The Role of Forest Certification for the Conservation of Biodiversity and Sustainability of Cork Oak Woodlands

TESE APRESENTADA PARA A OBTENÇÃO DO GRAU DE DOUTOR EM ENGENHARIA FLORESTAL E DOS RECURSOS NATURAIS

Orientador: Doutor Miguel N. Bugalho

Co-orientador: Professor Doutor Jorge Orestes Cerdeira

FILIPE EDUARDO PARREIRAS SILVA DIAS

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“We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.”

Edward O. Wilson

Consilience – The Unity of Knowledge

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Resumo

A gestão florestal sustentável é considerada um elemento chave para a conservação dos ecossistemas florestais, da sua biodiversidade e serviços do ecossistema que prestam. São contudo escassos os dados quantitativos que fundamentam esta visão. A certificação florestal visa promover a gestão sustentável das florestas através da valorização dos produtos florestais gerados de maneira sustentável. A certificação do Forest Stewardship Council (FSC) é um dos sistemas dominantes a nível global, cobrindo 184 milhões de hectares. Neste trabalho foi avaliado o papel da certificação FSC na conservação dos montados de sobro no sul de Portugal. Especificamente foi analisado 1) se as áreas de montado certificado coincidem, à escala regional, com áreas de elevado valor de biodiversidade (aves, anfíbios e répteis); 2) o efeito da certificação FSC na condição ecológica de cursos de água Mediterrânicos que atravessam propriedades de montado e 3) o efeito do estabelecimento de zonas de conservação (ZC) FSC na regeneração de sobreiro e diversidade do subcoberto arbustivo. Por último, 4) utilizando os conceitos de Áreas de Alto Valor de Conservação, criado pela certificação FSC, e de optimalidade de Pareto, foi estudada a existência de áreas de montado que combinam elevados níveis de biodiversidade (aves e répteis ameaçados) com a prestação de serviços do ecossistema (armazenamento de carbono e recarga de aquíferos). Os resultados sugerem que a certificação 1) se iniciou em montados cujo valor de biodiversidade não é, em geral, mais elevado que o dos não certificados; 2) melhora a condição ecológica de linhas de água que atravessam montados certificados, comparativamente com montados não certificados e 3) o estabelecimento de ZC promove a regeneração do montado e contribui para diversidade de espécies arbustivas. Por último identificaram-se 4) áreas significativas na zona de distribuição do montado nas quais coincidem valores elevados de biodiversidade e de serviços do ecossistema.

Palavras-chave: montado de sobro, certificação florestal, zonas de conservação, Forest Stewardship Council, conservação da biodiversidade.

Abstract

Sustainable forest management is crucial for the conservation of biodiversity and ecosystem services. Forest certification (FC) is a market-based conservation tool based on third-party auditing of compliance with environmental and socio-economic sustainable management standards. Forest Stewardship Council (FSC) certification is a major certification scheme covering 183 million hectares of forests worldwide. However, there is a dearth of quantitative data on the effects of FSC certification on forest conservation. In this thesis the effects of FSC certification on the conservation cork oak (*Quercus suber*) woodlands of southern Portugal were evaluated. Specifically it was analyzed 1) if, at the regional level, certified cork oak woodlands overlap with areas with high biodiversity value (birds, reptiles and amphibians); 2) the effects of certification on the ecological condition of Mediterranean streams crossing cork oak woodlands and 3) the effects of FSC conservation zones on the abundance of cork oak regeneration and on the diversity of the shrubland understorey. Finally, 4) the FSC concept of “High Conservation Value Areas” and Pareto optimality were used to study the existence of areas with high biodiversity value (threatened bird and reptile species) that also provide ecosystems services (carbon storage and aquifer recharge). Results suggest that FSC certification 1) started in cork oak woodlands whose biodiversity value is not significantly greater than that of non-certified areas; 2) the ecological condition of Mediterranean streams crossing certified cork oak woodlands is significantly higher than that of streams crossing non-certified cork oak woodlands; 3) establishing FSC conservation zones promotes cork oak regeneration and diversity of understory shrublands and 4) there are large areas of cork oak woodlands with high biodiversity value that also provide ecosystems services.

Keywords: cork oak woodlands, forest certification, conservation zones, Forest Stewardship Council, biodiversity conservation

Resumo alargado

A gestão florestal sustentável é um elemento chave para a conservação dos ecossistemas florestais, da sua biodiversidade e dos serviços do ecossistema que prestam. A certificação florestal tem como objectivo promover a gestão sustentável das florestas através da valorização no mercado dos produtos florestais gerados de maneira sustentável. A nível global existem dois grandes sistemas de certificação florestal: o “Program for the Endorsement of Forest Certification” (PEFC) que cobre 235 milhões de hectares de florestas e o Forest Stewardship Council (FSC) que cobre 183 milhões de hectares. O sistema FSC é considerado pela maioria das organizações não-governamentais de ambiente como aquele que oferece maiores garantias para a conservação da biodiversidade. O principal objectivo da certificação FSC é “promover a gestão sustentável das florestas do mundo do ponto de vista ambiental, social e económico”. A norma de certificação do FSC é constituída por 10 princípios e 57 critérios desenvolvidos através de um processo de participação pública de partes interessadas. Estas incluem a administração pública, organizações não-governamentais, representantes da indústria florestal, de proprietários e instituições de investigação. O cumprimento das normas FSC por parte dos produtores e gestores florestais é avaliado através de um processo de auditoria realizado por uma entidade independente. As questões relacionadas com a conservação da biodiversidade são abordadas ao nível do Princípio 6 “Impacte ambiental” e do Princípio 9 “Manutenção das Florestas de Alto Valor de Conservação”. O Princípio 6 indica que “a gestão florestal deve conservar a diversidade biológica e os valores a ela associados, os recursos hídricos, os solos, os ecossistemas e paisagens frágeis e singulares, mantendo assim as funções ecológicas e a integridade das florestas”. Em termos práticos o Princípio 6 traduz-se na criação de zonas de conservação com uma área correspondente a aproximadamente 10% das propriedades certificadas. O Princípio 9 estabelece que “as actividades de gestão em Florestas de Alto Valor de Conservação devem manter ou melhorar os atributos que definem tais florestas e que as decisões sobre elas

tomadas devem seguir o princípio da precaução" e preconiza a criação de uma lista de atributos que definem uma Floresta de Alto Valor de Conservação (ww.fsc.org). Apesar de a certificação florestal FSC cobrir uma área extensa a nível global e de a conservação da biodiversidade ser um elemento central na norma FSC, existem poucos trabalhos publicados que analisem seu papel na conservação da biodiversidade. Os escassos trabalhos realizados focaram-se em florestas tropicais, existindo muito pouca informação para florestas temperadas e menos ainda para florestas Mediterrânicas.

Em Portugal existem 349 mil hectares de florestas certificadas pelo FSC das quais 100 mil são de montado de sobro. O montado de sobro é um sistema agro-silvo--pastoril de grande valor económico e ambiental que cobre cerca de 1 milhão de hectares no sudoeste da Europa e 1.5 milhões de hectares no norte de África. Este sistema caracteriza-se por uma densidade relativamente baixa de sobreiros (30-60 árvores/ha) (*Quercus suber*) em consociação com outras espécies de carvalhos como a azinheira (*Quercus rotundifolia*) ou o carvalho-português (*Quercus faginea*) ou de pinheiros (*Pinus pinea*, *Pinus pinaster*). O subcoberto arbustivo é composto por matos bastante diversos, intercalados com pastagens, culturas agrícolas e habitats ripícolas associados a rios e reservas de água. Esta diversidade de habitats encontra-se associada a níveis de biodiversidade elevados, incluindo diversas espécies de vertebrados endémicos (ex: sapo-parteiro-Ibérico *Alytes cisternasii*) e criticamente ameaçados (ex: lince-Ibérico *Lynx pardinus*, abutre-negro *Aegypius monachus* ou águia-imperial-Ibérica *Aquila adalberti*). O montado de sobro, quando bem gerido, presta ainda diversos serviços do ecossistema, incluindo a regulação do ciclo da água ou protecção do solo contra a erosão.

Apesar da sua importância sócioeconómica e ambiental, o montado de sobro em Portugal enfrenta problemas de conservação. Em algumas áreas o abandono e ausência de gestão promovem uma colonização acentuada por matos e o aumento do risco de incêndio. Noutras áreas, a sobreutilização, nomeadamente o sobre-pastoreio ou a utilização intensiva de maquinaria pesada para o controlo de matos, podem provocar compactação do solo e a diminuição da regeneração arbórea. A certificação FSC visa contribuir para a gestão sustentável do montado de sobro através de incentivos de mercado que resultam da tendência crescente dos consumidores para darem preferência a produtos florestais sustentáveis. Este factor tem vindo a aumentar a procura de produtos florestais certificados por parte da indústria transformadora. A adopção de práticas de gestão FSC que impõem, por exemplo, a delimitação de zonas de conservação e gestão menos intensiva, pode também afectar de forma positiva a sustentabilidade ecológica e biodiversidade dos montados.

A presente dissertação teve como objectivo geral fazer um diagnóstico dos efeitos da certificação florestal FSC sobre o montado de sobro e avaliar se a certificação FSC está a contribuir positivamente para a conservação dos montados de sobro em Portugal.

Especificamente, esta tese visa:

1) avaliar se as áreas de montado de sobro certificado coincidem, à escala regional, com áreas de elevado valor de biodiversidade em termos de aves, anfíbios e répteis;

2) determinar se a condição ecológica de cursos de água Mediterrânicos, que atravessam áreas de montado de sobro certificado é superior à condição ecológica de cursos de água em montados não certificados;

3) avaliar se o estabelecimento de zonas de conservação FSC promove a regeneração natural de sobreiro e a diversidade do subcoberto arbustivo;

4) investigar, combinando os conceitos de Áreas de Alto Valor de Conservação, resultante do Princípio 9 da certificação FSC e de optimalidade de Pareto, a

existência de áreas de montado de sobro que albergam elevados níveis de biodiversidade (espécies de aves e répteis ameaçados) e geram serviços do ecossistema importantes (armazenamento de carbono e recarga de aquíferos). Este estudo tem a finalidade de prioritizar áreas para aplicação de mecanismos de conservação como a certificação florestal ou outras ferramentas de conservação.

Relativamente ao Objectivo 1, verificou-se que o valor de biodiversidade das áreas actualmente certificadas pelo FSC não é significativamente diferente do de áreas não certificadas. Nexto contexto sugere-se a implementação de incentivos à certificação nas áreas de elevado valor de biodiversidade.

Em relação ao Objectivo 2, os resultados indicam que, após 5 anos de gestão certificada, a condição ecológica dos troços de rio que atravessam montados de sobro certificados é significativamente superior à condição ecológica de troços de rio em montado não certificado. Os resultados indicam também que a condição ecológica destes troços de rio é idêntica à de troços de rio localizados em zonas de referência e classificados como em “Bom Estado de Conservação” pelas entidades públicas.

No que diz respeito ao Objectivo 3, os resultados sugerem que a implementação de zonas de conservação no âmbito da certificação FSC promove a regeneração do montado e a diversidade do sub-coberto arbustivo.

Em relação ao Objectivo 4, identificaram-se a nível regional as áreas de montado de sobro mais eficientes relativamente à conservação dos valores de riqueza de aves e répteis ameaçados, carbono armazenado e de taxas de recarga de aquíferos. Foi também identificado o subconjunto destas áreas que apresenta valores de riqueza de espécies de aves e répteis ameaçados, de armazenamento de carbono e de taxas de recarga de aquífero acima da média. Estes resultados sugerem que, no Sul de Portugal, existem vastas áreas que combinam elevado valor de biodiversidade com a prestação de importantes serviços do ecossistema. Estas áreas deverão ser consideradas como prioritárias para a implementação de mecanismos que incentivem a gestão florestal sustentável e a conservação da biodiversidade e serviços do ecossistema, tais como a certificação florestal ou outros mecanismos (ex: pagamentos de serviços do ecossistema).

Palavras-chave: montado de sobro, certificação florestal, zonas de conservação, Forest Stewardship Council, conservação da biodiversidade.

Chapter I - General Introduction

1. Conservation of forest ecosystems

Forests ecosystems, including plantations, cover approximately an area of 4000 million hectares corresponding to 31% of the Earth's surface (FAO 2010). These ecosystems harbour over two thirds of the world's terrestrial biodiversity and support the livelihood of 1600 million people (Thompson et al. 2009). Forests supply key ecosystem services such as carbon sequestration and protection against floods, landslides, avalanches, ocean surges and desertification and provide clean water, medicines, crops and space for recreation and exercise (FAO 2010). By 2050 the global human population will surpass 9600 million people (United Nations 2013) which will increase food demand by over 70% (FAO 2009). Simultaneously climate change is expected to reduce crop yields in many countries (IFPRI 2009). Studies suggest that after 2030 food, fibre and fuel will compete intensively with forest ecosystems for land and water resources (FAO 2009). In this context it is crucial to develop mechanisms to ensure the conservation of forest ecosystems, the biodiversity they harbour and the services they provide.

Protected areas (PA) have long been the main conservation tool ensuring the protection of forests and other ecosystems. PA coverage has increased from 8.5% of the terrestrial surface (including inland waters) in 1990 to 15.4% in 2014 (Leadley et al. 2010; Pereira et al. 2010, www.protectedplanet.net). However, area allocated to PAs has been insufficient to stop biodiversity loss due to deforestation and forest degradation (Joppa and Pfaff 2009; Joppa and Pfaff 2010; Butchart et al. 2010). Developing alternative conservation tools complementing the role of protected areas in conserving forest ecosystems is a key issue in conservation science.

Forest certification is a market-based conservation tool based on third-party auditing of compliance with environmental and socio-economic management standards. These standards are developed through public participation of different stakeholders that include: public administration and governmental agencies, environmental non-governmental organizations, industry associations, landowners, and social groups (Auld et al. 2008).

2. The rise of forest certification

2.1 Forest Stewardship Council certification

Non-governmental forest certification schemes were created due to increasing concerns among environmental non-governmental organizations (NGO) and other stakeholders over global forest degradation, mainly due to unsustainable industrial logging and the failure of governments to tackle the problem (Auld et al. 2008). In 1989, NGOs campaigned for the development of forest certification and labeling systems that could ensure that tropical timber was originated from sustainably managed sources. These campaigns were halted when International Tropical Timber Organization (ITTO), an intergovernmental organization promoting the conservation and sustainable management, use and trade of tropical forest resources, refused to support the proposal presented by NGOs (Auld et al. 2008; Gulbrandsen 2010). After this set back, the World Wide Fund for Nature (WWF), a global environmental NGO, became increasingly convinced that such certification system would have to be developed by the private initiative and civil society. This conviction gained strength when, at the United Nations Earth Summit held in 1992, in Rio de Janeiro, governments of developing and developed countries were only able to agree on a politically non-binding list of Forest Principles on sustainable forest management. These principles stated only general guidelines for forest management relating to economic, environmental and developmental concerns without clarifying how use and conservation of forests should be balanced (Auld et al. 2008; Gulbrandsen 2010).

In 1993, as a response to these events, environmental NGOs, timber traders, representatives of indigenous peoples, forest worker organizations, and other stakeholders founded the Forest Stewardship Council (FSC). The goal of FSC is to "promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests". "Environmentally appropriate" meant maintaining "the forest's biodiversity, productivity, and ecological processes", "socially beneficial" meant local people and society as a whole would commit to long-term management of forests, thus guaranteeing future forest benefits And “economically viable” meant that profits would be generated without jeopardizing “the forest resource, the ecosystem, or affected communities” (Auld et al. 2008).

FSC is registered as a non-profit organization, governed by a General Assembly with a tripartite structure that includes equitable social, environmental and economic chambers. These chambers are open to the participation of a wide range of individuals and organizations, including governmental agencies. Each chamber holds one third of the votes with voting parity between stakeholders from developing and developed countries to ensure that no specific interests dominate rule making (Gulbrandsen 2010).

FSC forest management standards are based on ten principles and 56 criteria addressing biodiversity conservation, forestry planning (including plantations), land tenure, indigenous peoples' rights, worker's rights and the use of forest products and services (www.fsc.org). FSC principles and criteria are adapted to countries or regions through public participation of stakeholders representing social, environmental and economic chambers. The national/regional standard is then submitted to the FSC board of directors for approval. Forest products originated from FSC certified forests can then be sold with a FSC label meant to show retailers and consumers that these products were sustainably generated. The verification of conformity with FSC rules and requirements is conducted by an independent certification body which needs itself to be recognized by FSC. This auditing process involve several steps including 1) a preliminary assessment to identify potential non-compliances with the standards, 2) an on the ground field inspection by a team that usually includes foresters, biologists and other experts, 3) consultations with local communities, 4) the preparation of a preliminary assessment report by the certifier, 5) peer review of the report, 6) a discussion with the applicant, 7) a final certification determination and the issue of a certificate and 8) an annual follow-up audit. FSC auditors are required to disclose a public summary report with the audit results and FSC certificates are issued for five years with annual inspections (Meidinger 2006).

FSC certification of forest management is thus a complex and time consuming process.

Companies that sell FSC certified products can also obtain FSC Chain of Custody certification, which aims to ensure that certified forest products that undergo stages of processing, manufacturing, and distribution are kept separate from non-certified and non-controlled materials across the supply chain. FSC certified products can be mixed with non-certified products as far as these are originated from "controlled sources". FSC "controlled sources" include forest products that were not illegally harvested, were not harvested from forests being converted to plantations or from high conservation value forests (see below) (www.fsc.org). FSC has a standard of "controlled sources" defining standards for non-FSC certified material that can be used in FSC mixed products. This enables manufacturers and traders to avoid timber and non-timber forest products originated from uncontrolled sources.

Contrary to other conservation mechanisms such as protected areas, FSC certification is a voluntary mechanism, meaning that landowners can choose to adhere or leave certification at any moment. Currently, FSC certification covers 183 million hectares of forests across 79 countries: 45% in Europe, 39% in North America, 7% in South America and the Caribbean, 5% in Asia, 3% in Africa and 1% in Oceania including broadleaved and evergreen conifer forests and plantations, both in northern and southern hemispheres (FSC 2014).

2.2 The Program for the Endorsement of Forest Certification (PEFC) and other certification schemes

The creation of FSC certification was followed by the creation of a number of competing certification programs, backed by the forest industry and landowner associations, both in Europe and North America. Industry and landowners claimed that FSC standards were too intrusive and stringent and argued that those actors implementing sustainable forest management should develop certification standards themselves (Cashore et al. 2004; Gulbrandsen 2005). In 1998 and 1999 several European forest associations started establishing landowner-dominated programs at the national level and, in 1998, created the Pan-European Forest Certification Scheme (PEFC). PEFC aimed to facilitate mutual recognition of national forest management programs and to provide forest products with a common label (Gulbrandsen 2010). In 2003 PEFC was restructured, became a global organization and its name was changed to Program for the Endorsement of Forest Certification, keeping former acronym. PEFC is composed by a council of national governing bodies primarily representing forest owner associations and other forestry organizations whose task is to approve national schemes if they comply with the criteria, indicators and rules of the PEFC umbrella. Whereas FSC is a global forest certification scheme with a single set of principles and criteria, PEFC is a mutual recognition framework that endorses national certification schemes on the basis of certain requirements, focused mostly on forest management issues, which are reviewed by a panel of experts and a PEFC General Assembly. PEFC does have a set of basic requirements for national level certification programs and many of the specific requirements for forest operations are left to the discretion of national member programs (Gulbrandsen 2004; Auld et al. 2008). Presently, PEFC certification covers 265 million hectares across 39 countries, 59% in North America, 33% in Europe, 4% in Oceania, 2% Asia and 2% in Central and South America also covering broadleaved and evergreen and conifer forests and plantations (PEFC 2014). However, contrary to FSC certification, PEFC has very little implementation in tropical regions.

In the United States of America and Canada, besides FSC and PEFC, a number of smaller producer-backed certification schemes were also created. An example is the Sustainable Forestry Initiative (SFI), backed by the American Forest and Paper Association and the American Tree Farm System (ATFS), which aims to provide a certification option for smaller non-industrial landowners in the USA. These certification schemes were endorsed by PEFC in 2005 and 2008, respectively, but cover relatively small areas of forest in North America (Gulbrandsen 2010).

3. Forest Stewardship Council certification and the conservation of biodiversity and ecosystem services

FSC certification is considered by the largest environmental non-governmental organizations in the world (WWF, Greenpeace and The Nature Conservancy) as the most credible forest certification scheme (Auld et al. 2008; Gulbrandsen 2010). FSC certification addresses the conservation of biodiversity and ecosystem services in Principle 6 ‘‘Environmental Impact’’ and Principle 9 ‘‘Maintenance of High Conservation Value Forests’’ of its management standards. Principle 6 states that ‘‘forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes’’ Whilst Principle 9 states that ‘‘management activities in high conservation value forests shall maintain or enhance the attributes which define such forests’’ (Auld et al. 2008; www.fsc.org).

Principle 6 requires the creation of conservation zones and protection areas within forest management units to protect rare or endangered species or habitats and natural resources, such as water and soil. The size of conservation zones is variable but should be appropriated to the scale and intensity of forest management and the characteristics of the affected resources (Tollefson et al. 2009). Activities that may jeopardize the conservation of species or habitat are not allowed or heavily restricted in conservation zones.

Principle 9 addresses the maintenance of high conservation value forests (HCVF), which are “areas containing biological, ecological, social or cultural values of outstanding significance or critical importance” (e.g. Senior et al. 2014). HCVF are characterized by six conservation attributes addressing biodiversity values and ecosystem services, including cultural services provided by forest management units. HCVF 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 high conservation attributes” (www.hcvnetwork.org). HCVF attributes are used to classify forests according to their value for biodiversity and ecosystems services and cultural significance, as well as on their role in fulfilling the needs of local communities (see Table 1 for a full description of attributes). In countries where FSC certification exists a National or Regional Interpretation of HCVF adapts this framework to the specificities of regions or countries. This Interpretation results from a public participation process that includes a variety of stakeholders such as farmers, forest associations, industry representatives, public administration bodies and non-governmental associations, during which a set of criteria and indicators for identifying HCVF is developed.

4. Effects of forest certification on the conservation of biodiversity and ecosystem services

Forest certification (FSC, PEFC and other certification schemes) has been implemented on the ground for almost 20 years, presently covering over 10% of forests in the world (FAO 2010, FSC 2014, PEFC 2014). Despite its expansion and although several authors have argued that forest certification positively affects biodiversity conservation (e.g. Bennett 2001; Gullison 2003; Putz et al. 2012) there are still surprisingly few studies quantifying the effects of forest certification on the conservation of forest ecosystems.

Of the two main certification schemes, PEFC and FSC, FSC is considered to have more stringent environmental criteria (Cashore et al. 2004; Auld et al. 2008). In 2006, WWF in collaboration with the World Bank, created a Forest Certification Assessment Guide (FCAG) meant to evaluate the effectiveness of forest certification schemes (WWF/World Bank 2006). In 2009, PEFC and FSC were evaluated with respect to the requirements of the FCAG, and it was concluded that FSC was the scheme that best met core conservation requirements of WWF (Walter 2009). The same study considered that PEFC lacked transparency in decision-making and reporting, was not being able to demonstrate improvements on the ground and did not attempt to exclude timber and non-timber forest products from forests converted to other land-uses (Walter 2009). Contrary to FSC, PEFC is mainly focused in forest management pursuing flexible and sometimes discretionary management standards (Cashore et al. 2004). FSC certification has a relatively strict set of management standards that address environmental, social and economic issues. Possibly because of this, the limited scientific literature assessing the effects of certification on forest conservation is mainly focused on FSC certification (e.g. Bennett 2001, Putz 2012). There are no studies available in the scientific literature on the impact of PEFC certification on forest ecosystems. Less than 10% of FSC certified forests are located in tropical regions (FSC 2014), but most published studies on the effects of FSC certification on forest ecosystems were conducted in the tropics. A study conducted in Gabon reported that reduced impact logging, which was implemented with FSC certification, caused lower losses of above-ground biomass and lower changes in tree species composition when compared to conventionally logged areas (Medjibe et al. 2013). A study in Indonesia found that certified forests attained tree densities similar to those of primary forests only ten years after logging (Arbainsyah et al. 2014). Also, a report by van Kuijk et al. (2009) reviewed a total of 67 studies, mostly conducted in the tropics, to evaluate the hypothesis that forest biodiversity in well-managed forest management units (including certified management units) is higher or more intact (e.g. higher species richness) than in similar but conventionally managed areas. These authors found that, in general, good forest management practices commonly associated with forest certification appear to benefit biodiversity in certified managed forests. Putz et al. (2012) conducted a meta-analysis based on over 100 studies across tropical regions which revealed that in selectively logged FSC certified forests, harvested stands retain about 76% of their above-ground carbon and 85–100% of species of mammals, birds, invertebrates and plants remain after logging.

In the northern hemisphere, where over 85% of FSC certified forests are located, there is a dearth of information on the ecological effects of forest certification. There is only one published study on this (Elbakidze et al. 2011), conducted in boreal forests of Russia and Sweden. These authors showed that Russian certification standard included indicators for all spatial scales of biodiversity conservation, from tree and stand to landscape and ecoregions, while the Swedish standard focused mainly on stand and tree scales. They also compared areas of formally and voluntarily set aside forests for biodiversity conservation and evaluated their structural habitat connectivity. The area of voluntary set-asides for FSC was similar in Sweden and Russia, while formal protection in the Russian case study was three times higher than in the Swedish one. Swedish set-aside core areas were two orders of magnitude smaller, had much lower structural and potential functional connectivity and were located in a fragmented forestland holding (Elbakidze et al. 2011).

The effects of FSC certification on ecosystem services have also been rarely evaluated and are still poorly understood. Ioras et al. (2009) mentioned that the implementation of FSC certification in Bosnia and Herzegovina, and Romania caused forest managers to evaluate the impacts of forestry on ecosystem services such as regulation services (e.g. erosion prevention) and cultural services without however, formal quantification of its impacts. FSC is currently developing an ecosystem services strategy for assuring that certificate holders have access to emerging ecosystem services markets. This strategy, planned to be completed by the end of 2015, aims to strengthen the incentives for responsible forest management (FSC 2015).

