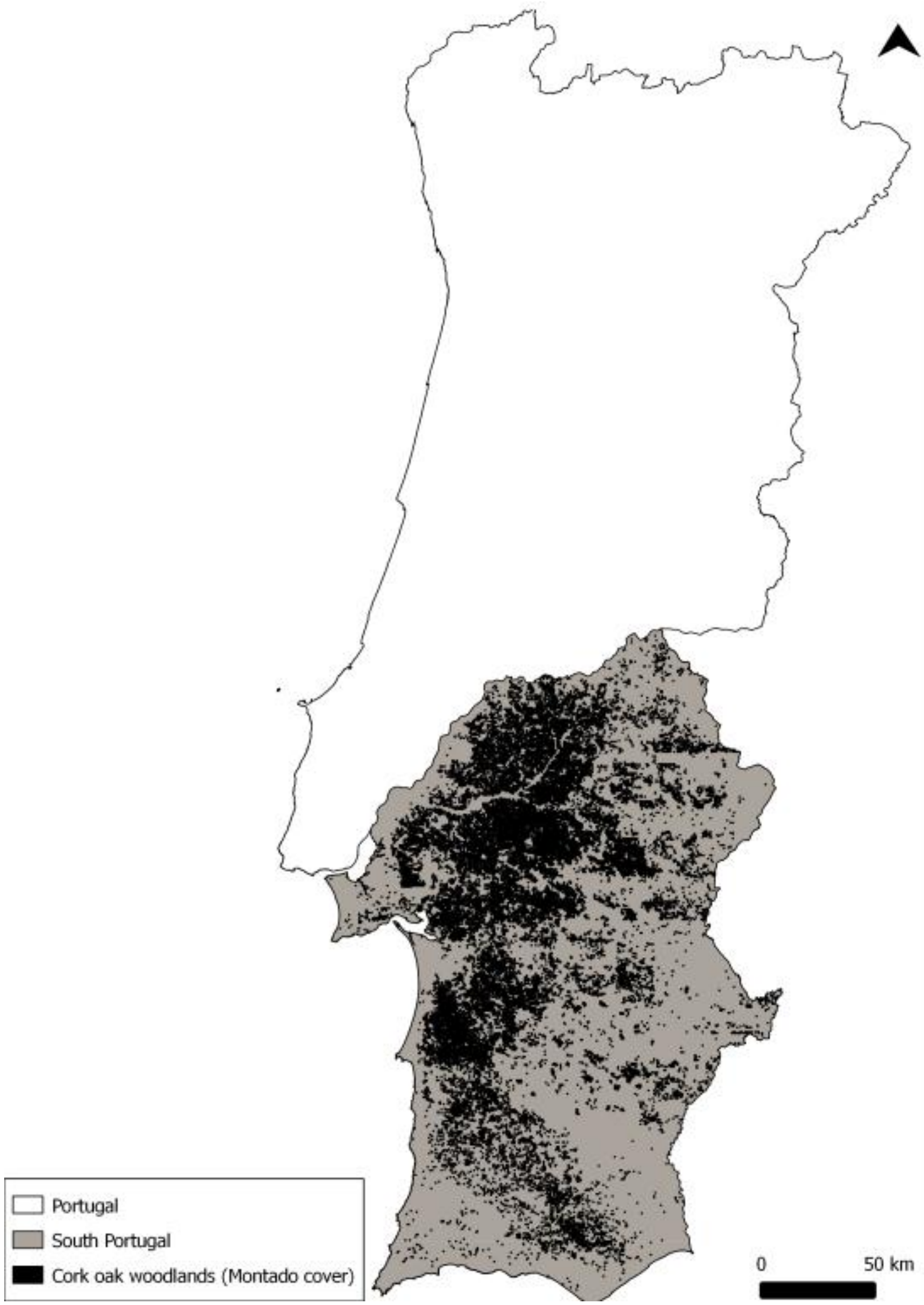
Portugal
South Portugal
Cork oak woodlands (Montado cover)
0
50 km