Table 1 – Criteria and description of High Conservation Value Forests (adapted from Brown et al. 2013)

HCVF 1 - Concentrations of biological diversity including endemic species, and rare, threatened or endangered species, that are significant at global, regional or national levels.	HCVF 1.1 - Protected areas, that are a proxy for concentrations of biodiversity.
	HCVF 1.2 - Areas where Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) (following the criteria of the International Union for the Conservation of Nature).
	HCVF 1.3 - Areas where endemic species occur.
	HCVF 1.4 - Areas where seasonal concentrations of species occur, including seasonal breeding sites, migration routes or corridors.
HCVF 2 - Large landscape-level ecosystems and ecosystem mosaics that are significant at global, regional or national levels.	Areas that harbor viable populations of the great majority of the naturally occurring species in natural patterns of distribution and abundance.
HCV 3 - Rare, threatened, or endangered ecosystems, habitats or refugia.	Areas that include ecosystems, habitats or refugia of special importance because of their rarity or the level of threat that they face or their rare or unique species composition or other characteristics.
HCV 4 – Ecosystem services	Basic ecosystem services in critical situations, such as the protection of water catchments and control of erosion of vulnerable soils and slopes.
HCV 5 - Community needs	Sites and resources fundamental for satisfying the basic needs of local communities or indigenous peoples (for livelihoods, health, nutrition or water), identified through engagement with these communities or indigenous peoples.
HCV 6 - Cultural values	Sites, resources, habitats and landscapes of global or national cultural, archaeological or historical significance, and/or of critical cultural, ecological, economic or religious/sacred importance for the traditional cultures of local communities or indigenous peoples, identified through engagement with these local communities or indigenous peoples.

5. Forest certification in Mediterranean forests and woodlands

The area of FSC certified forests and woodlands in the Mediterranean Basin has sharply increased over the past years, covering more than four million hectares of plantations and natural forests (FSC 2014). In Portugal, for example, area of certified forests is approximately 300 thousand ha including Eucalyptus plantations or woodlands such as cork oak (*Quercus suber*) with over 100 thousand certified ha (15% of total cork oak cover in the country) (FSC 2014). Little is known, however, on the effects of FSC certification on the conservation of cork oak woodlands.

5.1 Cork oak woodlands

Cork oak woodlands are, structurally, a savanna type silvopastoral systems that occur in the western Mediterranean Basin, covering 1.5 million hectares in southwestern Europe and 1 million hectares in North Africa (Figure 1). This system is characterized by a sparse tree cover (30–60 trees/ha) of cork (*Quercus suber*) or other evergreen oaks (e.g. *Quercus rotundifolia*) and pine trees (e.g. *Pinus pinea*, *Pinus pinaster* Aiton). Cork oak is a long-lived tree, native to the western Mediterranean Basin that occurs in regions with an average annual precipitation above 600 mm and average temperatures near 15°C (Tenorio et al. 2005).

Cork oak usually grows in acidic soils on granite, schist, or sandy substrates or, more rarely, in limestone-derived soils or in neutral soils overlying dolomitic bedrocks (Serrasolses 2009). Presently, cork oak shows a non continuous distribution from Morocco and the Iberian Peninsula to the western rim of the Italian peninsula. It also occurs on Corsega and Sardinia, and in scattered parts of southern France and some coastal plains and hilly regions of Morocco, Algeria, and Tunisia (Tenorio et al. 2005; Pausas et al. 2009).

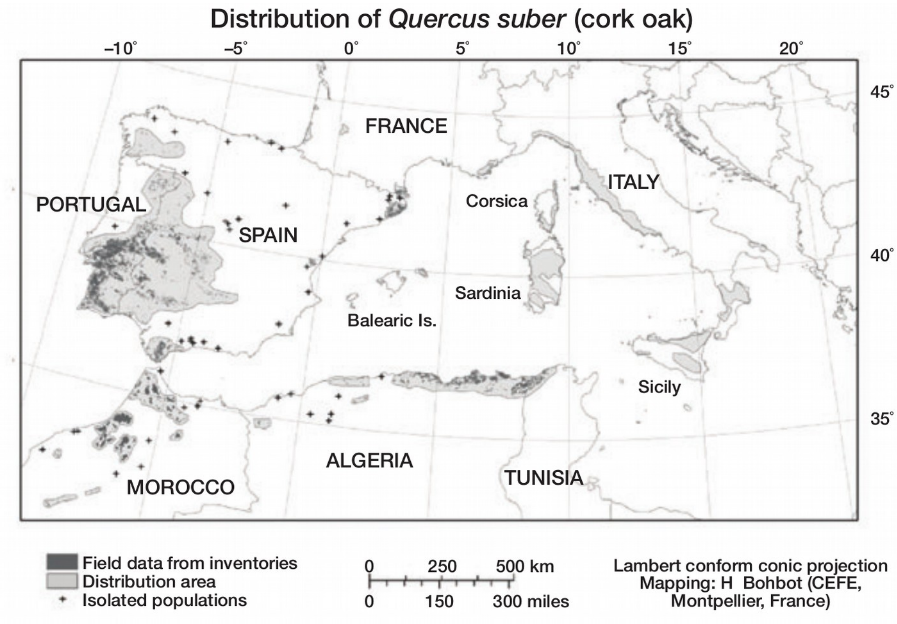

Figure 1 - Distribution of cork oak in the western Mediterranean Basin from Aronson et al. (2009b).

The understory of cork oak woodlands is composed of a diverse mix of sclerophyllous shrub species (e.g. rockroses *Cistus* spp, gorse *Ulex spp* basil-leaved rock rose *Hallimium ocymoides Willk.,* topped lavender *Lavandula stoechas* and rosemary *Rosmarinus officinalis)*, interspersed with annual grasslands (e.g. *Agrostis* spp, *Avena* spp, *Bromus* spp.), pastures, fallows and cereal crops (Bugalho et al. 2009). Encroaching shrubs are usually cleared at intervals of 4-7 years to reduce the risk of severe wildfires and to promote the establishment of pastures or annual crops (Bugalho et al. 2011b). This habitat rotation creates a dynamic mosaic of habitats of high conservation value (Díaz et al. 1997).

The main sources of income in cork oak woodlands are cork and livestock production. Cork, the bark of the oak tree, is a non-timber forest product, harvested each 9 to 12 years without felling the trees. Cork is mainly used for wine bottle stoppers (over 70% of the production) worldwide, but other applications include flooring, clothes, decoration and thermal insulation materials (e.g. it is used to isolate the fuel tanks of NASA's space shuttles) (Mendes and Graça 2009). Cork is the sixth most important non-timber forest product in the world with an estimated annual export value of 1.229 million euros in 2010. Portugal is the country with the largest area of cork oak (approximately 736 thousand ha) and the largest cork producer with 61.3% of the global production (APCOR 2011).

5.2 Biodiversity of cork oak woodlands

The heterogeneity and wide variety of habitats that coexist in cork oak woodlands support a high diversity of animal and plant species. These include endemic vertebrate species to the Iberian Peninsula such as: the Cabrera's vole (*Microtus cabrerae*), the Iberian midwife toad (*Alytes cisternasii*), the Iberian painted frog (*Discoglossus galganoi*) and the Bedriaga's skink (*Chalcides bedriagai*). Cork oak woodlands are also a key habitat for several migratory and overwintering birds, such as the 70 000 Eurasian cranes (*Grus grus*) and 6 million wood pigeons (*Columba palumbus*) that visit the Iberian Peninsula every year (Díaz et al. 1997). Several critically endangered species including the Iberian imperial eagle (*Aquila adalberti*), the Eurasian black vulture (Aegypius monachus) and the Iberian lynx (*Lynx pardinus*) use cork oak woodlands (Díaz et al. 1997; Cabral et al. 2006; Equipa Atlas 2008; Loureiro et al. 2008; Catry et al. 2010). In relation to vascular plant species, more than 135 species have been found per 0.1 ha (Díaz-Villa et al. 2003).

Freshwater habitats are also an important component of cork oak woodlands. As in other Mediterranean ecosystems, streams and rivers play an important role in shaping and structuring the landscape by supporting a wide variety of biotic assemblages in a seasonally water-stressed environment (Gasith and Resh 1999; Naiman 2005). Streams and riparian areas often support dense, productive and biodiversity rich forest habitats, which are very distinguishable from the adjacent habitats. Freshwater habitats usually have high levels of plant diversity (Gasith and Resh 1999; Santos 2010) and are important habitat for mammalian carnivores (Matos et al. 2009). Freshwater systems in montados also harbor several threatened species of fish, such as the critically endangered river lamprey *Lampetra fluviatilis* (recently described by Mateus et al. 2013) or the endangered cyprinid *Iberochondrostoma lemmingii* (Cabral et al. 2006). Frequently, freshwater habitat types provide a distinct assemblage of species from the surrounding matrix which increases habitat heterogeneity at the landscape level (Gasith and Resh 1999).

5.3 Conservation threats in cork oak woodlands

Despite of a recent increase in reforestation programs, the density of cork oak trees has been decreasing (Pulido et al. 2010; Bugalho et al. 2011a) mainly because of high adult oak mortality and low tree regeneration (Branco and Ramos 2009; Pausas et al. 2009; Plieninger et al. 2010).

Pests and diseases, such as the root fungus (*Phytophthora cinnamomi*), weevils (e.g., *Curculio elephas*), beetles (e.g. *Coroebus undatus*) and moths (e.g., *Cydia* spp.) reduce oak crown cover, acorn production and seedling survival also affecting the quality and quantity of produced cork (Branco and Ramos 2009). For instance, the larvae of *C. undatus* feed under the bark of the tree trunk, excavating galleries in the cambium, where the new cork tissue is formed negatively affecting cork production (Merle and Attié 1992).

Over the last few decades a decrease in the regeneration of cork and holm oak coupled with an increase in the susceptibility of both species to pests and diseases, has been observed throughout the western Mediterranean (e.g. Gallego et al. 1999). Different studies suggest that intensive management practices, such as overgrazing or frequent shrub clearing with heavy machinery, combined with growing aridity are increasing the vulnerability of oak species to pests and diseases and increasing their mortality rates (e.g. Branco and Ramos 2009; Serrasolses et al. 2009).

Shrub clearing is a common management practice in cork oak woodlands conducted to reduce the risk of severe wildfires. Forest wildfires are a major concern in the Mediterranean Basin, particularly in Portugal and Spain. Over 400 000 hectares of forest and shrublands burned in Portugal during 2003 and 2005. This area included over 60 000 hectares of cork oak woodlands (Silva and Catry 2006). Frequent use of heavy machinery (e.g. heavy plows and disc harrows) to reduce vegetation fuel loads and control shrub encroachment is a common practice that became widespread in the 20th century (Pinto Correia and Fonseca 2009). Intensive use of heavy machinery may also destroy oak regeneration and oak's superficial roots, mobilize the soil excessively with consequent reduction of soil organic matter and expose the soil to higher wind and water erosion (Pausas et al. 2009; Serrasolses et al. 2009).

Livestock production is an important source of income in cork oak woodlands (Aronson et al. 2009a). Grazing also contributes for maintaining the open savanna structure of the system and control shrub encroachment (Aronson et al. 2009a; Bugalho et al. 2011a). At moderate levels grazing enhances habitat heterogeneity at the local and estate level (Bugalho et al. 2011b) and contributes to maintain grassland diversity (Veldman et al. 2015). Overgrazing, however may negatively impact oak regeneration. In Portugal and Spain cattle grazing has been heavily subsidized on a per-head basis by the Common Agricultural Policy (CAP) of the European Union (Bugalho et al. 2011a). Although livestock production is a crucial source of income in several cork oak woodlands, these policies may have encouraged overgrazing in some regions, which may have contributed to reduce seedling and sapling survival (Bugalho et al. 2006; Pausas et al. 2009; Pulido et al. 2013).

Overgrazing may also negatively affect species richness of shrublands and riparian habitats (Belsky et al. 1999; Campos et al. 2007). Indeed long-term grazing pressure may reduce shrub cover and the species richness of the soil seed bank and, consequently, the species richness of the above ground vegetation (Chaideftou et al. 2009). These effects, however, vary with animal species (e.g. cattle, sheep, deer) and systems. For example, in the semi-arid grasslands of Arizona (USA), overgrazing by cattle can induce shrub encroachment as the consumed grassland species lose their competitive ability against shrub species (Browning and Archer 2010). As for riparian habitats, overgrazing reduces the cover and continuity of the riparian vegetation, causing erosion of the stream banks and increasing the quantity of sediments entering the water (Belsky et al. 1999; Naiman 2005). This can also negatively affect the water quality and the stream channel morphology (Belsky et al. 1999; Stella et al. 2013).

5.4 The socio-economic context

Most cork woodlands are privately owned in the Iberian Peninsula, 96.4% in Portugal and 91% in Spain (Diaz-Fernandez et al. 1995; APCOR 2011). Changes in rural socio-economic conditions may have important effects on the conservation of cork oak woodlands (e.g.Bugalho et al. 2009; Godinho et al. 2014). In Mediterranean Europe the active rural population, i.e., economically active persons engaged in agriculture, hunting, forestry or fishing has steadily declined over the past decades (Bugalho et al. 2011, http://faostat.fao.org/). This has led to lack of management and abandonment of several agricultural and silvopastoral systems. Abandonment of silvopastoral systems such as cork oak woodlands induces shrub encroachment and increases the risk of severe wildfires (e.g. Aronson et al. 2009a; Bugalho et al. 2011a). Shrub encroachment can cause cork oak woodlands to fall in a cycle of arrested succession, under which tree regeneration is halted by low seed availability, lower rates of scatter-hoarding, high rates of post-dispersal seed predation, low rates of germination and high seedling mortality (Acácio et al. 2007).

The main source of income incentivizing management and maintenance of cork oak woodlands is cork production (Mendes and Graça 2009; APCOR 2011). Between 2003 and 2008 the world cork market prices declined 30 % mainly due to the economic crisis and competition with metal screw caps and synthetic bottle stoppers (Mendes and Graça 2009). Lower cork prices may also disincentive management and conservation of cork oak woodlands. Finding mechanisms that provide incentives for the sustainable use and conservation of cork oak woodlands is thus a key issue when tackling the conservation of these systems.

5.5 Other ecosystem services provided by cork oak woodlands: long-term carbon storage, water regulation and protection against soil erosion

Ecosystem services are the benefits that people obtain from nature (Millenium Ecosystem Assessment 2005). Cork oak woodlands provide a number of ecosystem services such as livestock production, crops, cork, firewood, hunting, recreation or mushroom gathering (Bugalho et al. 2011). The cork oak ecosystem generates regulating ecosystem services such as long-term carbon storage, control of soil erosion or watershed protection (Berrahmouni et al. 2009; Branco et al. 2010; Bugalho et al. 2011a). Effective delivery of these services however depends on management.

As other savanna type ecosystems, cork oak woodlands accumulate and maintain carbon stocks for extended periods of time (Ciais et al. 2008). For instance, cork oak woodlands with an average tree cover of 30% can sequester up to 140 g C/m^2/year (Pereira et al. 2007), a value close to that found in oak savannas of California (Baldocchi et al. 2004) and close to the range estimated for old growth forests (Ciais et al. 2008). Cork harvest only represents 4% of the total biomass produced between successive cork extractions (Pereira unpublished), which has a negligible effect on sequestered carbon. Management affects carbon storage of the system. Both over- and under-use can affect the carbon balance. In overused systems, lack of tree regeneration and adult tree mortality will reduce carbon stocks (Tiessen et al. 1998). Conversely, in under-used, not managed cork oak woodlands, shrub encroachment may shift carbon storage from below ground to above ground plant biomass. This may increase the risk of carbon losses through wildfires (Jackson et al. 2002). Shrub encroachment due to lack of management and abandonment may also facilitate severe crown fires, increasing carbon emissions in the short term and reducing carbon sequestration in the long through reduced tree growth (Murphy et al. 2010).

Adequate forest management has also positive impacts on the hydrological cycle and water resources. Water availability is a pressing issue in Mediterranean climate regions especially given projections for future climate change (Giorgi and Lionello

2008). In California, Mediterranean oak woodlands functionally similar to cork oak woodlands play a critical role in water supply, providing runoff from winter rainfall events. These oak woodlands host two-thirds of California drinking water reservoirs (O'Geen et al. 2010). For example, a study conducted in Sonoma, California, showed that oak woodlands, with a tree cover of 40 to 60%, consumed on average as much ground water as irrigated vineyards in a year (Grismer and Asato 2012). However, vineyard groundwater consumption was 3.5 times higher than that of oak woodlands in late summer to early fall, which could further stress groundwater resources during droughts (Grismer and Asato 2012). Also, studies conducted in Mediterranean oak woodlands of Portugal and Spain found positive effects on water resources. In Extremadura, Spain, it has been shown that cork and holm oak cover on hill slopes decreases surface water runoff and promotes water infiltration particularly under the oak canopies, as compared to open areas, by intercepting on average 26.7% of the total precipitation (Schnabel 1997; Rodríguez and Schnabel 1998). Research in Southern Portugal and Spain also found that cork oak cover affects availability of groundwater. For instance, it has been estimated in a cork and holm oak woodland of southern Portugal that the yearly groundwater contribution to oak transpiration is 30.3% (Pinto et al. 2014). This value can reach 70% during drought season (David et al. 2007; Pinto et al. 2014). Effects of cork oak cover and management in water resources, particularly in Portugal, becomes more evident when considering cork oak covers approximately 36% of that the main aquifer of the country (Branco et al 2010).

Soil protection is another important service provided by well managed cork oak woodlands. Cork oak woodlands typically occur in areas of shallow soils and low fertility (Serrasolses et al. 2009). Some of these areas also have a history of over-use due to overgrazing or intensive agriculture (e.g. Pinto-Correia and Fonseca 2009). For instance, from 1929 until the early 1960s, extensive areas in the south of Portugal were cultivated for wheat, following a government policy known as the Wheat Campaign, which aimed to provide food safety to the country and which strongly subsidized wheat production (Pinto-Correia and Vos 2004). Following an intensive use for wheat cultivation soil fertility decreased and susceptibility to soil erosion increased in several regions of Portugal (Pinto-Correia and Vos 2004). Well managed cork oak woodlands, namely with high canopy cover, contribute to protect soil against erosion (Berrahmouni et al. 2009). For example, a study conducted in Extremadura, Spain, showed that during exceptionally high intensity storms, soil losses on holm oak woodlands with a canopy cover of 60% were below of 0.3 ton/ha whilst in areas with a 20% canopy cover soils losses were 2 ton/ha (Schnabel et al. 2009). As a consequence, management practices favoring oak canopy cover, long term shrub clearings (4 to 7 years) conducted with light machinery and the maintenance of plant cover in steeper slopes may contribute to prevent soil erosion.

5.6 Can FSC certification benefit the conservation of cork oak woodlands?

As a result of an increasing demand for FSC certified products in the international markets, Corticeira Amorim, the world's largest cork supplier, based in Portugal, applied for FSC certification for its supply chain in 2007. Following this decision, cork oak producers in Portugal also engaged in FSC certification (Berrahmouni et al. 2009; Bugalho et al. 2011a). Certification was further encouraged by the cork industry that started paying a premium of 0.5 euros per 15 kg of FSC certified cork (APCOR 2011). In 2011 and 2012, during the global financial crisis, certified cork (as compared to non-certified cork) had priority access to markets. One of the main cork oak producer associations in Portugal, "Associação de Produtores Florestais de Coruche", reported in 2011 that, contrary to non-certified cork, all certified cork was sold (Conceição Silva, personal communication). These findings suggest that FSC certification may bring economic benefits to the cork industry and pressure cork oak producers to generate certified cork.

It remains to be seen, however, if and how FSC forest management standards may positively affect the conservation of cork oak woodlands. In Portugal, FSC certification currently covers over 100 000 hectares of cork oak woodlands (approximately 15% of total cork oak cover of the country) however, as for other forest ecosystems, little is known on the effects of FSC certification on the conservation of these ecosystems.

The present thesis sets a path to provide answers to this question.

6. Thesis aims and objectives

The main aim of the present thesis was to assess the effects of FSC forest certification on the conservation of cork oak ecosystems of southern Portugal.

Specific objectives were:

1) To assess if FSC certified areas within the distribution of cork oak woodlands in southern Portugal coincide with areas of high biodiversity (Chapter 2).

2) To assess if FSC certification positively affects the ecological condition of Mediterranean streams crossing certified cork oak woodlands (Chapter 3).

3) To investigate if FSC conservation areas promote oak regeneration and understory shrub diversity in cork oak woodlands (Chapter 4).

4) To exemplify the use of the High Conservation Value Forests framework to identify regions within cork oak distribution in southern Portugal that are simultaneously important for the conservation of biodiversity and ecosystem services and that should be prioritized for the implementation of certification or other conservation mechanisms.

7. Synopsis of the main results

A brief synopsis of main findings of the thesis is presented here.

7.1 Chapter 2

In this Chapter, published in Biodiversity and Conservation it was shown that FSC certification has expanded in cork oak woodlands (covering 90 000 hectares in 2012) and that this area is concentrated in the Portuguese regions of northern Alentejo and in the municipalities of Chamusca, Coruche, Mora, Ponte de Sôr, Montemor-o-Novo. These are regions with relatively favorable socio-economic contexts with above average estate size and cork production. It could be concluded that the biodiversity value of certified areas in terms of birds, reptiles and amphibians was not significantly higher than that of non-certified areas. Therefore, it would be important to encourage FSC certification in areas of high biodiversity. In Portugal there are governmental funds supporting costs of forest certification (e.g. Permanent Forest Fund - http://www.icnf.pt/portal/fundos/fundo-florestal-permanente), that could be used to incentivize certification of cork oak woodlands of high biodiversity value.

7.2 Chapter 3

Results of this chapter (published in the Journal of Applied Ecology) suggest that FSC certification positively affects the ecological condition of the riparian vegetation of stream reaches located in cork oak woodlands. These effects are only measurable after five years of certification. After this period, the condition of the reaches located in certified areas is similar to that of reaches located in least disturbed and well-conserved sites. Streams and riparian zones in certified areas are usually integrated into FSC certified conservation zones where livestock grazing and shrub clearings are not allowed or heavily reduced. Control of grazing and shrub clearing may have allowed the recovery of the riparian vegetation. The improved condition of the riparian vegetation also created more habitats types for aquatic invertebrates and fish and stabilized stream banks. These results suggest that FSC certification promotes the conservation of riparian vegetation, reduces river bank erosion and can improve the availability of micro-habitats at the stream reach scale.

7.3 Chapter 4

In this Chapter (submitted for publication) it was shown that the establishment of FSC conservation zones increases cork oak regeneration (higher abundance of seedlings and saplings) and species richness and diversity of understory shrubs. These results may be partially explained by lower livestock grazing and less frequent shrub clearings, conducted with light machinery in FSC conservation zones.

7.4 Chapter 5

In this chapter (published in Agroforestry Systems) the High Conservation Value framework of FSC certification was combined with Pareto optimality for identifying areas within the distribution of cork oak in Portugal that are important for the conservation of biodiversity and ecosystem services. Areas that maximize number of threatened species of birds and reptiles, as well as carbon storage and aquifer water recharge rates were identified. It was also identified the subset of regions in which species richness of birds and reptiles, carbon storage and aquifer recharge rate have values above the correspondent averages. These results suggest that there are regions within the main area of cork oak distribution in Portugal where promoting sustainable forest management through forest certification (or other conservation schemes) may simultaneously favour the conservation of biodiversity and ecosystem services.

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Chapter II - Is forest certification targeting areas of high biodiversity in cork oak savannas?

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Is Forest Certification Targeting Areas of High Biodiversity in Cork Oak Savannas?

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1. Abstract

Over the last four decades the world has been losing biodiversity at an alarming rate despite the increasing number of protected areas (PAs). Certified forest management may complement the role of PAs in protecting biodiversity. Forest certification aims to promote sustainable forest management and to maintain or enhance the conservation value of certified forests. The area of forest under certified forest management has grown quickly over the past decade. Forest Stewardship Council (FSC) certification, for example, currently covers 148 million hectares, i.e., 3.7% of the world's forests. In spite of such increase there is, however, a dearth of information on how forest certification is related to biodiversity. In this study we assessed if FSC certification is being applied in high biodiversity areas in cork oak savannas in Portugal by comparing biodiversity values of certified and non-certified areas for birds, reptiles and amphibians. We calculated the relative species richness and irreplaceability value for each group of species in certified and non-certified areas and compared them using randomization tests. The biodiversity value of certified areas was not significantly greater than that of non-certified areas. Since FSC certification is expanding quickly in cork oak savannas it is important to consider the biodiversity value of these areas during this process. Prioritizing areas of high biodiversity value would enhance the conservation value of forest certification and facilitate integrating certification with other conservation initiatives.

Keywords: Forest management, Biodiversity conservation, Conservation strategies, Mediterranean, Species richness, Irreplaceability.

2. Introduction

Over the last four decades the world has been losing biodiversity at an alarming rate, despite increasing conservation efforts (Butchart et al. 2010; Pereira et al. 2010). Protected areas (PAs) have long been the cornerstone of biodiversity conservation strategies worldwide, covering now 12.9% of the terrestrial surface (Jenkins and Joppa 2009). However, this strategy has been insufficient to prevent biodiversity loss (CBD 2010) mainly due to conflicts with human activities (Loucks et al. 2008; Joppa and Pfaff 2009).

In 2050, the human population is expected to reach 9000 million and resource consumption to increase considerably (UNEP 2011; Tilman et al. 2011). This will exert further pressure on biodiversity conservation and therefore it is crucial to find effective ways of reconciling sustainable production and biodiversity conservation (Shahabuddin and Rao 2010; Miller et al. 2011).

Forest certification is a conservation tool that 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 is based on third-party auditing of compliance with environmental and socio-economic standards, developed by governmental actors, environmental non-governmental organizations, industry associations, and social groups through participatory public processes. Forest certification relies on the willingness of a growing number of consumers to pay more for sustainably generated products and it aims to reward forest managers that follow sustainable forest management practices (Brown et al. 2001; Auld et al. 2008; Suzuki and Olson 2008).

The first steps towards the creation of sustainable forest certification were taken after the 1992 United Nations Conference on Environment and Development (UN CED), when governments failed to commit on a legally binding global forest management agreement that ensured the sustainable management of tropical forests (Humphreys 2009). Forest Stewardship Council (FSC) certification was created in 1993 to "promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests" (Auld et al. 2008) www.fsc.org).