Figure 2

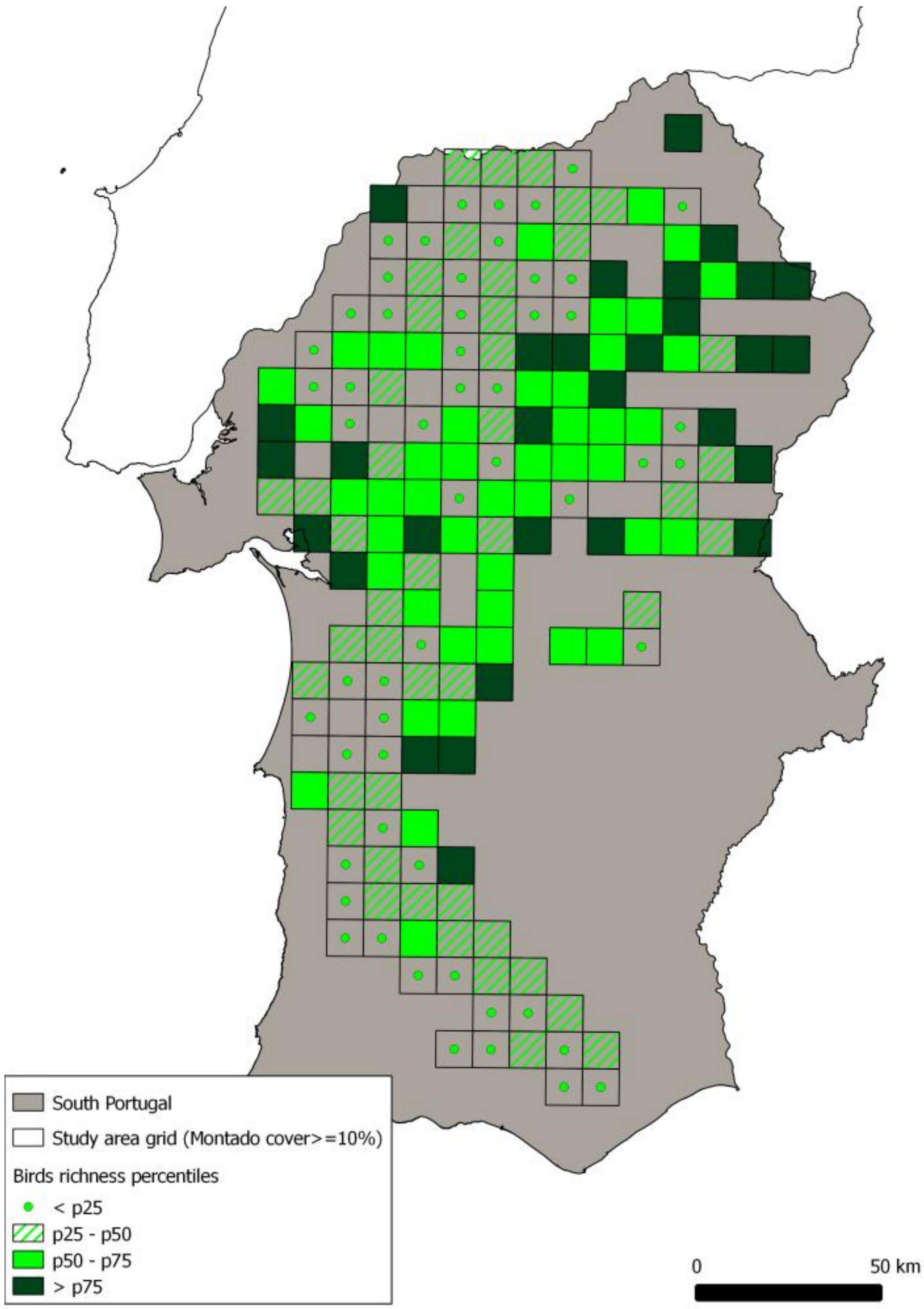
South Portugal
Study area grid (Montado cover>=10%)
Birds richness percentiles
< p25
p25 - p50
p50 - p75
> p75
0
50 km