FSC certification comprises 10 principles and 57 criteria that cover environmental, social and economic aspects of forest management. Biodiversity conservation is addressed by Principle #6 "Environmental Impact" and by Principle #9 "High Conservation Value Forests". Principle #6 states that "forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes". Principle #9 states that "management activities in high conservation value forests shall maintain or enhance the attributes which define such forests" ((Auld et al. 2008); www.fsc.org).

The area under FSC certification has grown quickly over the last decades and now covers 148 million hectares (Forest Stewardship Council 2014), representing 3.7% of the world's forests (www.fao.org). FSC certification has had a positive effect on biodiversity conservation, both in tropical (Azevedo-Ramos et al. 2006) and temperate forests (Gullison 2003; Gulbrandsen 2004; Ioras et al. 2009; Elbakidze et al. 2011). However less is known for Mediterranean type forests, where currently there are 4 million ha of FSC certified forests. Specifically it is not known if FSC certification is occurring in areas of high biodiversity value and thus contributing to the sustainable management and conservation of these areas.

Mediterranean cork oak savannas are silvopastoral systems (hereafter cork oak savannas) typically of the West Mediterranean Basin which may have resulted originally from the transformation of dense cork oak forests through cattle grazing, shrub clearing, human induced fires and, more recently, through reforestation

(Berrahmouni et al. 2009; Pinto-Correia and Fonseca 2009). They form multiple-use systems where cork and livestock production are dominant activities, that when properly managed have both economic and conservation value (Bugalho et al. 2011).

Cork oak savannas cover approximately 1.5 million hectares in southwestern Europe and 1 million hectares in North Africa (Pausas et al. 2009). This system is characterized by a sparse tree cover (30-60 trees per hectare) of cork oak, solely or mixed with other evergreen oaks (e.g. *Quercus rotundifolia*) or pine trees (e.g. *Pinus pinea*), and an understory of shrub species (e.g. *Cistus sp. pl.*) interspersed with grasslands, fallows and sometimes cereal crops (Bugalho et al. 2009). The heterogeneity and wide variety of habitats that coexist within these ecosystems supports a high diversity of animal and plant species. For instance, more butterfly and passerine bird species can be found in cork oak savannas than in adjacent closed-canopy oak woodlands, grasslands or croplands (Diaz et al. 1997). Also, more than 135 species of vascular plants can be found per 0.1 ha of cork oak savanna, including a high diversity of shrub species (Díaz-Villa et al. 2003).

Cork oak savannas support a high diversity of birds, mammals, amphibians and reptiles, many of which are endemic to the Iberian Peninsula, such as the Cabrera's vole (*Microtus cabrerae*), the Iberian midwife toad (*Alytes cisternasii*), the Iberian painted frog (*Discoglossus galganoi*) or the Bedriaga's skink (*Chalcides bedriagai*). Cork oak savannas are also a key habitat for several migratory and overwintering birds, such as the 70,000 Eurasian cranes (*Grus grus*) and the 6 million wood pigeons (*Columba palumbus*) that annually visit the Iberian Peninsula (Diaz et al. 1997) and for several critically endangered species such as the Iberian imperial eagle (*Aquila adalberti*), the Eurasian black vulture (*Aegypius monachus*) and the Iberian lynx (*Lynx pardinus*) (Diaz et al. 1997; Cabral et al. 2006; Equipa Atlas 2008; Loureiro et al. 2008; Catry et al. 2010).

FSC certification has been implemented in cork oak savannas in Portugal, which is the country with the largest area of cork oak cover, 716,000 ha. Forest certification schemes such as FSC may complement the role of other regulatory tools for conservation currently implemented in Portugal, including PAs which cover 1.69% of cork oak savannas and the Natura 2000 network – a Pan European network of protected areas – which covers 26% of cork oak distribution (cork oak savannas are a “classified habitat” under Natura 2000). Also, farmers located in the Natura 2000 network can benefit from the Agri-environmental schemes of the Common Agricultural Policy of the European Union, which are a set of payments for farmers developed to favor sustainable agricultural practices in these areas (Bugalho et al. 2011).

The main source of income in cork oak savannas is cork production, 70% of which is used to make wine bottle stoppers. Since 2003 cork market prices have declined 30% due to the economic crisis and competition with metal screw caps and synthetic stoppers (Mendes and Graça 2009). Portugal is the world's largest cork producer, with 49.6% of the world's production, followed by Spain with 30% (Mendes and Graça 2009). Since 2007, cork oak landholders and producers in Portugal started certifying cork production according to FSC standards, in an attempt to reclaim market share, and as response to the global market demand for FSC certified cork (Berrahmouni et al. 2009; Bugalho et al. 2011). As of June of 2011 there were over 100 000 hectares of FSC certified cork oak savannas in the Mediterranean, 90 000 of which in Portugal, 9 940 ha in Spain and the remaining area in Italy (www.info.fsc.org). In spite of such expansion there still is little information about how FSC certification is related to areas of high biodiversity value.

We addressed this issue by comparing the biodiversity value of certified and non-certified areas of cork oak savanna in Southern Portugal using data on the distribution of birds, reptiles and amphibians.

3. Methods

3.1 Study Area

This study was conducted in south Portugal, where the world's largest continuous area of cork oak is located. Ninety four percent of the cork oak cover in Portugal occurs in this region (Autoridade Florestal Nacional 2010). The terrain is moderately hilly with a mean altitude of 178 meters with values ranging between 0 and 1 019 meters above the sea level. The climate is typically Mediterranean, with a hot and dry summer and a rainy winter. Mean annual temperatures range between 15 to 18˚C and precipitation levels between 600 and 800 mm/year (www.ipma.pt). The dominant forest cover types 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.

To define the study area we followed the criterion of Food and Agriculture Organization (FAO) that considers an area as a Mediterranean forest if it has a canopy projection ≥ 10 % (FAO 2006). We took the 10x10 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 % (Fig. 1). This threshold value is reasonable for cork oak savannas given the typically low tree density of the system.

3.2 Data Collection

For each cell of the study area we compiled the most recent data on: (1) occurrences of breeding non marine birds (Equipa Atlas 2008), reptiles and amphibians (Loureiro et al. 2008) that spend part of their life cycle in cork oak savannas, (2) area of cork oak savannas (Autoridade Florestal Nacional 2010) and (3) area of FSC certified cork oak savannas (http://info.fsc.org) using Quantum GIS 1.8 (QGIS Development Team 2014).

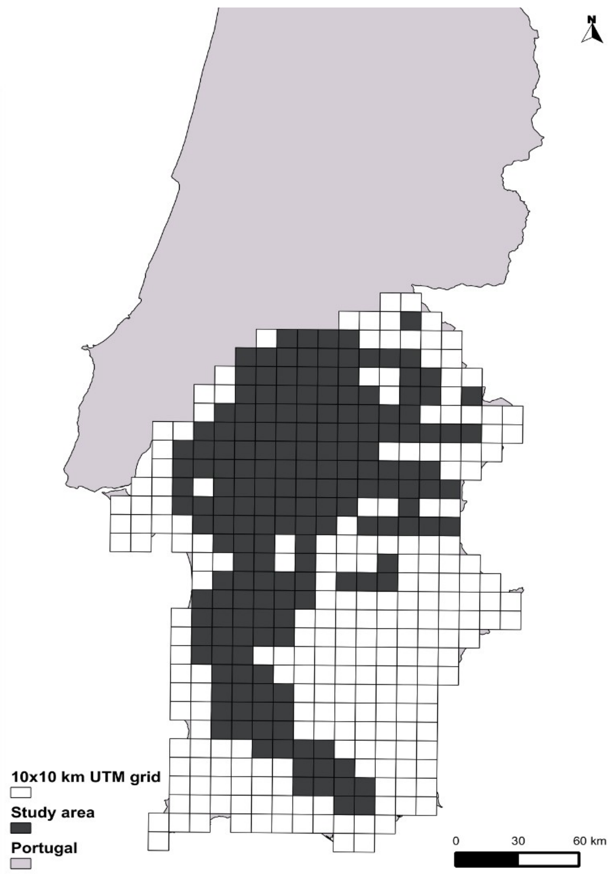

Figure 1 - Location of the study area (black cells) superimposed on the 10x10 km UTM grid (white cells). The cells included in the study area have a percentage of cover by cork oak savannas ≥ 10 %.

Two hundred and nine species were recorded in the study area, 172 birds, 15 amphibians and 22 reptiles. Of these, 10 species are classified as Critically Endangered (10 birds), 15 as Endangered (13 birds and 2 reptiles) and 25 as Vulnerable (23 birds and 2 Reptiles) (Appendix 1).

We gathered biodiversity data for 86 582 ha of cork oak savannas that were FSC certified between 2007 and June 2011. This value is overestimated because it also includes agricultural lands that are a component of cork oak savannas, which could not be excluded from the analysis due to lack of information.

A cell was considered certified if the percentage of certified cork oak savanna in that cell was greater or equal than a threshold value (Thr) of 2, 5, 10 and 20% (that is 200, 500, 1000 and 2000 ha, respectively). The use of thresholds is common when data are at different spatial scales (e.g. Araújo et al. 2007).

3.3 Assessing the biodiversity value of a set of cells

The biodiversity value of a group of cells, with respect to all species and threatened species, was measured in two different ways.

(1) One that only accounts for species representation and measures the percentage of species represented in a set of cells, in relation to the total number of species in the study area. We call this index the relative richness of the set of cells.

(2) The other is based on the concept of irreplaceability (Pressey et al. 1994; Carwardine et al. 2006). To calculate the irreplaceability of each cell, we determined all minimum sets of cells where every species can be represented at least T times. This was achieved by repeatedly solving a “minimum set cover problem” with additional constraints which cut from feasibility the optimal solutions obtained in previous iterations (Rodrigues et al. 2000; Wilson et al. 2009). We implemented this approach in C++ and used CPLEX (IBM 2010) as an integer programming solver. We defined the irreplaceability of a cell as the percentage of minimum solutions (m.s.) that include the cell, for the corresponding target representation T. We used targets T equal to 1 (T1) and 2 (T2) to consider two different conservation scenarios, a less demanding (1 representation per species) and a more demanding (2 representations per species, whenever possible)

To obtain the T-irreplaceability value of a group of cells, we summed the T-irreplaceability values of its cells. Note that contrarily to the relative richness, the T-irreplaceability of a set may exceed 100.

Groups of cells with a high relative richness may present high or low irreplaceability value, depending on the distribution of species with few representations. For example, if poorly represented species occur in cells with low relative richness, the irreplaceability value of the cells with high relative richness will be low.

3.4 Comparing the biodiversity value of certified and non certified areas

To compare the relative richness and irreplaceability value of FSC certified and non-certified cells we used randomization tests described as follows. Considering the certification thresholds Thr=2, 5, 10 and 20%, we calculated the relative richness (overall relative richness and relative richness of threatened species) and summed T-irreplaceability of the group of certified cells. Then we compared the biodiversity value of the certified cells with the biodiversity value of 10 000 randomly selected groups of non-certified cells with the same size. We did this by calculating the percentage of randomly selected groups of non-certified cells that had lower relative richness and/or T-irreplaceability than the group of certified cells. High percentages (> 90%) indicate that the biodiversity value of the certified cells is significantly greater than that of the non-certified cells.

The group of threatened reptiles was excluded from the analysis because it only had three species. All computations were performed using R 2.12.2 (R Core Team 2014).

4. Results

4.1 Certified Area

The area of cork oak savanna with at least 10% of forest cover was mainly located in southwest Portugal (Fig. 1). Within this area, certified cells were concentrated in the northern part of the study area. The cells with higher percentages (≥10%) of certified area were also clustered in the northern part of the study area (Fig. 2).

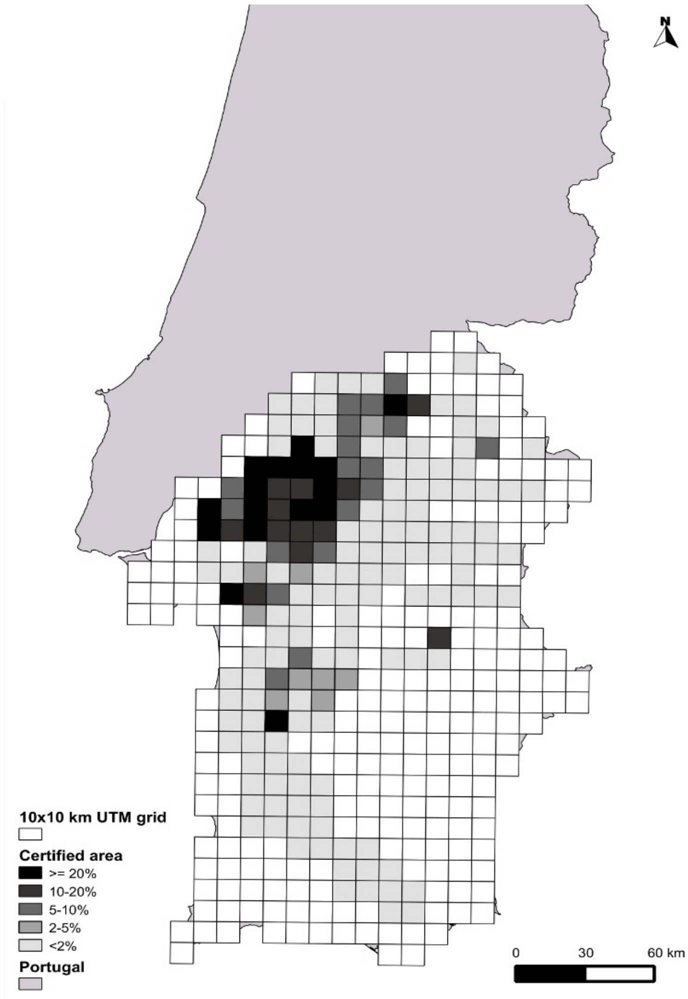

Figure 2 - Percentage of certified cork oak savanna per cell in the study area, according to the four certification thresholds, 2, 5, 10 and 20%. A certification threshold of, for example 2%, means that at least 2% of the area of the cell is certified.

The distribution of certified area per cell was asymmetrical. There was a high number of cells with low percentages of certified area and a low number of cells with high percentages of certified area. For example, 37% of certified cells had less than 10% of certified area (Fig. 3).

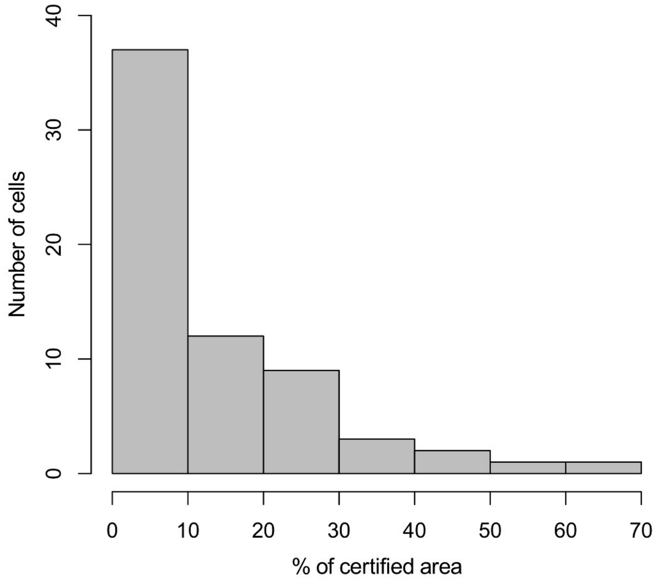

Figure 3 - Frequency distribution of certified area per 10x10 km cell.

Certified area varied with the certification threshold. For example, for Thr=2% (certified area ≥ 200 ha), 55 cells or 31% of the study area was considered certified. Conversely, for Thr=20% only 16 cells or 9% of the study area was considered certified (Table 1).

4.2 Relative richness

The number of species per individual cell in the study area varied between 68 and 118, with an average of 90 and a standard deviation (SD) of 10.5. The number of threatened species per cell ranged between 1 and 11, with an average of 4.2 and SD of 1.64. The cells with higher number of total species and threatened species were mostly located in the northern part of the study area (Fig. 5a and Fig. 6a).

Table 1 - Number and area of 10 x 10 km certified cells per certification threshold (% and area) as of June 2011. A cell is considered certified if its percentage of certified area is greater or equal than a threshold value of 2, 5, 10 and 20%.

Threshold		Number of certified cells	Certified area within the study area (%)
%	ha		
2	200	55	31
5	500	46	26
10	1000	28	16
20	2000	16	9

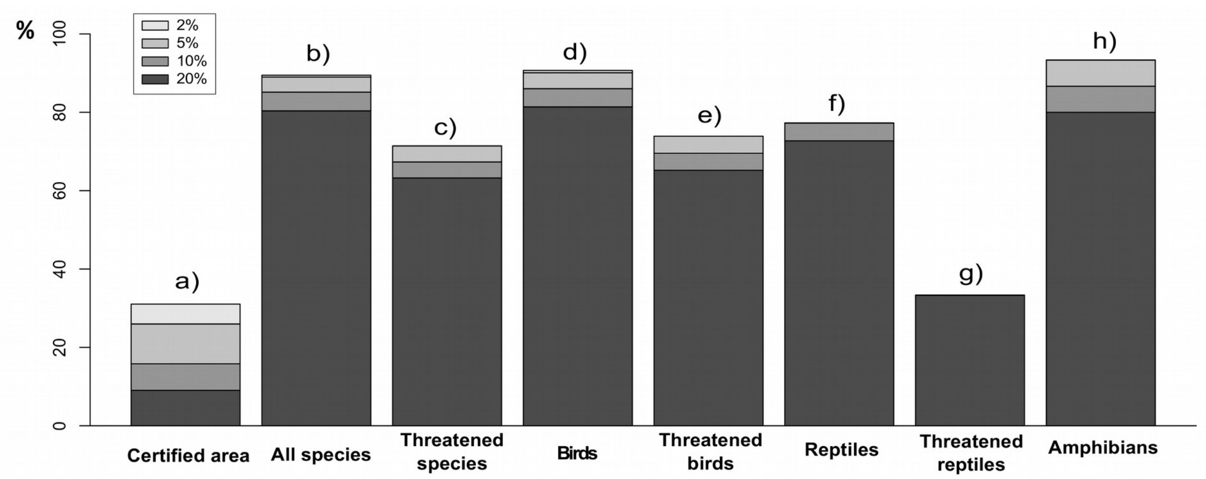

Figure 4 - Bar a) is the ratio (%) between the number of certified cells and the total number of cells in the study area. Bars b) to h) are the relative richness of each group of certified cells. Shaded areas refer to four certification thresholds Thr=2%, 5%, 10% and 20%. A cell is considered certified if the percentage of certified area in that cell is greater or equal than a threshold value of 2, 5, 10 and 20%.

The certified area covered 80.4 % and 89.5 % of all species for Thr=20% and Thr=2%, respectively, and covered 63.3 % and 71.4% of the threatened species, for the same thresholds (Fig. 4). The cells with a certified area ≥ 2000 ha represented most of the species occurring in the study area and the other certified cells only added a few unrepresented species.

Regardless of the threshold, more than 80% of all species, all birds and all amphibians, and more than 60% of all threatened species, all reptiles and threatened birds are represented in certified areas. Only one of the three threatened species of reptiles is represented in certified cells (Fig. 4).

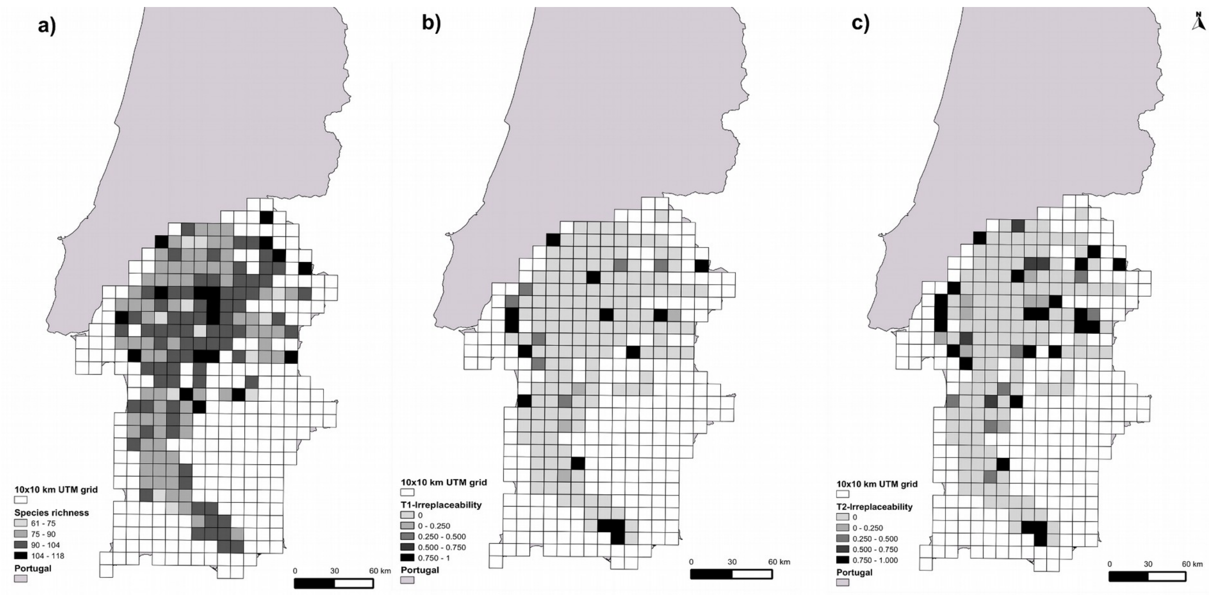

Figure 5 - Biodiversity value of the cells located in study area, considering all species, expressed in: a) Species richness, b) T1-Irreplaceability c) T2-Irreplaceability.

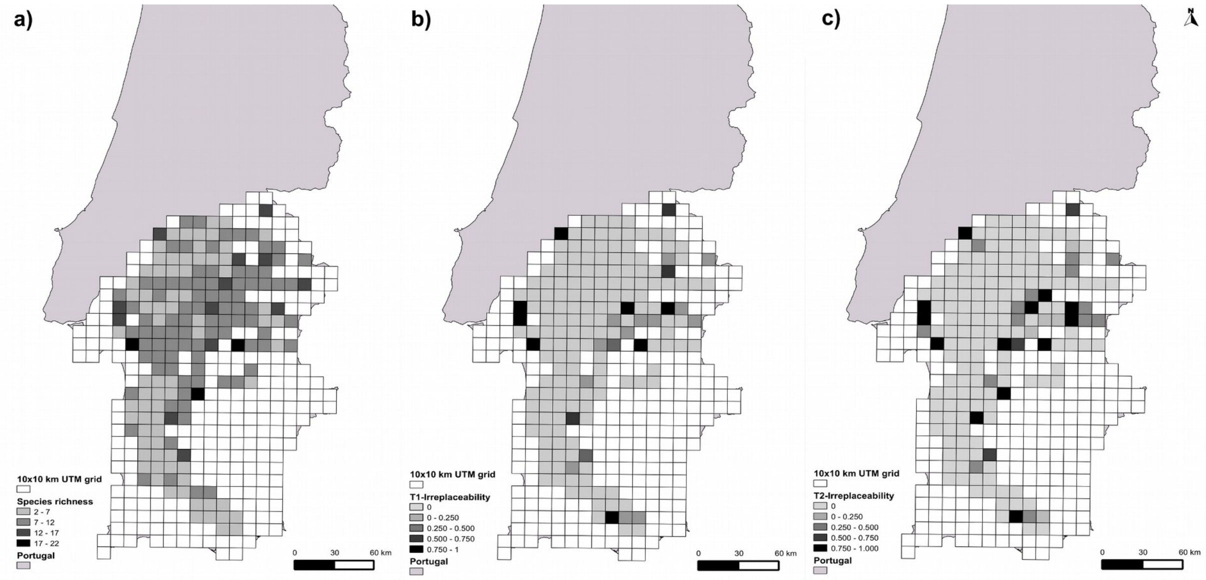

Figure 6 - Biodiversity value of the cells located in study area, considering only threatened species, expressed in: a) Species richness, b) T1-Irreplaceability c) T2-Irreplaceability.

4.3 Irreplaceability value

It is possible to represent all 209 species at least once and at least twice in 18 and 31 cells, respectively, which are the sizes of the corresponding minimum set cover solutions. The number of different minimum solutions (m.s.) are 48 and 684 for T1 and T2, respectively. All 49 threatened species can be represented at least once in 12 cells (78 m.s.) and at least twice in 21 cells (2826 m.s.).

When considering all species, and regardless of the representation target (T1 and T2), the cells with irreplaceability > 0 were scattered across the study area (Fig. 5b and 5c). The same was observed for threatened species (Fig. 6b and 6c). These cells also presented a low coincidence with certified areas (Fig. 2, Fig. 5 and Fig. 6).

The percentages of T-irreplaceability of certified cells, for all groups of species, were below 34.9%, regardless of the certification threshold. Birds presented the highest values and amphibians the lowest (Fig. 7).

For the groups of threatened species and threatened birds, all cells with positive T1-irreplaceability had a certified area ≥ 2000 hectares (i.e., are considered certified for a Thr=20%) (Fig. 7d and 7h). This was not the case for the other groups of species.

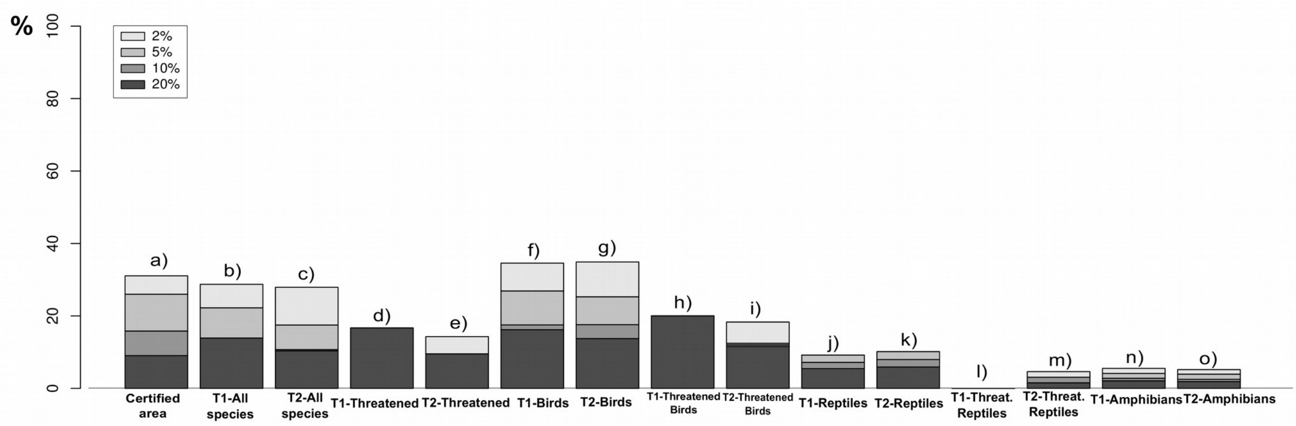

Figure 7 - Bar a) is the ratio (%) between the number of certified cells and the total number of cells in the study area. Shaded areas refer to four certification thresholds Thr=2%, 5%, 10% and 20%. Bars b) to o) are the percentage of T-irreplaceability of certified cells. The height of each bar represents the ratio between the T-irreplaceability of certified cells and the T-irreplaceability of all cells in the study area. A cell is considered certified if its percentage of certified area is greater or equal than a threshold value of 2, 5, 10 and 20%.

4.4. Comparing the biodiversity value of certified and non certified areas

A visual comparison between Fig. 2 and Fig. 5 suggests a low degree of overlap between cells with high percentages of certified area and cells with high relative richness and high irreplaceability value. This was confirmed by the randomization tests that resulted in a low percentage of simulated groups of non-certified cells with biodiversity values lower than the group of certified cells (Table 2). This indicates that, in general, the relative richness and T-irreplaceability of randomly chosen non-certified cells was higher than that of certified cells. Only in two cases more than 90% of the simulated sets of non certified cells exhibited lower values than the certified cells, T1-irreplaceability for birds and for threatened birds (both for Thr=20%) (Table 2).

For Amphibians less than 7% of simulated non-certified groups had lower irreplaceability values than the corresponding certified groups (Table 2).

5. Discussion

Most of the certified area of cork oak savannas is located in the northern part of the study area. 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 $kg.ha^{-1}.year^{-1}$ when the national averages are between 90.8 and 125.5 $kg.ha^{-1}.year^{-1}$ (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 hectares (Coelho 2003). 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 atain in this region helps to dilute the costs of forest certification and explain why certification has started here.

We found that, in general, the biodiversity value of certified areas was not significantly higher than the values obtained for randomly selected non-certified areas with the same size. With the exception of T-irreplaceability for all birds and for threatened birds with a certification threshold of Thr=20%, less than 90% of the simulated non-certified groups of cells presented lower biodiversity value than the certified cells (Table 2).

Table 2 - Percentage of the simulated groups of non certified cells that had lower biodiversity value than the group of certified cells for the four certification thresholds. A cell is considered certified if its percentage of certified area is greater or equal than a threshold value of 2, 5, 10 and 20%. The irreplaceability of a cell is the percentage of minimum solutions that include that cell, for a given species representation target. The T-Irreplaceability of a group of cells is the sum of the irreplaceabilities of each individual cell.

		Biodiversity Value	**Thr=2%**	**Thr=5%**	**Thr=10%**	**Thr=20%**
All species	All	Relative Richness	7.2	11.6	30.7	45.7
		T1 - Irreplaceability	34.6	29.5	42	84.3
		T2 - Irreplaceability	23	3.4	13.6	66.3
	Threatened	Relative Richness	1.9	5.4	44.9	85.5
		T1-Irreplaceability	2.2	11.1	58	88.8
		T2-Irreplaceability	0.1	0.1	11.7	57.8
Birds	All	Relative Richness	46.2	43	57.7	69.2
		T1 - Irreplaceability	71.5	55.8	62.1	90.8
		T2 - Irreplaceability	79.4	45.2	63.8	85.4
	Threatened	Relative Richness	9.7	16.9	61.5	89.1
		T1 - Irreplaceability	21.3	41.6	83.2	99.7
		T2 - Irreplaceability	1.5	1.3	28.7	71.7
Reptiles	All	Relative Richness	0	0	4.2	20.3
		T1 - Irreplaceability	0.1	1.2	13.8	35.9
		T2 - Irreplaceability	0.1	0.9	12	32.3
Amphibians	All	Relative Richness	29.4	41.8	53.8	0.4
		T1 - Irreplaceability	0	0	0.2	6.9
		T2 - Irreplaceability	0	0	0.1	4.8

Although not significantly higher than that of non certified areas, the relative richness of FSC certified cells regarding birds, reptiles and amphibians was substantial. More than 81% of all birds, 72% of all reptiles and 80% of all amphibians were present in certified areas (Fig. 4). Threatened species of these groups were also relatively well represented in certified areas, with more than 65% of the species present. For example, the Egyptian vulture (*Neophron percnopterus*) whose conservation status is Endangered and the northern goshawk (*Accipter gentilis*) that is listed as Vulnerable in Portugal, occur in certified areas. Reptiles were the only exception, since only one of the three threatened species that occurs in the study area (European pond turtle *Emys orbicularis*) was present in certified areas. The high relative richness of certified cells was due to a large number of species that are widespread over the study area. For example, 41% of the species occur in more than 50% of study area. Generalist species like the European goldfinch (*Carduelis carduelis*), the corn bunting (*Emberyza calandra*) and the African stonechat (*Saxicola torquatus*), that are very common in cork oak savannas (Catry et al. 2010), occur in every cell of the study area.

The 16 cells with a certified area above 2000 ha (i.e., Thr=20%) had a remarkably high relative richness, representing more than 80.4% of all the species occurring in the study area (Fig. 4). This is not completely surprising since these 16 cells cover a large area (160 000 ha). In fact, randomization tests confirmed that the relative richness of these cells is not significantly greater than that of any other 16 cells (Table 2). When the certification threshold is lowered to Thr=2% (i.e. increasing the number of certified cells from 16 to 55) the relative richness only increased by 9.1%. Similar results were observed for birds, reptiles and amphibians separately.

The T-irreplaceability of certified areas was generally low (<34.9%), regardless of the group of species considered and it was also not significantly higher than the observed for simulated groups, with the exception of birds (T1 and Thr=20%). For Amphibians the results suggest that non-certified areas presented higher irreplaceability value than the certified ones. In general these results can be explained by the lack of spatial coincidence between certified areas and irreplaceable cells. The minimum set cover solutions are strongly conditioned by the cells where species with only one or two representations occur (Rodrigues et al. 2000; Wilson et al. 2009). Ten among the 18 species that only occurred in 1 or 2 cells are not present in certified cork oak savannas. For example, the western olivaceous warbler (*Hippolais opaca*), that inhabits riparian vegetation associated with cork oak savannas, only occurs in one cell located in the south of the study area, that has no certified area. The reed bunting (*Emberiza schoeniclus),* that can be found in wetlands occurring in cork oak savannas, only occurs in one cell on the western limit of the study area, that also has no certified area. The Iberian frog (*Rana iberica)* and the golden eagle (*Aquila chrysaetos),* that inhabit cork oak savannas located in mountainous regions, only occur in two cells that also have no certified cork oak savannas. The non-overlap between certified areas and the regions where these poorly represented species occur determined the low T-irreplaceability values of the certified areas.

FSC certification provides an economic incentive for landowners to adopt sustainable forest management practices which also aims to benefit the conservation of biodiversity. In Portugal 26% of all cork oak savannas are under PAs or the Natura 2000 network. Of the 87 307 hectares of FSC certified cork oak savannas, only 5.3% coincide with these areas. FSC certification is thus contributing to the sustainable forest management of an additional 12% of cork oak savannas that were not under any conservation mechanism.

6. Conclusions

Although FSC certification has not targeted areas of high biodiversity in cork oak savannas, so far, it must be considered that the process only began 5 years ago and has only covered 12.6% of the total area of cork oak savanna in Portugal. The main Association of cork oak producers and landholders in Portugal, “União da Floresta Mediterrânica”, has made a public commitment to increase the area of certified cork oak savannas to 150 000 ha by the end of 2012 (www.unac.pt). If achieved, this objective would substantially enlarge the area of cork oak under forest certification. It would be desirable to consider the biodiversity value of these areas during this process. For example, prioritizing areas where productive forests coincide with high biodiversity values would enhance the conservation purposes of forest certification and facilitate integrating certification with other conservation initiatives.

Presently there are governmental funding programs that aim to compensate for the costs of forest certification and to incentivize it, such as the one implemented by the Forestry National Authority in Portugal or the "Woodland Grant Scheme" of the Forestry Commission in the UK. We suggest that these programs should, whenever appropriate, prioritize the certification of high biodiversity areas. Methods used here could contribute to identifying these priority areas.

Our study was a first step towards quantitatively assessing forest certification and its relation to biodiversity in cork oak savannas. Future research should address how certified forest management practices may contribute to maintaining or enhancing the biodiversity value of areas under forest certification.

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Chapter III- Effects of forest certification on the ecological condition of Mediterranean streams

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Effects of forest certification on the ecological condition of Mediterranean streams

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1. Abstract

Forest certification, a proxy for sustainable forest management, covers more than 10% of the world's forests. Under forest certification, forest managers and landowners must comply with environmental, economic and social management standards aiming to promote forest conservation. Despite an increasing area of certified forests, there is a dearth of data on how forest certification is affecting the conservation of forest ecosystems and associated habitats. Here we assess the effects of Forest Stewardship Council (FSC) certification, one of the largest certification schemes in the world, on the ecological condition of streams crossing Mediterranean evergreen oak woodlands. We used the Stream Visual Assessment Protocol (SVAP) to compare the ecological condition of streams located in areas with three and five years of certification, in non-certified areas and in least-disturbed streams. Forest certification positively affected the ecological condition of the surveyed streams but its effects were only measurable after five years of certification. Streams with five years of certification had more continuous, dense and diverse riparian vegetation when compared to streams located in non-certified areas. Moreover, the condition of streams located in areas with five years of forest certification was similar to the condition of least-disturbed streams. Forest certification promotes the ecological condition of streams occurring within Mediterranean evergreen oak woodlands. This mainly happens because in areas under forest certification managers and landowners have to comply with management practices that require them to remove or reduce the main causes for

stream degradation, allowing riparian habitats to recover. Within landscapes with large and increasing areas under forest certification, such as the Mediterranean cork oak woodlands, the positive effects of certification on the ecological condition of streams may spread across the hydrographic network in the medium to long term.

Keywords: Forest management, Stream Visual Assessment Protocol; freshwater habitats, riparian vegetation; Forest Stewardship Council; rapid bioassessment protocol; cork oak.

2. Introduction

Sustainable forest management is crucial for the conservation of forest ecosystems, their biodiversity and the ecosystem services they provide (Millenium Ecosystem Assessment 2005a). Forest certification aims to promote sustainable forest management by adding market value to products generated according to environmental and socioeconomic standards (Auld et al. 2008; Gomez-Zamalloa et al. 2011). Forest certification relies on the willingness of consumers to pay more for sustainable products and seeks to reward producers that adopt sustainable forest management practices (Brown et al. 2001; Auld et al. 2008; Suzuki and Olson 2008). To obtain certification forest managers must comply with management standards developed through public participation of governmental agencies, non-governmental organizations, industry associations and social groups. The compliance with these standards is audited and monitored by an independent third party (Auld et al. 2008). The two main forest certification schemes are the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) (Auld, Gulbrandsen & McDermott 2008) certification which cover 251 and 186 million hectares, corresponding to 6.1 and 4.5% of the world's forests, respectively (Forest Stewardship Council 2014; PEFC 2014). Both certification schemes aim to promote forest management practices that are economically viable, socially just and contribute for the conservation of biodiversity and ecosystem services provided by forests (www.fsc.org, www.pefc.org).

Streams, rivers, lakes and ponds are important components of forest ecosystems (Naiman 2005), which account for less than 1% of the Earth's surface but harbour 10% of all described species (Strayer and Dudgeon 2010). Freshwater ecosystems also provide key ecosystem services such as water provisioning and purification, flood control, harvestable organisms, hydropower and recreational use (Millenium Ecosystem Assessment 2005a; Abell et al. 2007; Kareiva and Marvier 2010). Despite their importance, freshwater ecosystems and the ecosystem services they provide are among the most threatened in the world (Ricciardi and Rasmussen 1999; Millenium Ecosystem Assessment 2005b; Tedesco et al. 2013). In the Mediterranean, streams and riparian habitats support a dense and productive forest ecosystem, which is very distinguishable from the adjacent semi-arid habitats (Naiman 2005; Salinas and Casas 2007; Santos 2010). These habitats also play an important role in shaping and structuring Mediterranean landscapes by supporting a wide variety of biotic assemblages in a seasonally water-stressed environment (Gasith and Resh 1999; Naiman 2005). Mediterranean riparian habitats are often threatened by livestock grazing along the river margins, vegetation clearing, soil mobilization and channelization, which restrict the riparian habitat to narrow vegetation corridors along the streams (Aguiar and Ferreira 2005; Ferreira et al. 2005; Santos 2010). Despite these disturbances and their small size, riparian habitats perform a disproportionate role in Mediterranean ecosystems (Gasith and Resh 1999).

Forest management practices have wide implications for the conservation of streams and rivers, both within and outside of forest management units. In several countries there are laws and directives to protect stream and river habitats in managed forests. For example, in the United States of America, the Clean Water Act and the National Forest Management Act address the protection of rivers and the impacts of forest management on water quality (Naiman 2005). In the European Union (EU), the Water Framework Directive (WFD) (Directive 2000/60/EC) requires all EU member states to achieve “good ecological status” for all ground and surface waters (European Commission 2009). This legal context creates an incentive for forest managers to evaluate how their management practices affect freshwater habitats and to adopt strategies to preserve and restore riparian habitats located in forest ecosystems (Stella et al. 2013). Assessing the effects of forest certification on the ecological condition of streams is both a timely and important goal.

In this study we assess the effects of the implementation of FSC forest certification on the ecological condition of low-order streams (Strahler 1957) in cork oak woodlands. Cork oak woodlands are silvopastoral systems with high economic and conservation value (Bugalho et al. 2011) typical of the West Mediterranean Basin, that cover 1.5 million hectares in southwestern Europe and 1 million hectares in North Africa ((Pausas et al. 2009).This ecosystem is characterized by a sparse tree cover (30–60 trees ha^{-1}) of cork oak *Quercus suber* L., frequently mixed with other evergreen oaks, e.g. holm oaks *Quercus rotundifolia* Lam., or pine trees (e.g. *Pinus* spp), and an understorey of shrub species (e.g. *Cistus* sp*)* interspersed with grasslands, pastures, fallows and sometimes cereal crops (Bugalho et al. 2009). Streams and riparian areas are key habitats in cork oak woodland ecosystems because they support high levels of plant diversity(Gasith and Resh 1999; Santos 2010), are an important habitat for mammalian carnivores (Matos et al. 2009) and harbour several threatened species of fish, such as the Critically Endangered river lamprey *Lampetra fluviatilis* L. (recently described by (Mateus et al. 2013) and the endangered cyprinid *Iberochondrostoma lemmingii* Steindachner *(Cabral et al. 2006)*. As in other regions, these streams are threatened by vegetation clearing and livestock grazing.

FSC certification covers 90 000 hectares of cork oak woodlands in Portugal (Dias et al. 2013) and its management standards address the impacts of forest management on freshwater habitats by preventing logging, vegetation clearing and waste disposal in and around freshwater ecosystems and by reducing livestock grazing. The development of new roads or pathways is prohibited and the use of fertilizers and pesticides is highly regulated to prevent runoff. Freshwater ecosystems are frequently classified as "conservation zones", these are areas delimited within forest management units for the purpose of maintaining or restoring forest biodiversity and its ecological functions (Tollefson et al. 2009). Despite an increasing area of FSC certified cork oak woodlands, the impact of FSC certification on the condition of streams in these ecosystems is unknown.

Here we assess the effects of FSC certification on the ecological condition of Mediterranean streams crossing cork oak landscapes. Specifically we 1) compare the ecological condition of streams located in certified and non-certified areas; 2) assess the differences in the ecological condition of streams located in areas with three and five years of forest certification and 3) compare the ecological condition of least-disturbed streams with that of streams located in certified areas.

3. Material and Methods

3.1 Study area

The study area is located in southern Portugal in a sub-basin of the Tagus River (Fig. 1). This is a moderately hilly region, with a mean altitude of 54 meters. Soils are mainly composed of limestone and other sedimentary formations. The climate is sub-humid Mediterranean, with a mean annual temperature of 16ºC and an average rainfall of 730 mm year^{-1} (AEM and IM 2011). Streams and rivers of the study area are classified as “rivers of the sedimentary deposits of Tagus and Sado - type S3”, according to the Portuguese national typology of rivers developed with the Water Framework Directive's criteria (INAG 2008). These streams have a mean drainage area of 390 km^2, high floods are common during autumn and winter but the flow decreases and streams dry out during late spring and summer. Riparian vegetation is dominated by a dense shrub layer (3–6 m high) mainly composed of willows such as *Salix salviifolia* Brot. and *Salix atrocinerea* Brot., but also of Hawthorn *Crataegus monogyna* Jacq., tree heath *Erica arborea* L., alder buckthorn *Frangula alnus* L. and wild blackberry *Rubus ulmifolius* Schott. Oleander *Nerium oleander* L. and African tamarisk *Tamarix africana* L. also occur but are less frequent. In more-disturbed areas two invasive species may occur, the giant reed *Arundo donax* L. and the parrot feather *Myriophyllum aquaticum* Verdc.. The dominant land-uses in the study area are cork oak woodlands (42%), agricultural crops (27%) and plantations of blue gum

Eucalyptus globulus Labill (9%). Grazing by cattle and sheep is common throughout the study area.

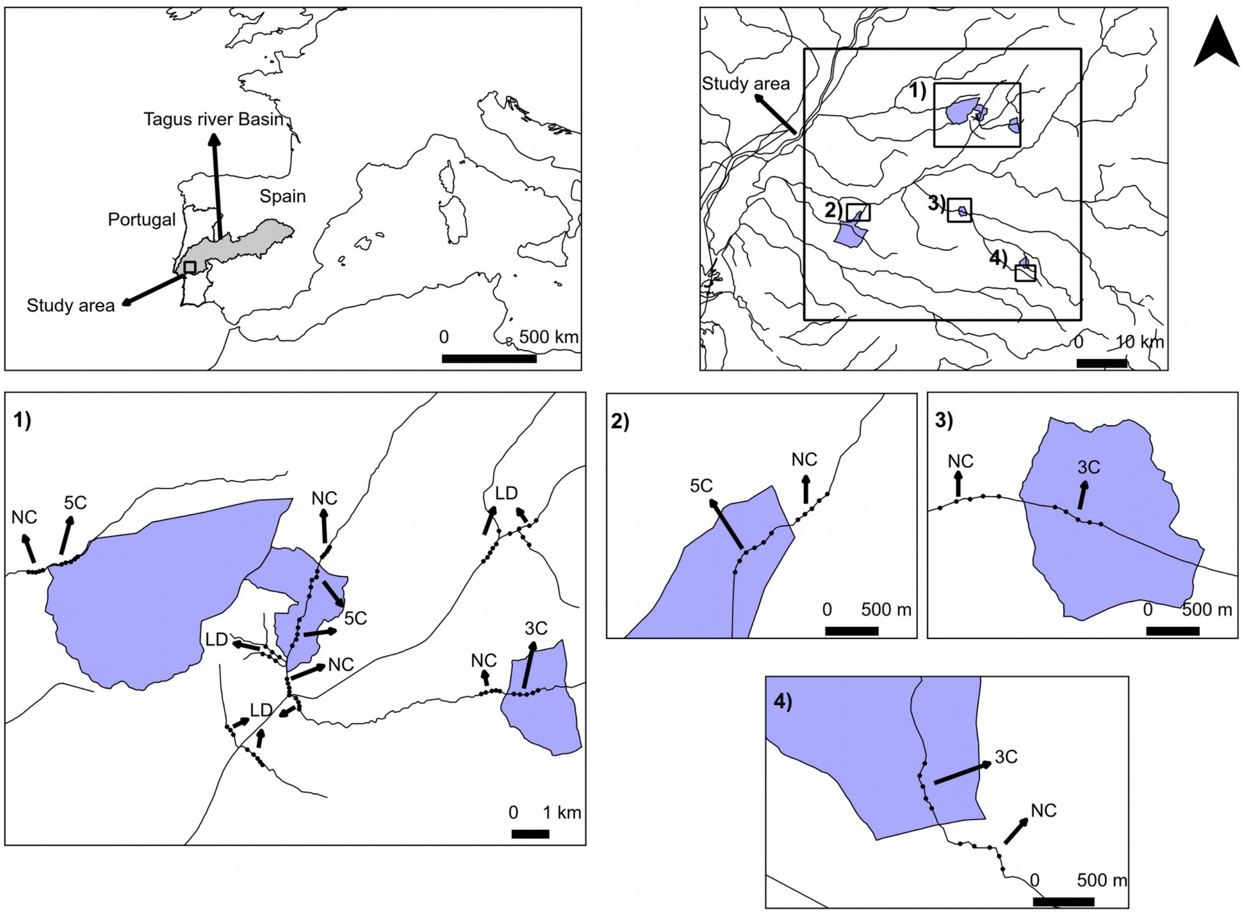

Figure 1 – Location of the study area and of surveyed properties, including the streams crossing those estates. The dots along the streams represent the center of each 100-meter stream reach where Stream Visual Assessment Protocol (SVAP) was applied. The purple polygons represent the properties. NC – non-certified reach, 3C – stream reaches with three years of certification, 5C – stream reaches with five years of certification and LD– least disturbed stream reaches.

3.2 Data collection

We used the Stream Visual Assessment Protocol (SVAP) Version 2 (NRCS 2009) to assess the condition of stream ecosystems. SVAP is a rapid bio-assessment protocol widely used in the United States of America (USA) that was developed by the Natural Resources Conservation Service of the United States Department of Agriculture and field tested in a wide variety of regions including Mediterranean California (Bjorkland et al. 2001; NRCS 2009). It evaluates the overall condition of wadeable streams, their riparian zones and in-stream habitats (NRCS 2009) and is based on the visual inspection and evaluation of up to 16 physical and biological parameters (hereafter “elements”) of in-stream and riparian environments. Scoring varies between one and ten according to the provided guidelines (see Appendix 2) . The final SVAP index is the arithmetic average of the scores of each element. Since SVAP requires a low level of expertise in stream ecology, it can be readily used by landowners or forest managers. Alternative rapid bioassessment protocols, such as the Riparian Quality Index (González del Tánago and de Jalón 2011) or the “Qualitat del Bosc de Ribera” (QBR) index (Munné et al. 2003) do not cover parameters such as water appearance and fish and aquatic invertebrate habitat. Moreover, SVAP has been successfully used to assess the condition of streams crossing cork oak landscapes (Matos et al. 2009). In this assessment we selected 13 elements and excluded the Salinity and Riffle embeddness parameters because there was no evidence of salinity in any surveyed streams and because riffles are not a common feature of these streams (personal observation). The element of Aquatic invertebrate community was not assessed because the features assessed by Aquatic invertebrate habitat, Nutrient enrichment and Water appearance are a known proxies for the distribution patterns of aquatic macroinvertebrates and of the availability of microhabitats and water quality (Hughes et al. 2009; Jähnig et al. 2010). To determine if the remaining SVAP elements were highly correlated with each other we calculated variance inflation factors (vif) for each element and used a cut-off value of five (Fox and Weisberg 2010). Aquatic invertebrate habitat had a vif score higher than five, resulting from its correlation with the element Fish habitat complexity. Although both metrics quantify habitat diversity types, they were assessed at different habitat scales (NRCS 2009) (Appendix 2), so their scores do not necessarily match in other types of streams. For this reason, we decided to keep both in order to facilitate comparisons with other studies.

We surveyed six low-order streams crossing six FSC certified areas with three and five years of certification and applied SVAP to 101 stream reaches. At the time of the study these were the only estates with three or more years of certification. Thirty-six reaches were located in certified areas and 35 reaches on non-certified areas (Fig. 1). Of the certified reaches, 15 had three years of certification and 21 had five years of certification (Table 1). Thirty least-disturbed stream reaches were surveyed in an area classified as a “reference site with high ecological status” during the pre-assessment surveys conducted for the implementation of the Water Framework Directive in Portugal (CIS-WFD 2003; Agência Portuguesa do Ambiente 2012) (Fig. 1). Each surveyed stream reach was 100 meters long, which corresponds to 50 times the average width of the stream channels. To minimize edge effects the surveyed reaches were located at least 300 meters away from local disturbances (e.g. bridges, weirs) and 150 meters away from the point where streams crossed the property boundary (Fig. 1). Field work was conducted in a period of low flow, as suggested in SVAP (NRCS 2009), during three consecutive weeks between June and July 2012. During the sampling period weather conditions were stable (mean temperature of 22ºC) and there were no precipitation, water discharges or water withdrawals. The surveys were conducted by a single observer (FSD) to maximize consistency. Since we were mainly interested in comparing the relative ecological condition of reaches, observer bias will not have a significant impact on the results. The observer travelled across the entire length of each reach for approximately 45 minutes and scored each SVAP element according to the guidelines (Table 2 and Appendix 2). Data collected during the surveys was stored and processed in Geographic Information System (GIS) using Quantum GIS 1.8 (QGIS Development Team 2014).

Table 1 – Number and length (meters) of the surveyed stream reaches in each surveyed estate and the number of years of certification in non-certified, certified and least disturbed areas

	Certified areas			Non-certified areas		Total	
Estates	**Reaches**	**Length**	**Years of certification**	**Reaches**	**Length**	**Reaches**	**Length**
Estate 1	5	500	5	5	500	10	1000
Estate 2	10	1000	5	10	1000	20	2000
Estate 3	5	500	3	5	500	10	1000
Estate 4	6	600	5	5	500	11	1100
Estate 5	5	500	3	5	500	10	1000
Estate 6	5	500	3	5	500	10	1000
Least disturbed 1	-	-	-	-	-	12	1200
Least disturbed 2	-	-	-	-	-	18	1800
TOTAL	36	3600	-	35	3500	101	10100

Table 2 – Description of the elements of Stream Visual Assessment Protocol (SVAP)

SVAP Element	Description
Channel condition	The geomorphic stage of the channel, according to the Schumm Channel Evolution Model (Schumm, Harvey & Watson 1984).
Hydrologic alteration	The frequency of bankfull or higher flows and the presence of development areas in the floodplain, water withdrawals, flow augmentation or water control structures
Bank condition	The degree of stability of stream banks, the degree of protection by natural vegetation, evidence of erosion and damage by recreational use or livestock grazing. Each margin is scored separately.
Riparian area quantity	The extent of the riparian area (length x width in relation to the bankfull width) and its degree of continuity. Each margin is scored separately.