Figure 3

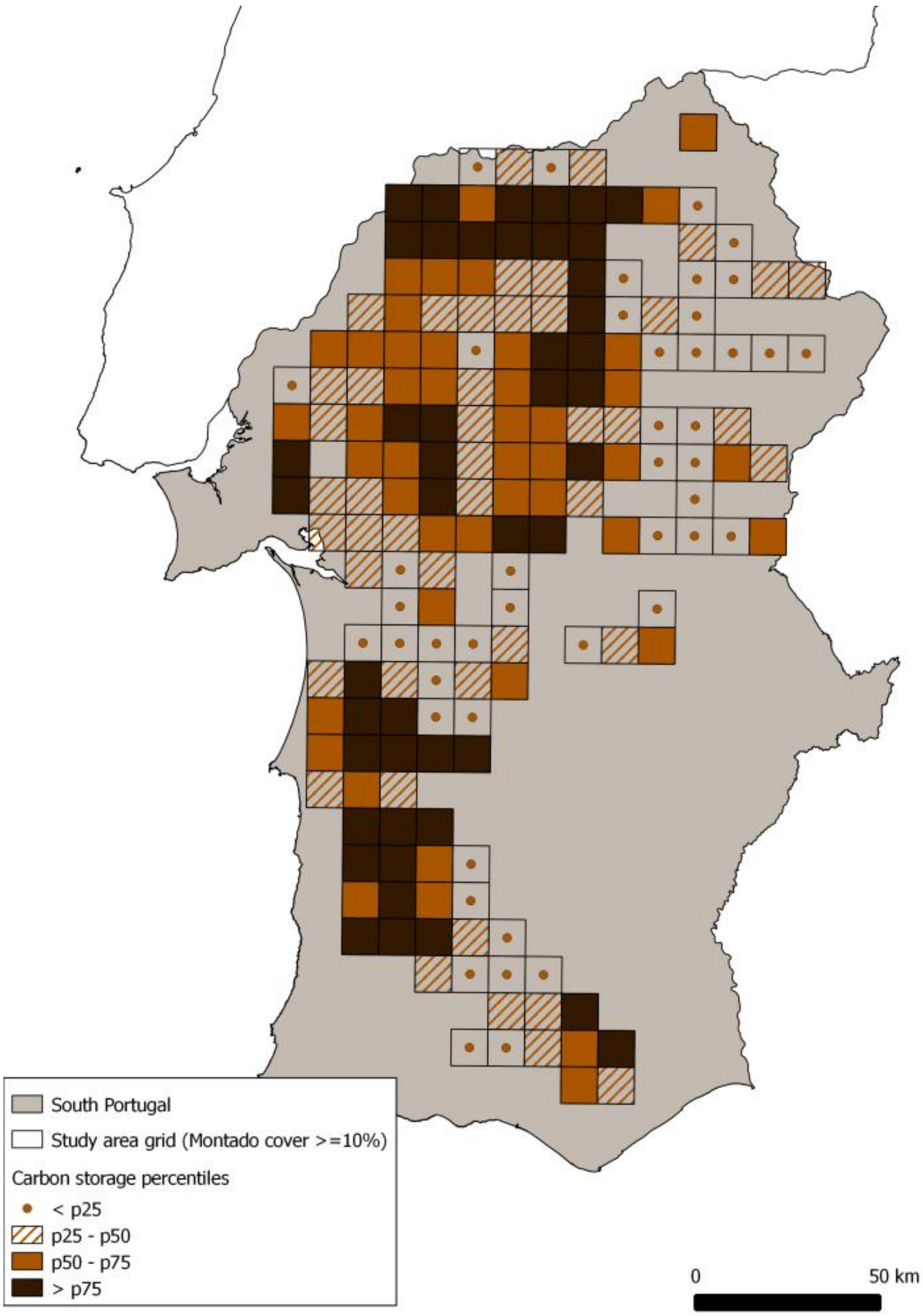
South Portugal
Study area grid (Montado cover >=10%)
Carbon storage percentiles
< p25
p25 - p50
p50 - p75
> p75
0
50 km