Riparian area quality	The composition, diversity and age structure of the riparian community and the percentage of cover by invasive species. Each margin is scored separately.
Canopy cover	The percentage of the stream reach surface that is shaded. In this case we used the scoring matrix for warm-water streams (see Appendix 2).
Water appearance	The degree of turbidity of the water and the presence of oil or metal precipitates.
Nutrient enrichment	The nutrient load of the water based on its colour and the amount of algal growth.
Manure or human waste presence	The existence of sewage or human waste discharges and whether livestock has access to the riparian area.
Pools	The number of shallow and deep pools.
Barriers to aquatic species movement	The presence of artificial physical barriers such as dam, dikes, culverts or livestock crossings.
Fish habitat complexity	The number of different habitat features for fish. E.g. logs/large wood, deep pools, other pools (scour, plunge, shallow, pocket) overhanging vegetation, boulders, cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, backwater pools, and other off-channel habitats.
Aquatic invertebrate habitat	The number of different habitat features for aquatic invertebrates, logs/large wood, leaf packs, fine woody debris, overhanging vegetation, aquatic vegetation, undercut banks, pools, and root mats.

3.3 Statistical analysis

We used linear mixed-effects modelling to assess the effects of forest certification on the ecological condition of streams to account for the fact the condition of adjacent stream reaches is not independent (Pinheiro and Bates 2009). All calculations were made in R 2.15.2 (R Core Team 2014) using the package “nlme” (Pinheiro and Bates 2009). We compared the overall SVAP index and the index for each SVAP element of (1) non-certified reaches, (2) reaches with three years of certification, (3) reaches with five years of certification and (4) least-disturbed streams by modelling these variables against a four-level categorical variable, hereafter referred as “reaches group”, using the lme() function. The location of the surveyed properties was used as a random effect (Fig. 1). To compare the SVAP indexes of each group of reaches we performed multiple comparisons with the Tukey's test (0.05 significance) using the glht() function of the R package “multcomp” (Bretz et al. 2010). The final models were validated by checking the normalized residuals for violations of normality and homogeneity and for spatial autocorrelation (Zuur et al. 2009). Normality of the distribution of the residuals was visually assessed through analysis of the residuals' histogram. Homogeneity was checked by visually analysing 1) the spread (the pattern of distribution) of the residuals versus fitted values in scatter plot and 2) the spread of the boxplots of the residuals grouped by each of the “reaches group” categories (Zuur et al. 2009). Homogeneity was only violated in a few cases for condition 2). In these cases a “VarIdent” variance structure was added to the model (Zuur et al. 2009). To check for spatial autocorrelation a semivariogram was built using the function Variogram(). When spatial autocorrelation was detected we added a linear, Gaussian, rational quadratic or exponential correlation structure to the model. Finally, we checked if the random effects of all models, obtained with the function ranef(), were normally distributed by visually analysing the corresponding histogram (Pinheiro and Bates 2009; Zuur et al. 2009).

4. Results

The SVAP index of reaches located in areas with five years of certification was significantly higher than that of reaches located in non-certified areas or in areas with three years of certification. There were no significant differences between the index of streams located in sites with five years of certification and the index of least disturbed streams. There were also no significant differences between reaches located in non-certified areas and in areas with three years of certification (Fig. 2, Table S1 and S2 in Appendix 2).

As for individual SVAP elements, the scores of the elements of Bank condition, Riparian quantity, Riparian quality, Canopy cover, Fish habitat complexity and Aquatic invertebrate habitat were significantly higher in reaches with five years of certification when compared with reaches without certification and with three years of certification. The scores of these elements on reaches with five years of certification were not significantly different from the ones located in least-disturbed sites (except for Canopy cover) (Fig. 2; Table S1 and S2 in Appendix 2).

No significant differences were found for the remaining scores, Channel condition, Water appearance, Nutrient enrichment, Manure and human waste, Pools and Barriers to fish movement across the surveyed streams when comparing certified, non-certified and least-disturbed sites (Figure 2; Table S1 and S2 in Appendix 2).

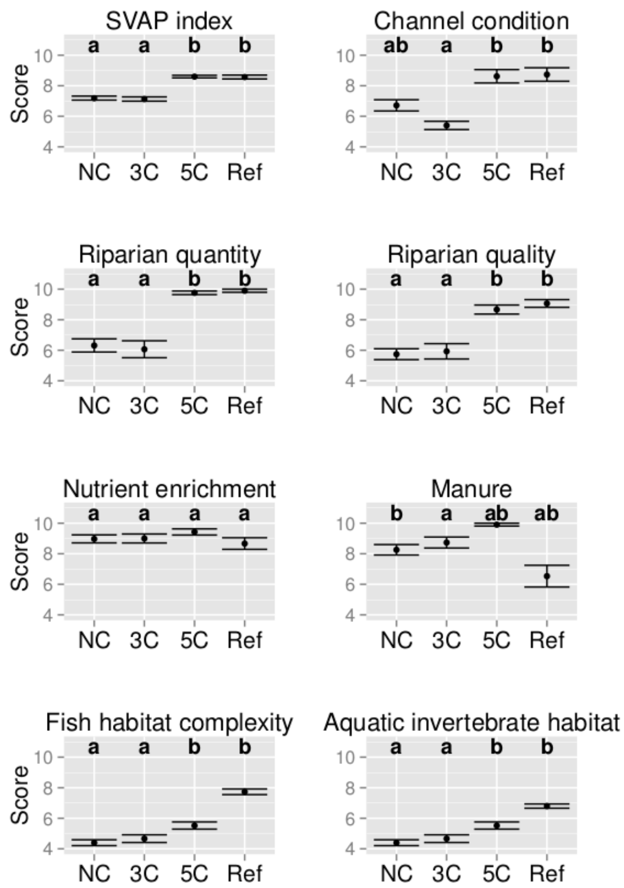

Figure 2 – Boxplots showing the distribution of the Stream Visual Assessment Protocol (SVAP) index and SVAP elements scores' on non-certified stream reaches (NC) (n=35), reaches with three years of certification (3C) (n=15), reaches with five years of certification (5C) (n=21) and least disturbed reaches (LD) (n=30). The results of the multiple comparisons performed with Tukey's test are presented with a compact letter display ("a","b" and "c"). Groups of reaches with significantly different scores ($P<0.05$) were assigned different letters and vice versa. The boxplots are defined by the 25th and 75th percentiles (lower and upper quartile) and the vertical lines (whiskers) have a length of 1.5 times the interquartile range. The median value for each group of reaches is shown with a thick horizontal line and an asterisk. The isolated points represent outliers.

5. Discussion

Our results suggest that Forest Stewardship Council (FSC) certification management standards had a positive effect on the ecological condition of the riparian vegetation of stream reaches located in cork oak woodlands. These effects, however, were only measurable after five years of certification. After this period, the condition of reaches located in certified areas is similar to that of those located in least-disturbed, well-conserved sites.

The high scores of reaches with five years of certification for Riparian quantity and Riparian quality, which measure the continuity of the riparian vegetation relative to the bankfull width and the diversity and structure of the riparian vegetation, respectively, suggest that forest certification is favouring the development of the riparian vegetation. The vegetation on these reaches is composed of a dominant layer of fast-growing willows and smaller shrub formations of hawthorn and alder buckthorn, which are adapted to poor soils and summer-dry streams and are very resilient to vegetation cutting and livestock disturbance (Ferreira et al. 2005). In non-certified reaches, possibly because of livestock grazing and vegetation clearing, riparian vegetation is scarcer and more patchily distributed and usually composed of shrubs less than two meters high (FSD, personal observation). The lower score of Riparian quality in non-certified areas also reflects the higher cover by the invasive giant reed, which is a species well adapted to riparian environments that undergo frequent physical disturbances (Bell 1997; Sabbatini et al. 1998). On reaches with five years of certification the condition of the riparian vegetation is similar to that found on reaches located in least-disturbed areas.

The better ecological condition of the riparian vegetation explains the higher scores of Bank condition, Fish habitat complexity, Aquatic invertebrate habitat and Canopy cover in reaches with five years of certification. Roots, branches and leaves from riparian trees and shrubs help maintain the stability of banks by protecting them against water and wind erosion (Thorne 1990; Corenblit et al. 2009). Species such as willows usually develop large root systems that can quickly stabilize river banks (< 12 months) (Shields et al. 1995). Higher scores of Canopy cover, Fish habitat complexity and Aquatic invertebrate habitat in areas with five years of certification may result from the development of more structurally complex plant communities. Dense and continuous riparian vegetation provides more shaded areas, logs, wood, litter accumulation and thick root mats, which form microhabitats for aquatic macroinvertebrates (Vannote et al. 1980; Aguiar and Ferreira 2005; Ode et al. 2005). These habitat features are also used by fish for hiding, resting and feeding (Allan and Flecker 1993; Fausch et al. 2002).

There were elements, such as Channel condition or Pools, for which the scores of reaches with five years of certification were only marginally higher (P=0.08) than the scores of reaches in non-certified areas and similar to the scores of least-disturbed sites. These results suggest that more than five years of certification are required to ameliorate these elements. Channel condition, which evaluates geomorphic characteristics, is influenced by the occurrence of incision and aggradation. Both these processes affect streams at different rates and across the entire channel and tend to respond slowly to management changes (Poesen and Hooke 1997; Gordon et al. 2004). Similarly, the element of Pools seems to be responding slower to forest certification, possibly because pools are usually formed by the accumulation of woody debris from older shrubs and trees that obstruct the stream-flow (Naiman 2005; Allan and Castillo 2007). On reaches with five years of certification the riparian vegetation is probably still too young to provide sufficient quantities of woody debris generating a significantly higher number of pools, as compared to non-certified reaches.

The scores of the elements of Hydrologic alteration and Barriers to fish movement did not differ among certified, non-certified areas and least disturbed sites. These elements evaluate the presence of artificial structures or management practices that affect the hydrological regime of streams and restrict fish movements. The surveyed streams have a typical Mediterranean hydrological regime, drying out during most of the summer, which makes the streams unsuitable for agriculture irrigation and also explains the lack of artificial structures.

Elements related to water quality, such as Water appearance, Manure and human waste and Nutrient enrichment had similar high scores among all surveyed reaches. Water appearance depends on the quantity of suspended particles that enter the stream through bank erosion, whilst Nutrient enrichment depends on the amount of phosphorus and nitrogen resulting from agricultural runoff (Busse et al. 2006; García-Ruiz et al. 2008). Both these processes are strongly influenced by management practices occurring in other parts of the river network and have effects downstream (Poesen and Hooke 1997; Ode et al. 2005). This, coupled with the fact that cork oak woodlands are rain fed systems with low artificial nutrient input (Pinto-Correia 1993) explains why no significant differences were observed among the surveyed streams. The lack of differences in the score of Manure and human waste among the surveyed streams is related to the presence of livestock grazing in cork woodlands, which is a prevalent activity in these systems (Bugalho et al. 2009), that also occurs in certified areas, albeit at lower stocking rates when compared with non-certified areas.

FSC certification as a passive restoration method

Our results suggest that FSC certification is improving the ecological condition of the surveyed streams, possibly through passive ecological restoration, which occurs when ecological disturbances are removed or reduced, relying on natural regenerative processes without additional remedial actions (Suding 2011). Compliance with FSC management standards requires removing or reducing the main causes for stream degradation and this allows the ecological succession to proceed. Our results confirm the findings of two recent studies conducted in Europe and North America. For example, (Hough-Snee et al. 2013) found in northern Utah (USA) that after four years of passive restoration the vegetation composition had changed from grazing tolerant graminoids and forbs to hydrophytic graminoid and shrub species. In France, (Forget et al. 2013) found that six years of passive restoration increased the tree cover on river banks and contributed to improve the physical integrity of the banks.

The positive effects of forest certification that we found at the reach scale may spread across the hydrographic network in the medium to long term because of a large and increasing area under forest certification. For example, in the Portuguese part of the Tagus river basin, where this study took place, there are over 348 787 hectares of cork oak woodlands, out of which 73 330 hectares are FSC certified and this number is projected to grow (Dias et al. 2013). As FSC certification promotes the reestablishment of the riparian vegetation, reduces bank erosion and improves the availability of microhabitats, it would be important to determine which part of the stream network in this area is under FSC certification and then analyse the landscape effects that forest certification may be having in this region. The results of this study would allow us to better understand how FSC certification is affecting the streams crossing the 186 million hectares of certified forests worldwide.

Stream Visual Assessment Protocol (SVAP) as a monitoring tool for FSC certification

FSC certificates are issued for periods of five years during which certificate holders are audited annually to determine compliance with the management standards (www.fsc.org). We suggest that rapid bio-assessment protocols such as SVAP can be used by forest managers, landowners or forest certification auditors to evaluate the impacts of forest management on the condition of streams. This would validate the effectiveness of FSC management standards and help managers to demonstrate that they are contributing to the conservation of streams and riparian habitats.

FSC certification requires forest managers and auditors to make auditing and monitoring reports publicly available (www.fsc.org). By integrating a standardized and straightforward monitoring tool such as SVAP in forest certification, it would be possible to create a global database with data on the ecological condition of the streams crossing the 186 million hectares of FSC certified forests worldwide. This would allow forest managers and the scientific community to improve their understanding of the effects of forest management practices on the conservation of stream habitats.

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Chapter IV - Conservation zones promote oak regeneration and shrub diversity in certified Mediterranean oak woodlands

Submitted for publication

Conservation zones promote oak regeneration and shrub diversity in certified Mediterranean oak woodlands

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1. Abstract

Mediterranean oak woodlands are ecosystems of high conservation and socio-economic value that occur in Southwestern Europe, North Africa and California. Oak regeneration failure is occurring in these ecosystems and may be endangering their long term conservation. Most studies suggest that inadequate management practices may be contributing to oak regeneration failure. Forest certification is a voluntary type of certification, based on third-party auditing of compliance with performance-based sustainable management standards, that has been expanding in forest ecosystems worldwide, including in Mediterranean oak woodlands. The Forest Stewardship Council (FSC) certification is the dominant certification scheme in Mediterranean oak woodlands and requires landowners to establish conservation zones in their estates. Conservation zones usually correspond to a tenth of the estate and are primarily managed for biodiversity conservation. In spite of recent studies reporting positive effects of FSC certification and conservation zones on biodiversity and forest structure in tropical regions, its effects on tree regeneration in Mediterranean oak woodlands are unknown. In this study, conducted in South-western Europe, we compared the abundance of cork oak regeneration and the cover and diversity of Mediterranean shrublands between conservation and non-conservation zones in FSC certified cork oak woodlands. We found that in conservation zones oak regeneration was more abundant and that the species richness and diversity of shrubs was significantly higher. Shrub cover did not differ between conservation an non-conservation zones. Our results suggest the creation of set-aside areas in cork oak woodlands, such as conservation zones, may help avert the tree regeneration crisis this ecosystem is facing.

Keywords: cork oak, tree regeneration, Forest Stewardship Council, Mediterranean shrublands, distance sampling

1. Introduction

Mediterranean oak woodlands are integrated in the World Biodiversity Hotspots of the Mediterranean Basin and the California Floristic Province (Myers et al., 2000). They occur in the Mediterranean regions of California, Southwest Europe and North Africa (Huntsinger et al., 2013) harbouring significant concentrations of endemic and threatened species (Díaz et al., 2013). These ecosystems are characterized by a savanna type structure with a diverse understory of shrublands intermixed with grasslands with high heterogeneity (Miguel Nuno Bugalho et al., 2011; Díaz et al., 2013). These ecosystems are also socio-economically important, generating a variety of services such as livestock production, long term carbon storage, hunting or recreation (Caparrós et al., 2013).

Oak regeneration failure has been reported in Mediterranean oak woodlands globally and associated with inadequate management practices (e.g. overgrazing and intensive shrub clearing to reduce risk of wildfires), which may be endangering the conservation of these ecosystems. For example, in California overgrazing and shrub encroachment, combined with the introduction of annual exotic grasses are negatively affecting oak regeneration (Tyler et al., 2006). In Southwest Europe, there are two main groups of factors causing regeneration failure: 1) localized overgrazing and excessive shrub clearing in some regions and 2) lack of management, which causes shrub encroachment and increases wildfire risk in others (Acácio et al., 2007;

Pulido et al., 2010). In North Africa overharvesting of wood, overgrazing and overcollection of acorns for human and animal consumption are causing oak regeneration failure (Campos et al., 2007).

Some authors suggest that setting aside areas with low or no management, initiating secondary succession processes where shrub cover increases, can protect and enhance oak regeneration (e.g. Ramírez and Díaz, 2008; Rey Benayas et al., 2008). Decreasing herbivory and trampling by cattle may promote oak regeneration (Plieninger et al., 2010) but may also increase shrub cover, where acorn predation by mice is high (Acácio et al., 2007). Also, there are species-specific effects that can affect oak regeneration. For instance, shrubs such as *Retama* spp. and *Ulex* spp. can ameliorate the effects of harsh high temperatures and light conditions, improving seedling survival, while others such as *Cistus ladanifer* L. have been reported to compete with oak seedlings and decrease seedling survival (Acácio et al., 2007). In this context, understanding if management practices that involve setting aside areas with low or no management contribute to promote oak regeneration is critical for the maintenance of these systems.

Forest certification is a voluntary conservation mechanism, based on third-party auditing of compliance with performance-based sustainable management standards (Auld et al., 2008). Under Forest certification landowners and managers have to comply with a set of sustainable management standards that include environmental and socio-economic criteria (Auld et al., 2008). Products generated in areas under forest certification are labelled for consumer recognition and have higher market value (Gulbrandsen, 2010). Certification has been expanding worldwide with the two largest certification schemes, the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC), covering currently 251 and 186 million hectares, corresponding to 6.27 and 4.65% of the world's forests, respectively (FSC, 2014; PEFC, 2014).

The dominant certification scheme in Mediterranean oak woodlands is FSC certification, which requires landowners and managers to establish conservation zones in their estates. These zones usually correspond to a tenth of the estate area and are primarily managed for biodiversity conservation (Tollefson et al., 2009).

Studies on the impacts of FSC certification and conservation zones are mostly limited to tropical regions (e.g. Bennett, 2001; Gullison, 2003) and generally conclude that FSC certification has positive effects on forest conservation (Putz et al 2012). There are very few studies on the impacts of FSC certification on temperate forests and Mediterranean oak woodlands. For instance, Dias et al (2015) found that FSC certification benefited the ecological condition of Mediterranean streams crossing certified cork oak woodlands.

Cork oak woodlands are typical of the Western Mediterranean Basin and cover 1.5 million hectares in Southwest Europe and 1 million hectares in North Africa (J. Pausas et al., 2009). These ecosystems harbour high levels of biodiversity (Díaz et al., 1997) and provide cork, a non-timber forest product harvested every 9 to 12 years which is mainly used for bottle stoppers (Aronson et al., 2009). As in other Mediterranean oak woodlands, low cork oak regeneration is threatening this ecosystem (Pausas et al., 2009). The largest cover by cork oak occurs in Portugal (approximately 736 000 ha or 40% of its total area) where 100 thousand ha are under FSC certification. In FSC certified conservation zones landowners are allowed to harvest cork but livestock grazing and shrub clearing are halted or significantly reduced.

The main purpose of the present study was to assess whether the creation of conservation zones in FSC certified areas in Mediterranean oak woodlands can promote oak regeneration. We compared 1) the abundance of seedlings, saplings and young cork oak trees and 2) the cover and diversity of Mediterranean shrublands, in conservation zones and adjacent non-conservation zones in FSC certified cork oak woodlands. We also investigated if increasing the percentage of

FSC certificated areas devoted to conservation would further improve oak regeneration.

2. Methods

2.1 Study area

The study area is located in Southern Portugal, in the Alentejo region. The terrain is relatively hilly with a mean altitude of 54 meters above sea level. The climate is sub-humid Mediterranean, with a mean annual temperature of 16ºC and an average rainfall of 730 mm/year (AEM and IM, 2011). The dominant soil types are litholic humic and non-humic soils and podzols (Cardoso, 1974).

Cork oak woodlands, the dominant forest type in this region (Fig. 1), are characterized by a sparse tree cover of cork oak, mixed with holm oaks *Quercus ilex rotundifolia* Lam. or pine trees and a diverse understory of shrublands (e.g. rockroses *Cistus* spp., gorse *Ulex* spp., basil-leaved rock rose *Hallimium ocymoides* Willk., topped lavender *Lavandula stoechas* L. and rosemary *Rosmarinus officinalis* L.) interspersed with grasslands (e.g. *Agrostis* spp., *Avena* spp., *Bromus* spp.), pastures, fallows and cereal crops (Bugalho et al., 2009).

2.2 Field sampling

We surveyed eight FSC certified cork oak woodland estates, seven of which with six years of certification and one with four years (Table 1). In these estates we surveyed a total of 14 conservation zones, and 13 adjacent non-conservation zones for oak regeneration, shrub cover and diversity and adult tree cover, using line transects, as described below.

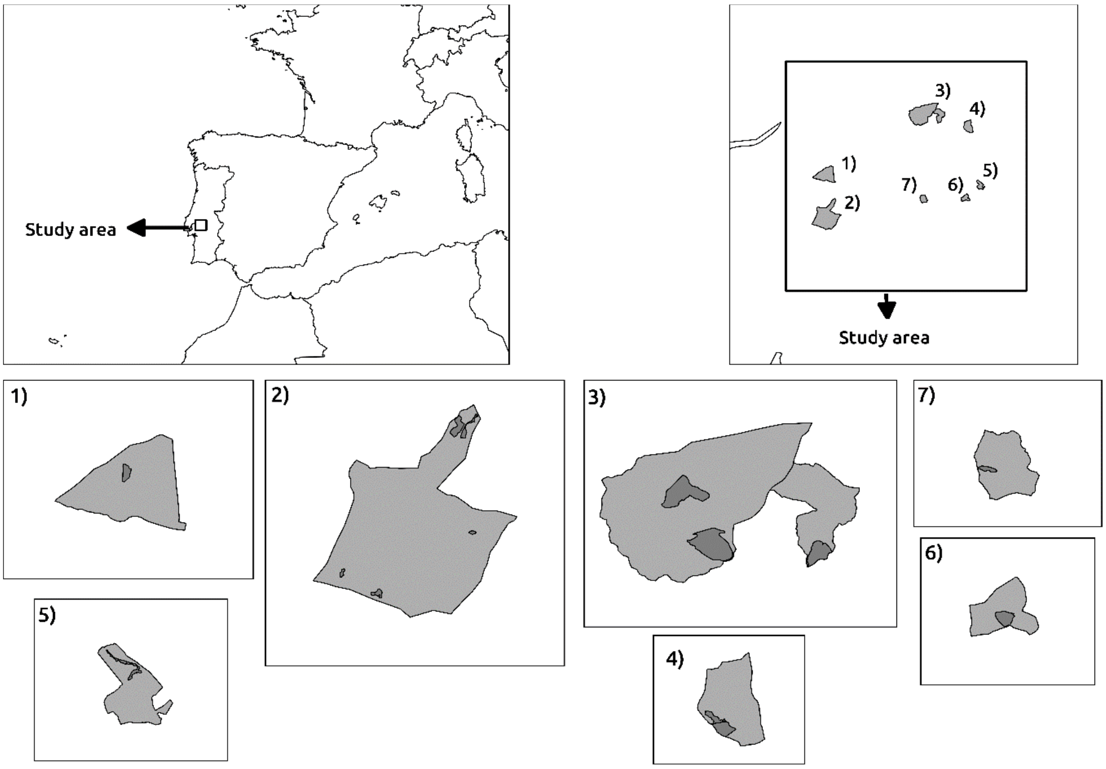

Figure 1 – Location of the estates (light grey) and of the surveyed conservation zones (dark grey). Map 3) shows two separate estates.

Three to five 50 metre line transects were randomly established in each conservation and non-conservation zone. Overall we established 86 transects, 41 in conservation zones and 45 in non-conservation zones (Table 1).

To estimate the abundance of cork oak regeneration we used distance sampling (Buckland et al., 2001). Distance sampling is a method for estimating population density based on surveying a number of randomly located transects. An observer travels along these transects and measures the perpendicular distance between each observation and the line. The method assumes the detection probability of an individual decreases with distance from the line, objects are stationary, all individuals located on the line are detected and distances are measured without error (Thomas et al., 2010). The distribution of the distances is used to estimate a detection function, expressing the probability of detecting an individual at a given distance. Numerical and factor covariates (e.g. plant height or habitat type) can be included in the detection function to improve model fit (Marques et al., 2007). The probability of detection can be incorporated into a robust (Horvtiz-Thompson-like) density estimator of abundance (Thomas et al., 2010). We recorded cork oak seedlings, saplings and young trees as well as the height of each recorded plant. Plants were classified as seedlings (height <= 10cm), saplings (10cm<height <=50 cm) and young trees (50 cm< height <=4 m and diameter at breast height <= 20 cm). We are aware that distance sampling is not common in vegetation surveys, despite the fact its assumptions are easily met in these studied, as there are no evasive movements and distances can be measured accurately (Buckland et al 2001). Distance sampling can offer some advantages relatively to conventional methods such as quadrat sampling, which consists in counting all individuals in a given sampling unit that can be of rectangular or circular shape (Krebs, 1998). Distance sampling does not assume that all individuals are counted, regardless of habitat conditions, which may not be possible for small plants and incorporates this uncertainty in the estimates. Also, surveyors can prospect larger areas in shorter periods, which is particularly important in highly heterogeneous areas such as Mediterranean oak woodlands.

We used the line intercept method to measure (relative) shrub cover (Canfield, 1941; Krebs, 1998). This method consists in recording the intercept length and perpendicular width of the shrub canopy projection of a shrub specimen intercepted by the transect. Shrub cover was calculated as a percentage of ground covered. The diversity of shrub species was calculated using the Shannon-Weaver diversity index.

We used the point-centered quarter method to measure (absolute) tree cover (Pollard, 1971). This method requires selecting a number of points along the transect and dividing the area around each point in four 90º quadrants. The distance between each points to the nearest tree, in each quadrant, is measured. We selected one point at the beginning, one at the middle (25 meters) and one at the end of each transect to avoid measuring the same individual at two successive points. Only trees with a diameter at breast height >=20 cm (adult trees) were considered. The diameter at breast height of each selected tree was recorded to calculate the basal area of the trees, which is a proxy for tree cover. With this information, using the point-centered quarter method, we computed the absolute cover of each tree species. Cork had highest tree cover and the cover by other species was negligible.

All field sampling work was conducted by the same 2 observers (FSD and JM).

Table 1 – Number and area of the surveyed conservation zones (CZ) and non-conservation zones (NCZ)

Estate	Years of certification	# CZ	Mean area of CZ (ha)	# Transects on CZ	# NCZ	Mean area of NCZ (ha)	# Transects on NCZ
Arrão	6	1	44.78	3	1	44.78	3
Caniceira	6	1	19.81	3	1	19.81	3
Cascavel	6	1	20.64	3	1	20.64	3
Cavaleiros	4	2	19.48	6	1	19.48	3
Fidalgos	6	5	7.72	15	5	7.72	15
Machoqueira	6	2	100.54	9	2	100.54	8
Onzenas	6	1	5.60	3	1	5.60	3
Pereira	6	1	8.49	3	1	8.49	3
TOTAL		14	45		13	41	

2.3 Density surface models

To model the effect of conservation zones on the abundance of cork oak seedlings, saplings and young trees we used density surface modelling (DSM) (Hedley and Buckland, 2004; Miller et al., 2013). This is a two-stage approach that involves 1) fitting a detection function to the distance data and using it to estimate the abundance of oak regeneration in each transect and 2) building a generalized additive model (Wood, 2006) to relate oak abundance per transect to environmental covariates.

Uniform, half-normal and hazard-rate detection functions were fitted to the data. Along with the adjustment terms, height of oak plants, shrub cover, tree cover and zone code (27 level factor) were included as covariates (one or two variables at a time) as they may affect plant detectability. Observed distances were truncated at six meters based on visual inspection of the detection function superimposed on the histogram of distances (Buckland et al., 2001) (Appendix 3). The best detection function was selected using Akaike's Information Criteria (AIC). All analyses were implemented using the Distance package version 0.9 for R version 3.0.1 (R Core Team, 2014). Oak regeneration abundances were estimated per transect from the detection function using a Horvitz-Thompson-like estimator (Borchers et al., 1998).

Models for the abundance of seedlings, saplings and young trees per transect were implemented using Generalized Additive Models (GAM) (Wood, 2006). Expected abundances in each transect were assumed to follow a Tweedie or quasi-Poisson distribution. The Tweedie power parameter was estimated during model fitting. The explanatory variables included the variable “zone type” which has two levels corresponding to conservation and non-conservation zones. Variables were divided in two groups “local” and “topographic”. This division allowed us to analyse the effects of local and topographic variables on cork oak regeneration, while minimizing correlation problems.

Local variables included absolute cover of adult trees and the cover and diversity of shrub species. We only considered shrub species that occurred in more than 20% of transects. These were: *Cistus salviifolius* L., *C. crispus* L., *Ulex spp.*, *Rosmarinus officinalis* L., *C. monspeliensis* L. and *Lavandula stoechas* L.. The topographic variables, which include slope, aspect and soil type were gathered from a Digital Elevation Model (METI and NASA, 2011) and Portugal's Soil Chart (Cardoso, 1974)

(Table 2) using QGIS 2.2 (QGIS Development Team, 2014). Each group of variables was used to fit the local and topographic variables.

GAM were fitted with the dsm package (Miller, 2014) for R 3.0.1 (R Core Team, 2014). Thin plate regression splines were used as the basis for the model's smooth terms. Basis complexity was selected by specifying an overly wiggly basis and then letting the penalty select the correct wigglyness of the term (Wood, 2006). To assess the degree of correlation and multiple correlation between the covariates, we calculated variance inflation factors (VIF) (Fox and Weisberg, 2010), all covariates had a VIF <3. Smoothness selection for the smooth terms was performed via restricted maximum likelihood (REML), because the REML criteria tends to have a more pronounced optima (Wood, 2011). The area surveyed in each transect multiplied by the average detection probability was used as an offset to account for effort expended. An estate identifier was included as an eight level random effect to account for non-independence in abundance within the same estate (Wood, 2013). Smooth terms were selected using approximate p-values ($p < 0.05$) and an extra penalty was included in the model that allowed each smooth term to be removed during model fitting (Marra and Wood, 2011). Deviance residuals were checked for normal distribution and constant variance (Wood, 2006). Spatial autocorrelation was assessed by examining a correlogram built with model residuals using function “correlogram” from the R package “spatial” (Venables, 2003).

2.4 Effects of increasing the area of conservation zones on oak regeneration

We applied the topographic models, which were built using variables that are available for the whole study area, to a prediction grid of cork oak woodlands collected and processes from the Portuguese National Forest Inventory (PNFI) comprising the whole study area (Autoridade Florestal Nacional, 2010). The PNFI is composed of 500 x 500 m squares that map the dominant land use in each square.

Table 2 – List of the variables included in the local and topographic density surface models

Variables	Name	Description and units
Seedlings abundance		Plants/transect (plants/300 m^2)
Saplings abundance		Plants/transect (plants/300 m^2)
Young trees abundance		Plants/transect (plants/300 m^2)
Local variables	Zone type	Categorical variable with two levels, that distinguishes between "conservation zones" and "non-conservation zones".
	Absolute cover of adult cork oaks	m^2/ha
	Shrub richness	Number of species
	Shrub diversity	Shannon-Weaver diversity index
	Lavandula stoechas cover	% of ground covered
	Rosmarinus officinalis cover	% of ground covered
	Cistus salvifolius cover	% of ground covered
	Ulex spp. cover	% of ground covered by *Ulex minor* and *Ulex australis*
	Cistus crispus cover	% of ground covered
	Cistus monspeliensis cover	% of ground covered
	Altitude	Meter
Topographic variables	Slope	Percentage
	Aspect	Azimuth
	Topographic ruggedness index	
	Topographic position index	
	Latitude	
	Longitude	
	Litholic soils	Percentage of cover
	Clayey soils with low saturation	Percentage of cover
	Podzol soils	Percentage of cover

We created three possible scenarios for testing if increasing the area of conservation zones would increase oak regeneration abundance: no conservation zones (Scenario 0), conservation zones covering 10% of the study area (Scenario 1), and conservation zones covering 20% of the study area (Scenario 2). Scenario 1 corresponds to the present FSC certification guidelines whilst Scenario 2 simulates a change in FSC guidelines requiring landowners to double the percentage of conservation zones area in their estates.

To predict the abundances of seedlings, saplings and young trees for Scenarios 1 and 2, we randomly selected as conservation areas 10% and 20% of the study area. For each Scenario 200 instances were created this way. For Scenario 0 200 instances replicating the respective condition were also created. The topographic models for seedlings, saplings and young trees were then used to predict, for each instance, the abundance per cell and the sum of these values gave an overall abundance estimate. The abundance estimate for each instance was stored and then these estimates were compared between different scenarios via the Mann-Whitney U test (e.g. : H_0 abundances generated when there was 10% conservation zones (Scenario 1) are from the same distribution as those abundances generated when 20% of cells were in the conservation zone (Scenario 2).

2.5 Shrub cover and diversity

For comparing the cover and diversity of shrub species between conservation and non-conservation zones, we applied linear mixed effects models using the R package “nlme” (Pinheiro and Bates, 2009). Shrub cover and diversity were used as response variables and “zone type” (categorical variable) as the independent variable.

We checked the model residuals for violations of normality and homogeneity and for spatial autocorrelation (Zuur et al., 2009). When homogeneity was violated a “VarIdent” variance structure was added to the model. To check for spatial autocorrelation a semivariogram was analysed. When spatial autocorrelation was detected we added a Gaussian correlation structure to the model. We determined if the random effects of the models were normally distributed by histogram inspection (Pinheiro and Bates, 2009).

3. Results

We counted 2409 cork oak plants in the 86 line transects. From these, 717 were seedlings, 1028 were saplings and 332 were young trees. The density of seedlings, saplings and young trees in conservation and non-conservation zones was (mean ± standard error of the mean) 1154 ± 144 plants/ha and 850 ± 173 plants/ha, 1639 ± 259 and 770 ± 119 plants/ha and 170 ± 33 plants/ha and 126 ± 31 plants/ha, respectively.

3.1 Detection function

The hazard rate detection function with plant height and zone code as covariates and with a truncation distance of 6 metre was selected by AIC. The other functions were poorer (ΔAIC > 59 ; Appendix 3, Table S1). The final truncation distance for the detection function was chosen by analysing how abundance estimates changed with the truncation distance. Since negligible differences were observed, we chose the model with the highest *p*-values from the Cramer-von Mises and Kolmogrov-Smirnov goodness of fit tests (Buckland et al., 2001). The average detection probability was 0.338 and its coefficient of variation was 0.03.

3.2 Local density surface models

DSMs with Tweedie distributions were selected. Seedling abundance was significantly higher in conservation zones and increased until cork oak cover reached 0.0025 m^2ha^{-1}, lowering afterwards (Fig. 2). Sapling abundance was significantly higher in conservation zones, increasing until the cover of shrub *Ulex* spp. Reached 11.5%, decreasing afterwards, and was negatively affected by *R. officinalis* cover

(Fig. 3). The abundance of young oaks increased significantly in areas of higher shrub diversity (Fig. 4) (Table 3).

3.3 Topographic density surface models

DSMs with Tweedie distributions were selected for seedlings and saplings. For young trees a quasi-Poisson distribution was selected. No topographic variables had an effect on the abundance of seedlings. The abundance of saplings was higher on the western part of the study area (Fig. 5). The abundance of young trees was significantly higher in areas with azimuth values of ~ 220 degrees, that is, in areas with a Southwest orientation. The abundance of young trees was also significantly lower in areas with higher percentages of cover of litholic soils and podzol soils (Table 3).

3.4 Predictions and uncertainty estimates

Adopting Scenario 1 would promote a significant increase in the abundance of seedlings ($W = 1050$, p-value < 0.0001) and saplings ($W = 0$, p-value < 0.0001), but not of young trees ($W = 20078$, p-value $= 0.9466$), when compared to the adoption of Scenario 0. The adoption of Scenario 2 would promote a significant increase of the abundance of seedlings ($W = 1313$, p-value < 0.0001), saplings ($W = 0$, p-value < 0.0001) but not of young trees ($W = 20310$, p-value $= 0.7889$) when compared to Scenario 1.

3.5 Comparing shrub cover and diversity between conservation and non-conservation zones

There were no significant differences in shrub cover between conservation (mean ± standard error of the mean) (12.46 ± 2.04 %) and non-conservation zones (10.05 ± 2.55 %). However, species richness (3.64 ± 0.28 vs 2.66 ± 0.65) and diversity (0.935 ± 0.10 vs 0.667 ± 0.13) of shrubs were significantly higher in conservation zones as compared to non-conservation zones. As for individual species, the cover of *Ulex* spp. was significantly higher in conservation zones (3.467 ± 0.273 vs 1.386 ± 0.100), but no significant differences were found for other species (Table 4).

Table 3 – Density surface models built using local and topographic variables, selected covariates and deviance explained. Smooth functions denoted by s( ). Zone type: conservation zone (+) denotes the abundance of seedlings, saplings or young trees was significantly higher on conservation zones.

Scale	DSM	Distribution	Covariates	Deviance explained
Local	Seedlings	Tweedie	Zone type:conservation zone (+), Cork oak cover, s(Estate)	35.7%
	Saplings	Tweedie	Zone type:conservation zone (+), *Ulex sp* cover, *R. officinalis* cover, s(Estate)	59.4%
	Young trees	Tweedie	s(Shrub diversity), s(Estate)	48.9%
Topographic	Seedlings	Tweedie	Zone type:conservation zone (+), s(Estate)	24.4%
	Saplings	Tweedie	Zone type:conservation zone (+), s(x and y coordinates)	44.7%
	Young trees	Poisson	s(Aspect), s(Area of litholitic non humic soil), s(Area of podzol soils), s(Estate)	63.1%

Table 4 - Summary table with the estimated regression parameters, standard errors (SE), t-values and *P*-values of the linear mixed effects models. The last column indicates the type (if any) of the added spatial correlation structure. *P*-values < 0.05 are printed in bold. “cons. zone” = conservation zone.

	Metric	Variable	Estimate	SE	t-value	p-value	Spatial correlation structure
Species richness	Richness	intercept	2.434	0.369	6.603	0.000	Gaussian
		cons. zone	1.033	0.345	2.989	**0.004**	
Shannon-Weaver diversity	Shrub diversity	intercept	0.615	0.108	5.707	0.000	Gaussian
		cons. zone	0.276	0.101	2.719	**0.008**	
Density	Overall	intercept	0.843	0.134	6.316	0.000	
		cons. zone	0.167	0.156	1.070	0.288	
	R.officinalis	intercept	0.076	0.047	1.623	0.109	
		cons. zone	0.016	0.050	0.327	0.745	
	C.salviifolius	intercept	0.382	0.067	5.712	0.000	
		cons. zone	-0.011	0.092	-0.117	0.907	
	Ulex sp	intercept	0.154	0.048	3.206	0.002	Gaussian
		cons. zone	0.072	0.036	1.974	0.052	
	C.crispus	intercept	0.136	0.055	2.502	0.015	
		cons. zone	-0.007	0.075	-0.098	0.922	
	L.stoechas	intercept	0.051	0.022	2.356	0.021	
		cons. zone	-0.009	0.022	-0.420	0.676	

	C.monspelliensis	intercept	0.0185	0.017	1.095	0.277	
		cons. zone	0.0119	0.017	0.712	0.479	
	Overall	intercept	9.624	2.704	3.559	0.448	
		cons. zone	2.122	2.782	0.763	0.448	
	R.officinalis	intercept	0.577	0.355	1.625	0.108	
		cons. zone	0.105	0.393	0.267	0.790	
	C.salvifolius	intercept	2.450	0.844	2.904	0.005	
		cons. zone	0.833	0.828	1.006	0.318	
Shrub cover	*Ulex sp*	intercept	1.606	0.807	1.991	0.050	Gaussian
		cons. zone	2.008	0.757	2.654	**0.010**	
	C.crispus	intercept	0.909	0.476	1.909	0.060	
		cons. zone	0.061	0.600	0.102	0.919	
	L.stoechas	intercept	0.288	0.186	1.549	0.126	
		cons. zone	0.058	0.126	0.462	0.645	
	C.monspelliensis	intercept	3.307	1.843	1.795	0.077	
		cons. zone	-2.769	2.345	-1.180	0.241	

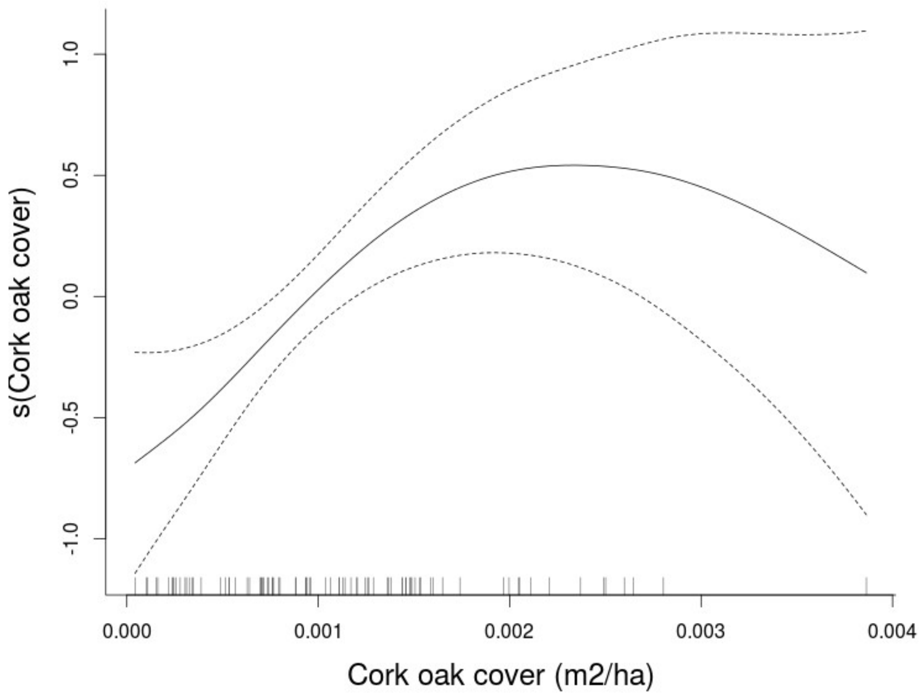

Figure 2 - Local seedlings model - smooth function of the variable Cork oak cover (m^2/ha).

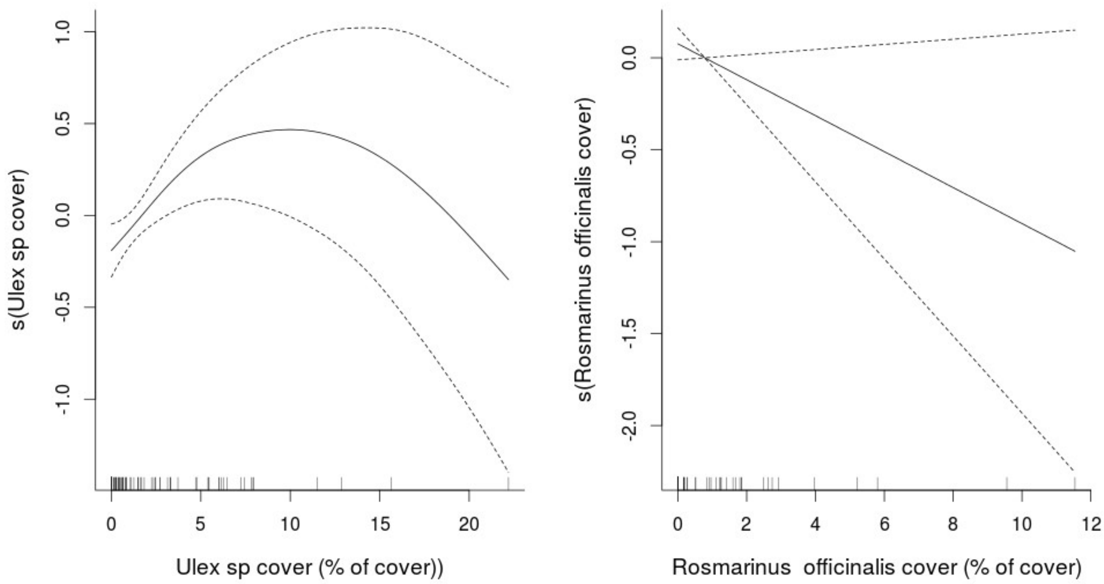

Figure 3 – Local saplings model - smooth functions for the variables *Ulex* sp cover (%) and *Rosmarinus offinalis* cover (%) included in the local saplings model.

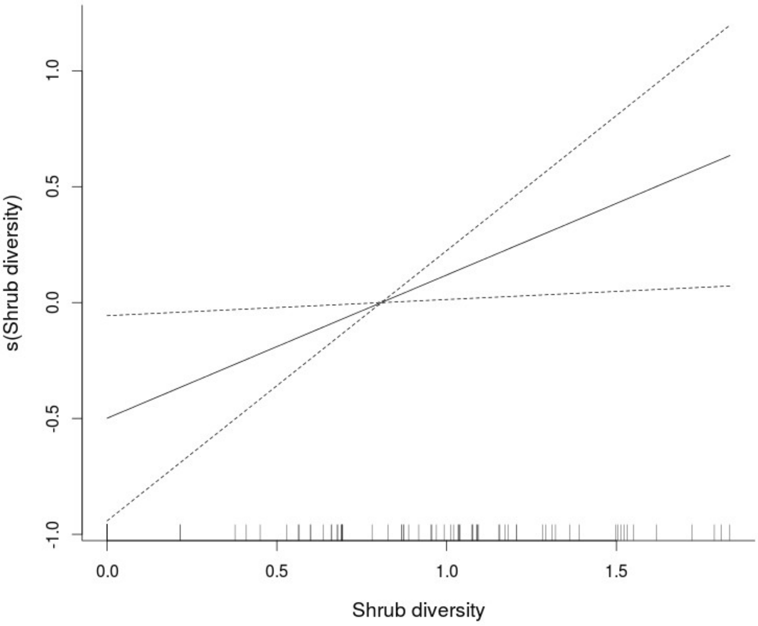

Figure 4 – Local young trees model - smooth functions for the variable shrub diversity.

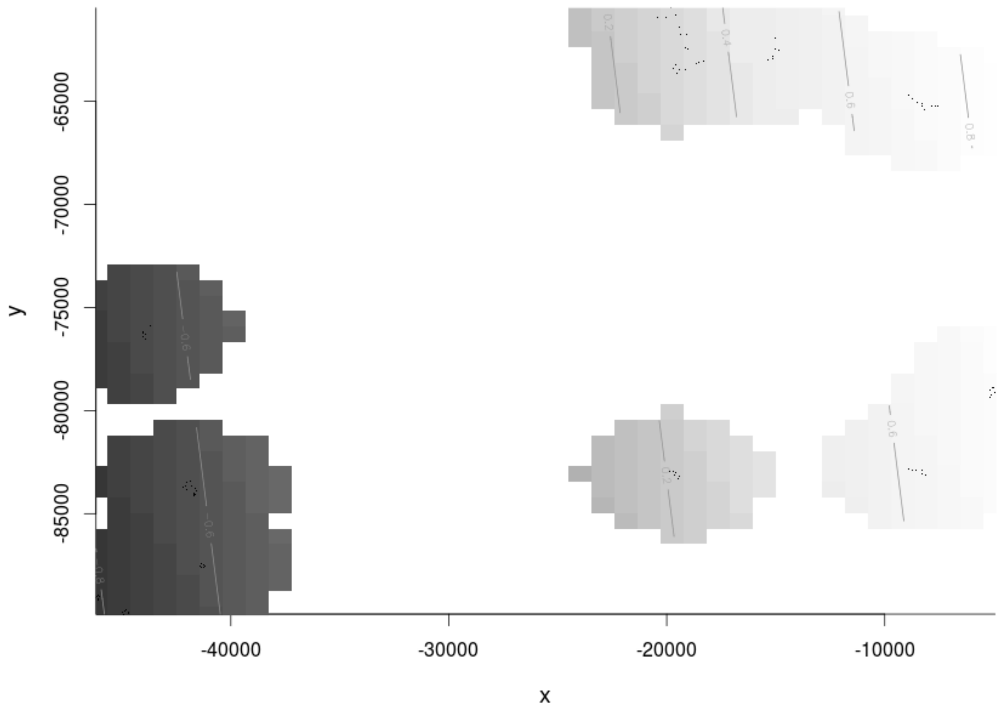

Figure 5 – Topographic saplings models – this image shows how the abundance of saplings changes with the x,y coordinates. Saplings abundance is shown in a colour

gradient ranging from light grey to dark grey. The black dots represent the locations where transects were started.

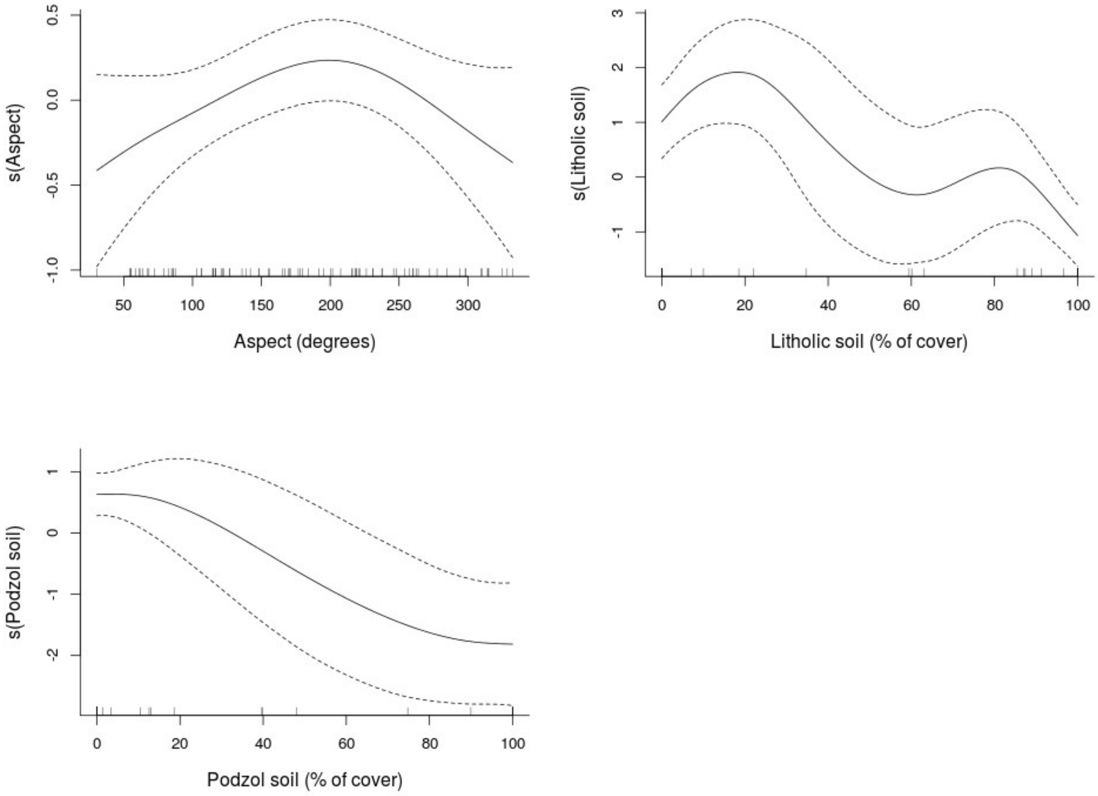

Figure 6 – Topographic young trees model - smooth functions aspect (expressed as azimuth value), cover of litholic soils (%) and cover of podzol soils (%).