Figure 4

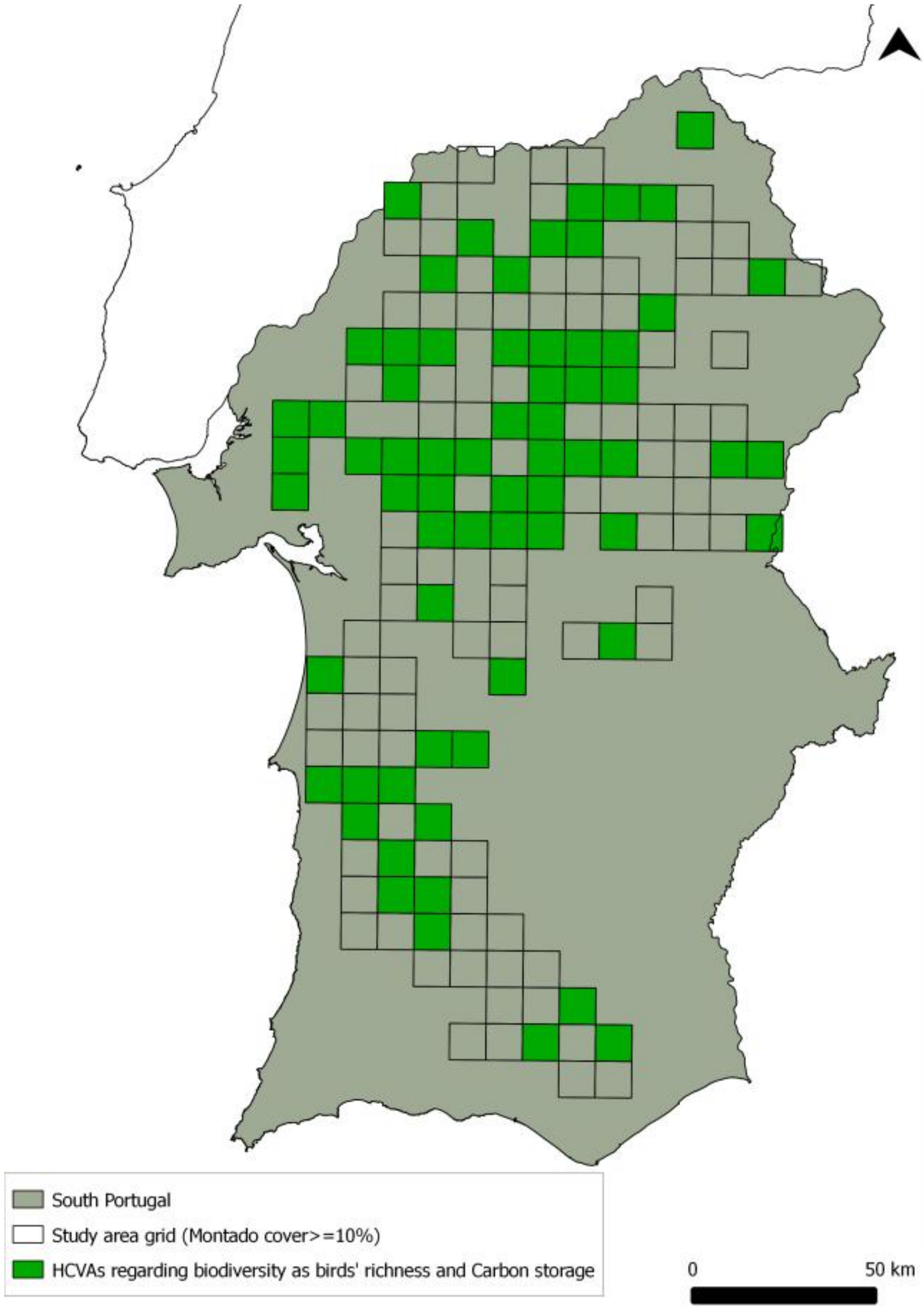
South Portugal
Study area grid (Montado cover>=10%)
HCVAs regarding biodiversity as birds' richness and Carbon storage
0
50 km

Table 1. The High Conservation Value Forests (HCVF) framework is based on six conservation attributes (HCV1 to HCV6) covering biodiversity values and ecosystem services identified at any forest management unit

HCV1	Concentrations of biological diversity
	HCV1.1 Protected areas
	HCV1.2 Threatened and endangered species
	HCV1.3 Endemic species
	HCV1.4 Critical temporal use
HCV2	Significant large landscape-level ecosystems
HCV3	Rare, threatened, or endangered ecosystems
HCV4	Basic ecosystem services
	HCV4.1 Forests critical to water catchments
	HCV4.2 Forests critical to erosion control
	HCV4.3 Forests providing barriers to destructive fire
	HCV4.4 Forests providing carbon storage and sequestering*
HCV5	Sites and resources fundamental for satisfying the basic necessities of local communities
HCV6	Sites, resources, habitats and landscapes of global or national cultural, archaeological or historical significance

* Attribute under discussion for inclusion into HCVF framework