4. Discussion

Our results suggest the implementation of conservation zones on certified cork oak woodlands had a positive effect on oak regeneration and shrub richness and diversity. Conservation zones are set-aside areas with less intensive management where livestock grazing and shrub clearing is halted or reduced. Grazing is important for maintaining the open structure of woodlands and promotes habitat heterogeneity

(Bugalho et al., 2011; Veldman et al., 2015), but high grazing pressure, decreases seedling survival and reduces oak regeneration (Plieninger, 2007). Over long periods, livestock grazing may reduce soil organic matter and cause soil compaction (Belsky et al., 1999), making it harder for young cork oak roots to grow and obtain water (Serrasolses et al., 2009). Shrub clearing is conducted in cork oak woodlands to reduce the risk of wildfires (Bugalho et al., 2009). However, it should be conducted over long rotation periods (e.g. 4 to 7 years) to allow for oak regeneration and recruitment (Aronson et al., 2009). Higher abundance of seedlings and saplings in conservation zones may be associated with low or no livestock grazing and less frequent shrub clearing. The period during which the surveyed estates were under forest certification (maximum of 6 years), however, did not allow for significant differences to be detected in the abundance of young trees. This is unsurprising as cork oaks are slow growing trees (Pausas et al., 2009).

Both grazing and shrub clearing reduction may explain the higher species richness and diversity of shrubs in conservation zones. It has been shown that long-term high grazing pressure reduces the species richness of the seed bank and the species richness of the above ground vegetation (e.g. Chaideftou et al., 2009). Shrub cover was similar in conservation and non-conservation areas, which may suggest grazing pressure differences and/or certification time may not have been enough to induce significant differences. The only shrub species whose cover increased in conservation zones were *Ulex* spp., which are very palatable species for livestock during its early stages of development when its spines have not hardened (Rodwell, 1998).

The abundance of seedlings increased with higher cork oak cover, which may be explained by a higher concentration of acorns beneath the tree canopy (Weltzin and McPherson, 1999). Positive effects on the microclimate under tree canopy may have also occurred. Drought is a key factor determining seedling survival in Mediterranean climates (e.g. (Gómez-Aparicio et al., 2005)). Tree canopy may facilitate seedling survival by protecting seedlings from high temperatures (Caldeira et al., 2014;

Puerta-Piñero et al., 2007) thus decreasing the need of water to transpire. Other indirect interactions include higher water availability through hydraulic lift (Brooker et al. 2008) or decreased competition with herbs whose biomass tend to be lower under oak canopies (Caldeira et al., 2014). Interestingly, seedling abundance did not respond to increased tree cover after a threshold of 0.0025 m^2/ha was reached. This may indicate that at such a tree cover competitive interactions between adult oak trees and seedlings may be prevalent (Plieninger et al., 2010).

Sapling abundance was higher in areas with intermediate levels of *Ulex* spp. cover but decreased with increasing cover by *Rosmarinus officinalis*. *Ulex* spp. are spiny, perennial, evergreen shrubs that can fix nitrogen and provide physical protection against livestock and shade to seedlings (Gómez-Aparicio et al. 2004). *R. officinalis* is an obligate seeder which is very competitive for water and soil nutrients, due to its high ratio root length to total plant biomass (Hernández et al., 2010). These traits may explain the negative effect of *R. officinalis* cover on the abundance of saplings.

The abundance of young trees seems to be positively associated with higher shrub diversity. Similar results were found for other oaks in the Mediterranean region (Plieninger et al., 2011). It has been shown that areas with a history of agriculture combined with intensive grazing in Mediterranean regions tend to present low shrub diversity due to seed bank depletion (Chaideftou et al. 2009). Some of these areas may also show low levels of oak regeneration due to habitat degradation (Navarro-González et al., 2013). Therefore, this result may suggest there is a higher abundance of young trees in areas where grazing and agriculture have been historically less intensive.

We did not find meaningful relations between the abundance of cork oak seedlings and saplings and topographic variables. Seedling survival is highly dependent on micro-environmental conditions (Plieninger et al., 2010) and probably the large scale nature of the topographic variables we used in this study does not translate into the finer regeneration niche scale of seedlings and saplings. The abundance of young trees was higher in areas with a Southwest orientation. Cork oak growth is particularly sensitive to water but also to light availability and older trees need enough light to be able to photosynthesise and produce photo-assimilates that exceed their respiratory needs (Caldeira et al., 2014). Also, cork oaks are particularly sensitive to frost and areas with a Southwest orientation are warmer and frost is less frequent (Pausas et al., 2009). Young trees are also less abundant in areas with higher cover by litholic non humic soils and podzols, which may be due to the fact these soil types have low organic matter content and are chemically poor (Serrasolses et al., 2009) and therefore less suitable for cork oaks. Cork oaks also develop better in soils not compacted or flooded with a structure that permits good aeration (Serrasolses et al., 2009).

The predicted abundance of seedlings, saplings and young trees increases in the study area with higher percentages of conservation zones (Scenarios 1 and 2). Currently, FSC certification requires landowners to establish conservation zones with an area corresponding to 10% of their estates (Scenario 0). Increasing the area of conservation zones to 20% (Scenario 2) would further increase oak regeneration but also reduce the availability of livestock grazing areas. In such cases, compensations to landowners could help balance the loss of financial returns from livestock production.

5. Conclusions

We show that conservation zones in certified Mediterranean oak woodlands promote oak regeneration and understory diversity. We also found that increasing the area allocated to conservation zones may contribute to increased oak regeneration at the landscape scale. This suggests that conservation zones can play an important role in ensuring the long term persistence of cork oak woodlands and promote their characteristic habitat heterogeneity on which several endemic and threatened species depend (Berrahmouni et al., 2009). We point out that these findings are likely to be highly conservative as we surveyed conservation zones in certified areas where management (even outside conservation zones) is already conducted according to environmental standards. FSC certification is expanding rapidly in forest ecosystems, therefore assessing how conservation zones are contributing to forest conservation is crucial to inform the present and future implementation of certification standards.

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Chapter V - Using the High Conservation Value Forest concept and Pareto optimization to locate areas optimizing biodiversity and ecosystem services in cork oak landscapes

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Using the High Conservation Value Forest concept and Pareto optimization to locate areas optimizing biodiversity and ecosystem services in cork oak landscapes

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1. Abstract

Montados 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 montados, but require adequate mapping and identification. The high conservation value forest (HCVF) framework allows systematic inventory of biodiversity and non-provisioning ecosystem services and is widely applied in forest ecosystems. Here we exemplify the application of HCVF to the cork oak landscape of southern Portugal using a WebGIS tool that integrates the HCVF framework, in conjunction with Pareto optimization, to identify areas important for the conservation of biodiversity and ecosystem services. We present a case study using threatened bird and reptile species, as examples of biodiversity attributes, and carbon storage and water

recharge rate of aquifers, as examples of ecosystem services attributes. We identify those areas in a cork oak landscape of southern Portugal where biodiversity and ecosystem services attributes are optimized. These areas can be prioritized for implementing conservation mechanisms, such as payment for ecosystem services, to promote sustainable forest management.

Keywords: Silvo-pastoral systems; montados; dehesas; Forest management; Biodiversity; Ecosystem services; Pareto optimization

2. 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 more closed or more open oak canopy, being structurally similar to forest or savanna type ecosystems, respectively. The typical silvo-pastoral system, called montado in Portugal and dehesa in Spain, has a relatively low density of trees (30–60 tree per ha) and a diverse undercover of 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; Oliveira et al. 2013).

Montados have considerable conservation value harboring several threatened and endemic vertebrate species (Diaz et al. 1997; Bugalho et al. 2011a) and are a priority habitat under the pan-European network of protected areas, the Natura 2000 network (Berrahmouni et al. 2009). There have been different revisions on the importance of these ecosystems for the conservation of biodiversity (Diaz et al. 1997; Joffre et al. 1999; Bugalho et al. 2011a) but few address non-provisioning ecosystem services (sensu Millenium Ecosystem Assessment 2005) delivered by these systems (for non-provisioning services delivered by montados see, for example: Berrahmouni et al.

2009; Bugalho et al. 2011a; Caparrós et al. 2013). Montados are human-shaped, socio-ecological systems maintained through management. Favoring adequate oak regeneration and a tree cover distributed over different age classes, clearing shrubs over long-term rotation cycles and maintaining grassland areas within the shrub matrix may contribute to the conservation of the system and its biodiversity (Benayas et al. 2008; Bugalho et al. 2011b; Santana et al. 2012). Mismanagement, including abandonment, endangers the ecological sustainability of the ecosystem. Overuse, namely overgrazing, 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 no shrubs (Pulido et al. 2001; Plieninger et al. 2003). Conversely, lack of management can lead to shrub encroachment which affects the whole ecology of the system (Eldridge et al. 2011). Effects of encroachment on the ecology of montados, namely facilitation or competition with oak seedlings can vary with shrub species identity (Rivest et al. 2011; Rolo et al. 2013). Shrub encroachment, however, usually increases the risk of severe wildfires (Acácio et al. 2007) and may cause loss of habitat heterogeneity and of biodiversity at certain spatial scales (Bugalho et al. 2011a; Bugalho et al. 2011b). For example, highly diverse grasslands (Díaz-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 (Acácio et al. 2007).

In Europe, montados occur mainly in the Iberian Peninsula, where they are mostly privately owned. Cork, a non-timber forest product harvested every 9 - 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 ensure cork production but to maintain oak regeneration and the ecological sustainability of the system (Caldeira et al. 2014). The socio-economic and ecological components are closed interlinked in montados. Economic incentives, based on valuation of biodiversity and ecosystem services, may complement cork and other provisioning services economic returns, and contribute to the sustainable use and conservation of montados. For example, compensating landowners for ensuring biodiversity conservation and delivery of non-provisioning services (Millenium Ecosystem Assessment 2005) is the basis of mechanisms such as payment for ecosystem services (PES) (Wunder 2005; Engel et al. 2008). However, implementation of such mechanisms requires the 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 (Senior et al. 2014; www.hcvnetwork.org) used to systematically identify biodiversity and ecosystem services delivered by forest ecosystems (Branco et al. 2010), which was developed under the Forest Stewardship Council (FSC) certification (Auld et al. 2008; Senior et al. 2014), a voluntary certification scheme which aims to promote the responsible management of the world´s forests. HCVF is covered by one of the FSC environmental 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 estates. HCV attributes cover biodiversity values and ecosystem services, including cultural services, identified in a particular forest management unit (Auld et al. 2008; Senior et al. 2014). 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 only on biodiversity values per se and away from ‘‘fortress conservation’’ approaches (e.g. Sarkar and Montoya 2011). By explicitly listing ecosystem services and including ‘‘human needs’’ into its framework, HCVF also relates to the Millennium Ecosystem Assessment classification of ecosystem services (Millenium Ecosystem Assessment 2005). Additionally, HCVF is an international standard adapted to the national and regional specificities through public interpretation of HCV attributes by multiple stakeholders (e.g. farmer and forest associations, public administration, non-governmental environmental organizations, research entities or private forest companies) which increases its power and legitimacy as a conservation tool. Although the application of HCVF concept has been criticized, particularly in tropical plantations (Edwards et al. 2012; Edwards and Laurance 2012), available data suggest that HCVF and FSC certification can deliver environmental benefits (Medjibe et al. 2013; Arbainsyah et al. 2014; Dias et al. 2015). HCVF has now been applied independently of forest certification and extended to other aims such as land-use and conservation planning, advocacy, or for developing responsible purchasing policies in forest and non-forest ecosystems (Senior et al. 2014; www.hcvnetwork.org). In the present work we exemplify the use of HCVF framework in conjunction with HCVs information and Pareto optimization (Pardalos et al. 2008), to identify areas important for the conservation of biodiversity and ecosystem services in cork oak landscapes of southern Portugal. We present a case study using threatened bird and reptile species as examples of biodiversity attributes and carbon storage and aquifer recharge rates as examples of ecosystem services attributes.

2. Methods

We used Pareto optimization, which defines a state in which resources are allocated in the most efficient manner (Pardalos et al. 2008), and data from the online geographic information system (WebGIS) ''Hotspot Areas for Biodiversity and Ecosystem Services'' (HABEaS) (www.habeas-med.org; (Branco et al. 2010; Bugalho and Silva 2014) to identify areas optimizing a set of HCV attributes in the main area of cork oak distribution in Portugal. HABEaS WebGIS uses the HCVF framework and provides free access to HCV attributes on biodiversity and ecosystem services in Portugal. The study area covers approximately 736,000 ha of cork oak landscapes including 500,000 ha located in the basin of rivers Tagus and Sado (Fig. 1). Data on cork oak distribution was taken from the Portuguese forest inventory (PFI) (Autoridade Florestal Nacional 2010). PFI data is based on photo-interpretation data (500 x 500 m resolution) collected at national scale between 2005 and 2006 (Autoridade Florestal Nacional 2010). PFI data discriminates land cover classes including forest cover, scrublands and agricultural areas with data on forest cover referring to tree cover only. The study area was formally defined using a 10 x 10 km UTM grid, commonly used in Portugal for national biodiversity surveys, by selecting the cells of this grid with a percentage of cork oak cover ≥ 10 %. We followed the Food and Agriculture Organization (FAO) criteria of classifying an area of Mediterranean forest if it has a canopy projection ≥ 10 % (FAO 2006).

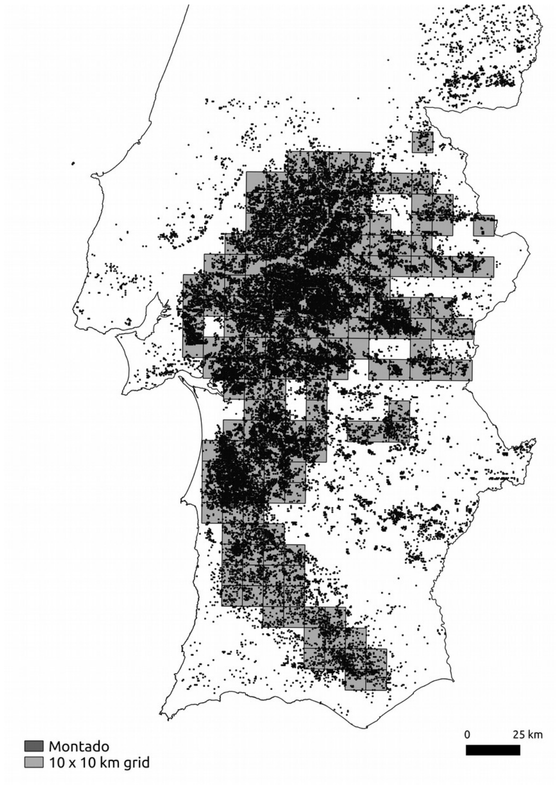

Figure 1 - Map of the study area showing the distribution of cork oak (Quercus suber) montado in southern Portugal in a superimposed on a 10 x 10 km cell grid. Data on cork oak distribution was taken from the Portuguese forest inventory which is based on photo-interpretation data (500 x 500 m resolution) collected at the national level.

We used data on threatened birds and reptiles occurring in cork oak ecosystems, as biodiversity attributes, and above ground carbon storage and aquifer water recharge rates, as ecosystem services attributes. We chose these attributes as bird species are frequently used as surrogates for biodiversity in different ecosystems (Larsen et al. 2012) and carbon storage and water regulation are frequently referred forest ecosystem services (Millenium Ecosystem Assessment 2005). We also included information on threatened reptiles as an additional biodiversity attribute. WebGIS data were originally gathered from publicly available information on biodiversity and ecosystem services. Data on bird distribution and bird species conservation status was gathered from the Portuguese Atlas on bird distribution (Equipa Atlas 2008) and the Red Book for Portuguese Vertebrates (Cabral et al. 2006). We followed a previous work by Dias *et al.* (2013) and selected those bird species that spend part or their whole life cycle in the cork oak montado. This includes 172 bird species from which ten are classified as critically endangered, 13 as endangered and 23 as "Vulnerable" (Dias et al. 2013). Data on the distribution of reptiles was collected from the Atlas of amphibians and reptiles of Portugal (Loureiro et al. 2008) which describes 22 reptiles occurring in cork oak ecosystems, from which two species are classified as ''Vulnerable'' and another two species are classified as ''Endangered''. The number of threatened species of birds and reptiles was computed for each 10 x 10 km cell within the grid of the study area. Data on cork oak forest biomass was also collected from the PFI (Autoridade Florestal Nacional 2010). Forest inventories were initially established to assess the commercial value of existent timber in stands but are currently being used worldwide as others sources of information, namely for the quantification and analysis of carbon pools at the regional level (Ciais et al. 2008). In the case of the PFI, aboveground biomass and carbon of montados was estimated through allometric equations that predict individual tree biomass per tree component (e.g. leaves, branches, stem, cork, wood and roots) (Autoridade Florestal Nacional 2010; Palma et al. 2014). We gathered from the PFI, a 500 x 500 m vector grid mapping the distribution of montado in Portugal. Each of these grid cells is classified under PFI as ''pure montado stands'', ''mixed stands where montado is dominant'' and ''mixed stands where montado is not dominant'' and has an associated average carbon storage (Autoridade Florestal Nacional 2010). We used this information to estimate the amount of carbon stored in each 10 x 10 km cell of the study area by summing carbon storage values associated with different montado classes occurring in this grid. Carbon storage data refers to biomass of cork oak trees only, not including information on other carbon pools such as the soil. We gathered data on aquifer water recharge rates from the management plans of the Tagus and Sado river basins and other river basins occurring in the study area (Lobo Ferreira et al. 1999; Oliveira et al. 2008; Agência Portuguesa do Ambiente 2012). This data consists on polygon vector layers which have associated mean aquifer water recharge rates. For each 10 x 10 km cell of the study area the weighted average of aquifer water recharge rates was computed using the area of each polygon as weight. We used QGIS 2.6 (QGIS Development Team 2014) to perform these calculations.

To identify areas that are important for biodiversity and ecosystem services we used the concept of Pareto optimality (Pardalos et al. 2008) which can be expressed as follows: consider a set of points in an n-dimensional space where each axis is associated to some (measurable) criterion. Each point can be viewed as a particular state with respect to the n criteria. A point P dominates point Q if P is at least as good as Q with respect to every criterion, and strictly better for at least one criterion. A point that is not dominated by any other point is called non-dominated or Pareto optimal. The concept of Pareto optimality has been increasingly applied to environmental management (Kennedy et al. 2007) and in different ecosystems including the montado (Porto et al. 2014). We identified the set of cells that are Pareto optimal regarding maximum values for four criteria: species richness of threatened birds, species richness of threatened reptiles, the amount of carbon stored in montado and the mean aquifer water recharge rates. We implemented this using the function ‘‘psel’’ from package ‘‘rPref’’ (Rooks 2014) of the software R 3.1 (R Core Team 2014). Although Pareto optimal cells may not have high values on every criterion, they may be viewed as the most suitable cells regarding the four criteria combined. Indeed, for every given non Pareto cell there is a Pareto optimal cell that is at least as good, or better, than that cell in representing every of the conservation attributes analyzed. To evaluate the relative importance of Pareto cells, the value of each criterion can then be compared with a reference value. In our example, we used the average and the median of particular attributes.

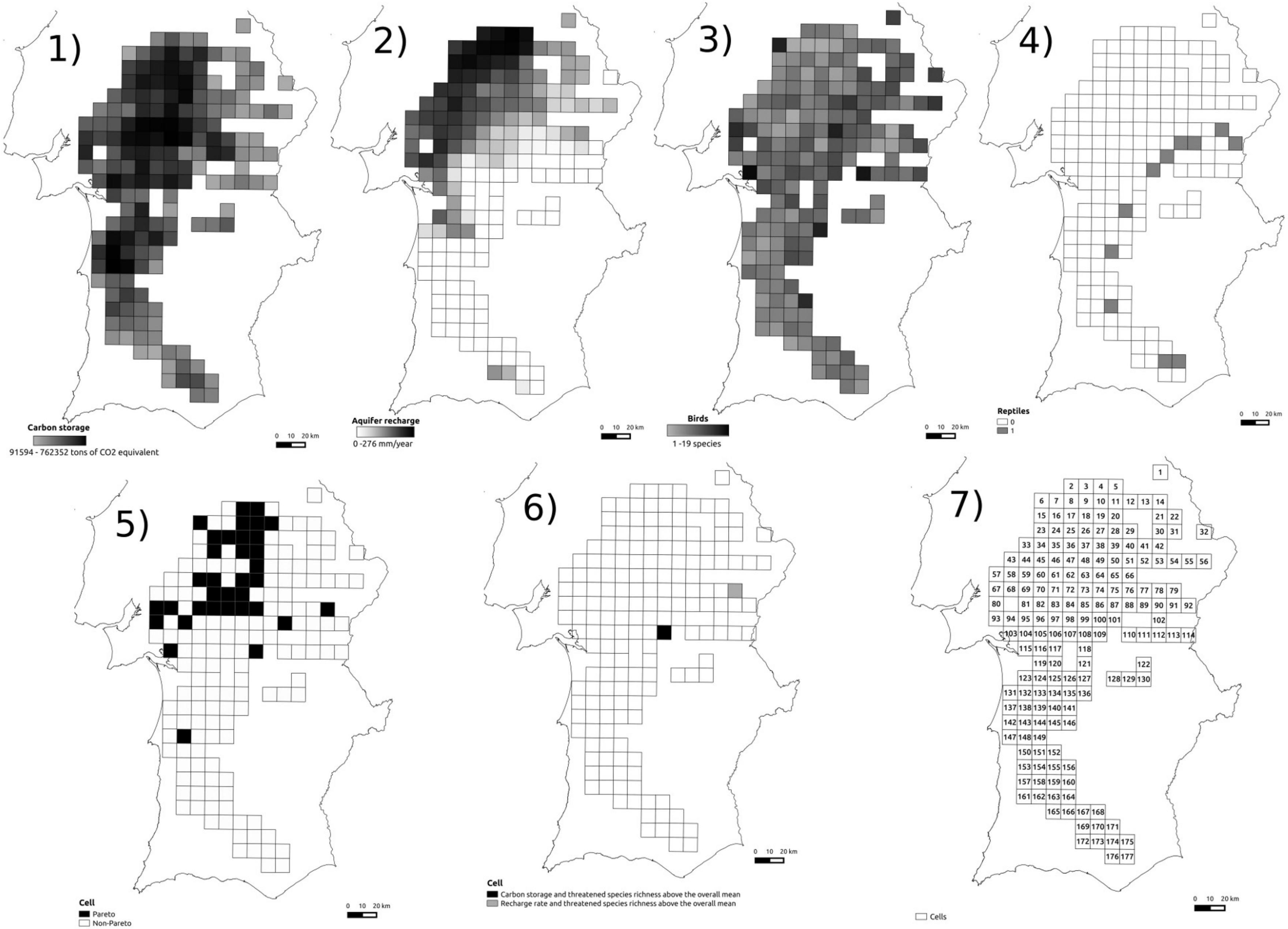
1)
Carbon storage
91594 - 762352 tons of CO2 equivalent
0 10 20 km
2)
Aquifer recharge
0 -276 mm/year
0 10 20 km
3)
Birds
1 -19 species
0 10 20 km
4)
Reptiles
0
1
0 10 20 km
5)
Cell
Pareto
Non-Pareto
0 10 20 km
6)
Cell
Carbon storage and threatened species richness above the overall mean
Recharge rate and threatened species richness above the overall mean
0 10 20 km
7)
Cells
0 10 20 km

Figure 2 - Map of the study area showing 1) carbon storage, 2) aquifer recharge rates, 3) number of threatened bird species, 4) number of threatened reptile species, 5) Pareto cells, 6) Pareto cells for which carbon storage and aquifer recharge rates, combined with number of threatened bird and number of threatened reptile species, are above the overall mean and median and 7) grid cell numbering for facilitating the description of the results. Data is represented on a 10 x 10 km grid cell and was obtained from different sources. Data on aboveground carbon storage was computed from the Portuguese Forest Inventory (Autoridade Florestal Nacional 2010). Data on aquifer recharge rates was taken from river basin management plans (Lobo Ferreira et al. 1999; Oliveira et al. 2008; Agência Portuguesa do Ambiente 2012). Data on threatened bird species and threatened reptile species was collected from the Portuguese Atlas on bird distribution (Equipa Atlas 2008) and Atlas of amphibians and reptiles of Portugal (Loureiro et al. 2008), respectively.

3. Results

The HCVF framework and the data gathered from HABEaS WebGIS allowed us to use Pareto optimization to identify areas maximizing biodiversity and ecosystem services in the study area (Fig. 2). Among the Pareto cells we identified those areas of cork oak landscapes associated with high levels of biodiversity and carbon storage and those areas that are biodiversity rich and associated with high aquifer water recharge rates. When simultaneously considering the number of threatened species of birds and reptiles, carbon storage and aquifer water recharge rates, 35 Pareto optimal cells could be identified in the study area (approximately, 350000 ha) (Fig. 2). That is, when considering each of the identified Pareto cells individually, no alternative cells can be found in the study area that optimize the four considered conservation attributes as well as that cell. When considering each attribute individually, the mean and median of Pareto cells were (with the exception of number of threatened bird species) higher than the overall mean and median of the attributes for the overall of the study area (Table 1). Pareto cells may have low values in some criteria but, in these cases, they will also be associated with high values in other criteria. For example, Pareto cell number 6 has a below average value for carbon storage and has no threatened reptile species, however it records one of the highest number ofthreatened bird species (15 species) in the study area (Table 1).

In general, the highest values for each attribute do not coincide in the same cells. For example, Pareto cell 4 has the highest water recharge rate in the study area but harbors no reptile species and has below average values for carbon storage and threatened bird species. Conversely, Pareto cell 14 has one of the highest carbon storage values in the study area but also a below average value of threatened bird species (4 species only) and it is located within an area of no aquifer influence (recharge rate is null) (Table 1). We could find one Pareto cell showing equal or above average values for carbon storage and threatened bird and reptile species (species richness) and another cell with equal or above average values for water recharge rates and species richness (Fig. 2).

4. Discussion

The HCVFs framework and data provided by HABEaS WebGIS, provides a simple and coherent way of inventorying and systematizing data on biodiversity and ecosystem services.This, combined with Pareto optimization, shows potential for identifying conservation priority areas through optimization of HCV attributes. Here we focused on four HCV attributes (2 biodiversity and 2 ecosystem services attributes). This approach allows the identification of sites optimizing multiple combinations of biodiversity and ecosystem services attributes. Identification of areas important for the conservation of biodiversity and ecosystem services is essential to prioritize areas for setting up conservation mechanisms promoting sustainable ecosystem management, such as payments for ecosystem services (PES) (Wunder 2005; Engel et al. 2008). For example, companies willing to invest in conservation could be viewed as potential buyers of services on which their core business depends and fund sustainable management practices in areas important for the conservation of biodiversity and ecosystem services.

Table 1- Mean and median values for carbon storage, aquifer recharge rate, number of threatened bird species and number of threatened reptile species for all cells (overall) and for Pareto cells in the study area. The number (and percentage) of Pareto cells which have values for each of the conservation attributes above, or equal, than the overall mean and median are also shown.

Conservation attribute	Mean for Pareto cells	Overall mean	Number and % of Pareto cells ≥ overall mean	Median for Pareto cells	Overall median	Number and % of Pareto cells ≥ overall median
Carbon storage (tons of CO_2 equivalent)	404 443	307 218	145 (82 %)	407 873	276 884	156 (88 %)
Aquifer recharge rate (mm/year)	154	87	156 (88 %)	188	50	156 (88 %)
Number of threatened bird species	6	7	62 (35 %)	6	6	62 (35 %)
Number of threatened reptile species	0.09	0.06	10 (6 %)	0	0	10 (6 %)

Different PES schemes can be found worldwide (Engel et al. 2008). For example, in Portugal, the World Wide Fund for Nature (WWF) leads a conservation initiative which aims to promote the sustainable use of cork oak landscapes by seeking donors willing to compensate landowners that commit to sustainable management practices (Bugalho and Silva 2014). This initiative uses information provided by HABEaS WebGIS to identify areas where biodiversity and particular ecosystem services overlap. Pareto optimization, coupled with this information, will contribute to prioritize areas according the main interests of donours. For instance, companies willing to mitigate their carbon footprint may be willing to invest in areas important for carbon storage and biodiversity, whilst bottling industry companies may be more interested in investing in areas important for biodiversity and water conservation. Electing conservation areas according to a set of optimized attributes is possibly more appealing to attract conservation funds.

Our results imply that in approximately 20 000 ha of the study area there are locations where biodiversity and carbon storage are high and locations where biodiversity and water recharge rates are high. This suggests that the implementation of conservation schemes promoting sustainable management in these locations may favor biodiversity and ecosystem services simultaneously. Similarly, identifying areas that optimize particular conservation attributes may be used to delimit and select conservation areas within forest certification schemes (Auld et al. 2008). Information provided by HABEaS WebGIS, has been used by forest landowner associations in Portugal (e.g. Forest Producer Association of Coruche, Forest Producer Association of Vale do Sado) to identify areas for conservation within their properties, as required by FSC certification. Pareto optimization may further increase the information on conservation attributes of particular locations and thus contribute to delimitation and selection of conservation areas in certified estates.

In the case of silvo-pastoral systems, such as montados, HCVF targets the forest component of the system. There are other conservation frameworks which target the farming component of these systems and which may benefit from the analytical approach presented here. An example is the high natural value farmland systems (HNVF). HNVF are low-input, extensive farming systems which generate habitat hosting species of conservation concern (European Agency for the Environment 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 McCracken 1996) and over 20 % of the European countryside qualifies as HNVF (Pointereau et al. 2007) including the cork and holm oak (*Q.rotundifolia* L.) silvo-pastoral systems (montados and dehesas) of the Iberian Peninsula (European Agency for the Environment 2004; Pointereau et al. 2007; Pinto-Correia and Ribeiro 2012). Other HNVF systems include seminatural grasslands, steppes and extensive cereal fields (Pointereau et al. 2007; Paracchini et al. 2008; Ribeiro et al. 2014). HNVF areas are frequently classified according to management intensity such as grazing pressure or levels of fertilizers and herbicides used (European Agency for the Environment 2004) which may vary widely within these areas. In montados, for example, management intensity may vary with grazing regimes and animals species used (e.g. cattle, sheep, game species) or with varying amounts of land allocated to grasslands, pastures, shrublands or complementary agricultural crops (Berrahmouni et al. 2009). This means that, provided information is available, indicators of management intensity could be analyzed using Pareto optimization to discriminate levels of farming intensity within HNVF systems, such as the montado. Such approach would allow prioritizing areas for of application of agri-environmental schemes in areas classified as HNVF (Kleijn et al. 2009). Using the HCVF or similar conservation frameworks, together with optimization approaches, to identify priority conservation areas in montados or similar ecosystems, is a line of research that deserves further work in the future.

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Chapter VI - General Discussion and Final Remarks

1. FSC certification and Protected Areas: socio-economic contexts

Conservation planning is a very complex field that has to deal with limited financial resources, which requires practitioners to define clear objectives and priorities (Margules and Pressey 2000; Noss et al. 2009) and to use a number of different conservation tools to achieve a given conservation goal (Sarkar et al. 2006). FSC certification is a market-based voluntary conservation tool, initiated by forest landowners or managers, which is based on the implementation of sustainable forest management standards developed through a public participation process (Auld et al. 2008). It is based on the assumption that certified products have added value market value and/or are allowed to access markets that are closed to unsustainable generated products (Auld et al. 2008; Araujo et al. 2009). Landowners can abandon FSC certification at any moment if they decide it is no longer advantageous to them. In this sense, forest certification contrasts with other conservation mechanisms such as protected areas. A protected area is a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values (www.iucn.org). Protected areas are based on the implementation of land use restrictions imposed by governmental agencies and stakeholders are frequently left out of the decision process, which often leads to conflict and has negative impacts on their conservation effectiveness (McDonald and Boucher 2011).

Studies have shown that most conservation actions rarely consider the broader social-ecological systems in which conservation planning initiatives operate, focusing instead on biodiversity values alone (e.g. Knight and Cowling 2003; Knight et al. 2006). Implementation of conservation actions, such as forest certification or design and management of protected areas imply financial costs that need to be accounted for and failing to do so may hinder their conservation objectives (Carwardine et al. 2006; Naidoo et al. 2006). As other conservation tools, FSC certification is strongly affected by the social and economic contexts. FSC certification is complex and requires frequent third-party auditing. As a consequence, it is more likely to be adopted in countries where the gap between FSC and government regulations is smaller (Mcdermott et al. 2008). Partly because of this, FSC certification expanded quicker in developed countries of Europe and

North America and is progressing slower in developing countries of Africa, South America and Asia (Auld et al. 2008).

In the present thesis we found that FSC certification in cork oak woodlands in Portugal started in regions with more favourable social and economic conditions (North Alentejo) characterized by high cork production and high average estate sizes (Chapter 2). In these regions Associations of cork oak producers are well implemented, employ professional forest managers and provide technical support to associates willing to adopt FSC certification. The existence of well established associations in these regions also encouraged the implementation of FSC Group certification, a certification variant that allows for a group of landowners to be certified under a single certificate, held by single a group manager entity (usually an Association) which reduces certification costs. In this case the group manager entity is responsible for auditing its members and is, in turn, audited by an independent third party (Lindahl and Garforth 2001; Marx and Cuypers 2010).

In other regions, namely those with a less favourable socio-economic context, the adoption of FSC certification is more challenging. For example, in the Portuguese regions of Southern Alentejo and Algarve, characterized by small average estate sizes (e.g. below 20 ha) (Coelho 2003) and where cork oak producers associations are less well established, the expansion of FSC certification is likely to be slower. In these regions, mechanisms for incentivizing cork oak landowners to aggregate their forest areas and manage them according to a common landscape-scale management plan are crucial for encouraging FSC certification. An example that could be synergetic with Forest Certification is the concept of Forest Intervention Zones (FIZ), which were created by the Portuguese government to mitigate the risk of wildfires. FIZ are continuous forest areas, comprising estates from more than one landowner that are subject to a single forest management plan and managed by a single entity (ICNF 2013). As of February 2015 there were 857 000 hectares of FIZ in Portugal, 47% of which were located in Southern Portugal (ICNF 2013). Assessing synergies between FIZ and forest certification may be a promising way to incentivize landowner associations to develop and implement common management plans and promote sustainable forest management in small estates.

2. Can forest certification complement the role of protected areas?

The establishment of protected areas is often biased towards areas of lower productivity and economic value, frequently not covering areas of high biodiversity (Loucks et al. 2008; Joppa and Pfaff 2009). Using and implementing conservation tools that complement the role of protected areas is therefore crucial. We found that FSC certification is not targeting areas of high biodiversity value in the cork oak woodlands of Portugal (Chapter 2). However, we also found that only 5.3 % of certified areas overlap with protected areas or the Natura 2000 network. That is, certification may be promoting sustainable forest management and conservation in areas that are not formally protected. Determining if and how currently certified areas may improve the functional and structural connectivity of protected areas and Natura200 network is an important line of future research (e.g. Tambosi et al. 2014).

Our results also suggest that creating set-aside areas such as conservation zones has positive effects on biodiversity conservation, improving the ecological condition of streams, increasing the richness and diversity of shrublands and the abundance of cork oak regeneration. By promoting the conservation of riverine and shrubland habitats, it is likely that species dependent on these habitat types will also be favored.

Indeed there are several studies documenting the importance of riparian vegetation for the conservation of birds and mammals. For instance, different studies have shown that riparian habitat condition is an important determinant for breeding bird assemblages both on Mediterranean oak woodlands (Layman 1984; Godinho et al. 2009) and temperate forests of North America (Cooke and Zack 2009). As for mammals, it has been shown that in cork and holm oak woodlands of Portugal, species richness of mammalian carnivores was significantly higher in sites close to riparian areas, when compared to adjacent agricultural areas (Matos et al. 2009). Also, streams in a better ecological condition tend to have a significantly higher number of carnivore species, when compared to those in poorer condition (Virgós 2001; Matos et al. 2009).

In the present thesis it is also shown that FSC certification thourgh the implementation of conservation zones favors the cover and diversity of the shrubland understory. Consequently, several species dependent on these habitat types, namely threatened vertebrates, may also be favored. Mediterranean shrublands are key habitats for the conservation of vertebrate species such as the critically endangered Iberian imperial eagle (*Aquila adalberti*), the Eurasian black vulture (*Aegypius monachus*) and the Iberian lynx (*Lynx pardinus*) (Cabral et al. 2006; Palomares et al. 2010). Maintenance and conservation of Mediterranean shrublands, favored by sustainable management practices and forest certification, may thus contribute to the conservation of these species. Different studies have also shown that the species richness and population density of more common mammalian carnivores (e.g. badger *Meles meles* L., *Martes foina* Erxleben. and *Herpestes ichneumon* L.) occurring in holm oak woodlands of Extremadura (Spain) is higher in areas with higher shrub cover (Mangas et al. 2008). In Mediterranean oak woodlands of California (USA) the presence of shrubs in tree patches is associated with high diversity of birds, mammals and reptiles (Tietje and Vreeland 1997). By promoting the conservation of shrub communities, forest certification and conservation zones are also likely to favor associated vertebrate species.

3. Monitoring the effects of forest certification: which survey methods?

Monitoring is essential for assessing the outcomes of conservation planning, be it the implementation of protected areas or forest certification (Gardner 2012). Although FSC certification requires frequent auditing to assess if forest management standards are being met, it does not require quantitative evaluation of conservation outputs. The implementation of user-friendly and straightforward assessment methods such as the Stream Visual Assessment Protocol for monitoring the ecological condition of riverine habitats, or Distance Sampling for assessing tree regeneration, may allow forest managers and FSC auditors to quantify the conservation outcomes of implementing certified management practices in different forest management units.

SVAP is a straightforward assessment method that can be applied by users with little or no training in stream ecology (Bjorkland et al. 2001; NRCS 2009). SVAP does not replace exhaustive methods such as, for instance, the River Habitat Survey (RHS), which aims to characterize and assess the physical structure of freshwater streams and rivers and to monitor and assess potential impacts of developments on stream ecosystems (Environment Agency 2003). However, it may help managers and auditors to determine if certified management practices are contributing for the conservation of stream and riparian habitats. Although RHS is widely used in Europe and has been adopted in Portugal to characterize the ecological and hydromorphological condition of streams under the Water Framework Directive (Ferreira et al. 2011), it is unsuitable for forest managers and auditors due to its complexity and specific training and accreditation requirements. SVAP may represent a reasonable and cost-effective monitoring methodology for managers and forest certification auditors to assess if certified management practices are benefiting conservation of streams.

Methods such as the line intercept method (Canfield 1941; Krebs 1998) the point-centered quarter method (Cottam et al. 1953) and distance sampling (Buckland et al. 2001; Thomas et al. 2010) may also be used by managers for monitoring shrub species composition, tree cover and tree regeneration (Chapter 3). The line intercept or the point-centered quarter method have been used by forest managers in North America for decades (Krebs 1998) and could surely be used in Portugal and other regions under forest certification. Also, distance sampling, which has rarely been used to estimate plant abundance (but see Buckland et al. 2007) could be a very useful tool for managers. Distance sampling allows prospecting large areas in a relatively quick way, thus covering more variability, which is particularly important in heterogeneous ecosystems such as cork oak woodlands (see Chapter 4). Moreover, the method assumes that not all individuals are observed and that detectability is affected by the distance to the individuals and habitat type. Also, because plants do not move, it can be assumed that all individuals along the center line (see Chapter 4) are counted and that distances between the individuals and the line are measured with minimal error. Additionally, distance sampling could be used by managers for monitoring others variables rather than tree regeneration such as wildlife, namely game species. There are several free software implementations of distance sampling methods that can be easily obtained by managers.

All the above methods could be used in the context of forest certification monitoring and auditing, since they are easy to learn, quick to apply and produce reliable estimates. This is possible way of progressing towards quantitative monitoring of forest certification.

4. Funding opportunities to promote forest certification

FSC certification in cork oak woodlands currently requires creating conservation zones usually corresponding to a tenth of the size of the estates (Tollefson et al. 2009). Results of the present thesis show that conservation areas promote oak regeneration. Increasing the area or number of conservation zones in estates may, however, imply limiting livestock grazing, an important source of income for several cork oak landowners. In cases where limiting land uses outweigh the economic benefits of forest certification, it will be necessary to find appropriate mechanisms to incentivize landowners to increase the area of conservation zones. For example, the Agri-environment schemes (AES) of the European Union's Common Agricultural Policy, which aim to promote environmentally friendly farming practices through monetary compensations to farmers (Kleijn and Sutherland 2003; Kleijn et al. 2009) could be adapted to these aims. Indeed, these schemes have been used to promote rotational grazing and temporary set-asides of land for promoting tree regeneration in landscapes facing a tree regeneration crisis (e.g. Manning et al. 2009; Lindenmayer 2011) which would agree with the aims of FSC conservation zones. However, the administrative complexity of these schemes may hinder their adoption by landowners and reduce their effectiveness (Kleijn et al. 2001). Other financial incentives, such a Payment for Ecosystem Services (PES), schemes under which landowners are financially rewarded for adopting and maintaining practices ensuring the conservation of biodiversity and ecosystem services (Wunder 2005) can be viewed as funding options. In this thesis (Chapter 4) it is shown that there are wide areas of cork oak woodlands located in regions of high carbon storage and of high aquifer recharge that overlap with areas of high biodiversity. PES could be implemented in these areas using FSC certification as a verification system for sustainable management practices (see for example Bugalho and Silva 2014). In such cases, PES financial rewards had to compensate the costs of reducing management practices generating income such as livestock grazing or increasing the area of conservation zones.

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Appendices

1. Appendix 1 – Chapter II

1.1 List of bird species

Scientific name	Common name	Conservation status[1]
Accipiter gentilis	northern goshawk	VU
Accipiter nisus	Eurasian sparrowhawk	LC
Acrocephalus arundinaceus	great reed warbler	LC
Acrocephalus scirpaceus	Eurasian reed warbler	NT
Actitis hypoleucos	common sandpiper	VU
Aegithalos caudatus	long-tailed tit	LC
Alauda arvensis	Eurasian skylark	LC
Alcedo atthis	common kingfisher	LC
Alectoris rufa	red-legged partridge	LC
Anas clypeata	northern shoveler	EN
Anas crecca	Eurasian teal	LC
Anas platyrhynchos	mallard	LC
Anas querquedula	garganey	NE
Anas strepera	gadwall	VU
Anthus campestris	tawny pipit	LC
Anthus trivialis	tree pipit	NT
Apus apus	common swift	LC
Apus caffer	white-rumped swift	NE
Apus melba	alpine swift	NT
Apus pallidus	pallid swift	LC
Aquila chrysaetos	golden eagle	EN
Aquila fasciata	Bonelli's eagle	EN
Ardea cinerea	grey heron	LC
Ardea purpurea	purple heron	EN
Ardeola ralloides	squacco heron	CR
Asio otus	long-eared owl	DD
Athene noctua	little owl	LC
Aythya ferina	common pochard	EN
Bubo bubo	Eurasian eagle-owl	NT
Bubulcus Ibis	western cattle egret	LC
Burhinus oedicnemus	Eurasian stone-curlew	VU
Buteo buteo	common buzzard	LC
Calandrella brachydactyla	greater short-toed lark	LC
Calandrella rufescens	lesser short-toed lark	CR
Caprimulgus europaeus	European nightjar	VU
Caprimulgus ruficollis	red-necked nightjar	VU
Carduelis carduelis	European goldfinch	LC
Cercotrichas galactotes	rufous-tailed scrub robin	NT

Certhia brachydactyla	short-toed treecreeper	LC
Cettia cetti	Cetti's warbler	LC
Charadrius alexandrinus	kentish plover	LC
Charadrius dubius	little ringed plover	LC
Chlidonias hybrida	whiskered tern	CR
Chloris chloris	European greenfinch	LC
Ciconia ciconia	white stork	LC
Ciconia nigra	black stork	VU
Circaetus gallicus	short-toed snake eagle	NT
Circus aeruginosus	western marsh harrier	VU
Circus cyaneus	hen harrier	CR
Circus pygargus	Montagu's harrier	EN
Cisticola juncidis	zitting cisticola	LC
Clamator glandarius	great spotted cuckoo	VU
Coccothraustes coccothraustes	hawfinch	LC
Coloeus monedula	western jackdaw	LC
Columba livia	rock dove	DD
Columba oenas	stock dove	DD
Columba palumbus	common wood pigeon	LC
Coracias garrulus	European roller	CR
Corvus corax	northern raven	NT
Corvus corone	carrion crow	LC
Coturnix coturnix	common quail	LC
Cuculus canorus	common cuckoo	LC
Cyanistes caeruleus	Eurasian blue tit	LC
Cyanopica cooki	Iberian magpie	LC
Delichon urbicum	common house martin	LC
Dendrocopos major	great spotted woodpecker	LC
Dendrocopos minor	lesser spotted woodpecker	LC
Egretta garzetta	little egret	LC
Elanus caeruleus	black-winged kite	NT
Emberiza calandra	corn bunting	LC
Emberiza cia	rock bunting	LC
Emberiza cirlus	cirl bunting	LC
Emberiza schoeniclus	common reed bunting	VU
Erithacus rubecula	European robin	LC
Falco naumanni	lesser kestrel	VU
Falco peregrinus	peregrine falcon	VU
Falco subbuteo	eurasian hobby	VU
Falco tinnunculus	common kestrel	LC
Fringilla coelebs	common chaffinch	LC
Fulica atra	Eurasian coot	LC

Fulica cristata	red-knobbed coot	CR
Galerida cristata	crested lark	LC
Galerida theklae	thekla lark	LC
Gallinago gallinago	common snipe	CR
Gallinula chloropus	common moorhen	LC
Garrulus glandarius	Eurasian jay	LC
Glareola pratincola	collared pratincole	VU
Gyps fulvus	griffon vulture	NT
Hieraaetus pennatus	booted eagle	NT
Himantopus himantopus	black-winged stilt	LC
Hippolais opaca	western olivaceous warbler	DD
Hippolais polyglotta	melodious warbler	LC
Hirundo daurica	red-rumped swallow	LC
Hirundo rustica	barn swallow	LC
Ixobrychus minutus	little bittern	VU
Jynx torquilla	Eurasian wryneck	DD
Lanius excubitor	great grey shrike	LC
Lanius senator	woodchat shrike	NT
Locustella luscinioides	Savi's warbler	VU
Lophophanes cristatus	crested tit	LC
Lullula arborea	woodlark	LC
Luscinia megarhynchos	common nightingale	LC
Melanocorypha calandra	calandra lark	NT
Merops apiaster	European bee-eater	LC
Milvus migrans	black kite	LC
Milvus milvus	red kite	CR
Monticola saxatilis	common rock thrush	EN
Monticola solitarius	blue rock thrush	LC
Motacilla alba	white wagtail	LC
Motacilla cinerea	grey wagtail	LC
Motacilla flava	western yellow wagtail	LC
Muscicapa striata	spotted flycatcher	NT
Neophron percnopterus	Egyptian vulture	EN
Netta rufina	red-crested pochard	EN
Nycticorax nycticorax	black-crowned night heron	EN
Oenanthe hispanica	black-eared wheatear	VU
Oenanthe leucura	black wheatear	CR
Oriolus oriolus	Eurasian golden oriole	LC
Otis tarda	great bustard	EN
Otus scops	Eurasian scops owl	DD
Pandion haliaetus	western osprey	CR
Parus ater	coal tit	LC
Parus major	great tit	LC
Passer domesticus	house sparrow	LC

Passer hispaniolensis	spanish sparrow	LC
Passer montanus	Eurasian tree sparrow	LC
Pernis apivorus	European honey buzzard	VU
Petronia petronia	rock sparrow	LC
Phoenicurus ochruros	black redstart	LC
Phoenicurus phoenicurus	Hodgson's redstart	LC
Phylloscopus bonelli	western Bonelli's warbler	LC
Phylloscopus collybita	common chiffchaff	LC
Phylloscopus ibericus	Iberian chiffchaff	LC
Pica pica	Eurasian magpie	LC
Picus viridis	European green woodpecker	LC
Platalea leucorodia	Eurasian spoonbill	VU
Plegadis falcinellus	glossy ibis	RE
Podiceps cristatus	great crested grebe	LC
Porphyrio porphyrio	purple swamphen	VU
Prunella modularis	dunnock	LC
Pterocles orientalis	black-bellied sandgrouse	EN
Ptyonoprogne rupestris	Eurasian crag martin	LC
Pyrrhula pyrrhula	Eurasian bullfinch	LC
Rallus aquaticus	water rail	LC
Recurvirostra avosetta	pied avocet	NT
Regulus ignicapilla	common firecrest	LC
Riparia riparia	sand martin	LC
Saxicola rubetra	whinchat	VU
Saxicola torquatus	African stonechat	LC
Serinus serinus	European serin	LC
Sitta europaea	Eurasian nuthatch	LC
Sterna albifrons	little tern	VU
Sterna hirundo	common tern	EN
Sterna nilotica	gull-billed tern	EN
Streptopelia decaocto	Eurasian collared dove	LC
Streptopelia turtur	European turtle dove	LC
Strix aluco	tawny owl	LC
Sturnus unicolor	spotless starling	LC
Sylvia atricapilla	Eurasian blackcap	LC
Sylvia borin	garden warbler	VU
Sylvia cantillans	subalpine warbler	LC
Sylvia communis	common whitethroat	LC
Sylvia conspicillata	spectacled warbler	NT
Sylvia hortensis	western orphean warbler	NT
Sylvia melanocephala	Sardinian warbler	LC
Sylvia undata	dartford warbler	LC
Tachybaptus ruficollis	little grebe	LC
Tadorna tadorna	common shelduck	NE
Tetrax tetrax	little bustard	VU

Tringa totanus	common redshank	CR
Troglodytes troglodytes	eurasian wren	LC
Turdus merula	common blackbird	LC
Turdus philomelos	song thrush	NT
Turdus viscivorus	mistle thrush	LC
Tyto alba	western barn owl	LC
Upupa epops	Eurasian hoopoe	LC
Vanellus vanellus	northern lapwing	LC

[1]Conservation status according to the Red Book of Vertebrates of Portugal (Cabral et al.,2006). CR - Critically Endangered, EN - Endangered and VU – Vulnerable.

1.2. List of amphibian species

Scientific name	**Common name**	**Conservation status[1]**
Alytes cisternasii	Iberian midwife toad	LC
Alytes obstetricans	common midwife toad	LC
Bufo bufo	common toad	LC
Epidalea calamita	natterjack toad	LC
Discoglossus galganoi	Iberian painted frog	NT
Hyla arborea	european tree frog	LC
Hyla meridionalis	Mediterranean tree frog	LC
Pelobates cultripes	western spadefoot	LC
Pelodytes sp	parsley frog	NE
Pleurodeles waltl	sharp-ribbed salamander	LC
Rana iberica	Iberian frog	LC
Pelophylax perezi	perez's frog	LC
Salamandra salamandra	common fire salamander	LC
Lissontriton boscai	Bosca's newt	LC
Triturus marmoratus	marbled newt	LC

[1]Conservation status according to the Red Book of Vertebrates of Portugal (Cabral et al.,2006). CR - Critically Endangered, EN - Endangered and VU - Vulnerable.

1.3. List of reptile species

Scientific name	Common name	Conservation status[1]
Acanthodactylus erythrurus	spiny-footed lizard	NT
Anguis fragilis	slow worm	LC
Blanus cinereus	Iberian worm lizard	LC
Chalcides bedriagai	Bedriaga's skink	LC
Chalcides striatus	western three-toed skink	LC
Chamaeleo chamaeleon	common chameleon	LC
Coluber hippocrepis	horseshoe whip snake	LC
Coronella girondica	southern smooth snake	LC
Elaphe scalaris	ladder snake	LC
Emys orbicularis	European pond turtle	EN
Hemidactylus turcicus	Mediterranean house gecko	VU
Timon lepidus	ocellated lizard	LC
Lacerta schreiberi	Schreiber's green lizard	LC
Macroprotodon cucullatus	false smooth snake	LC
Malpolon monspessulanus	Montpellier snake	LC
Mauremys leprosa	Mediterranian turtle	LC
Natrix maura	viperine snake	LC
Natrix natrix	grass snake	LC
Podarcis carbonelli	Carbonelli's wall lizard	VU
Podarcis hispanica	Iberian wall lizard	LC
Psammodromus algirus	large psammodromus	LC
Psammodromus hispanicus	Spanish psammodromus	NT
Tarentola mauritanica	common wall gecko	LC
Vipera latasti	Lataste's Viper	VU

[1]Conservation status according to the Red Book of Vertebrates of Portugal (Cabral et al.,2006). CR - Critically Endangered, EN - Endangered and VU - Vulnerable.

2. Appendix 2 – Chapter III

2.1 Stream Visual Assesment Protcol (SVAP) Elements with their narrative descriptions and scoring matrix

Adapted from: NRCS, 2009. Stream Visual Assessment Protocol Version 2, in: National Biology Handbook. Natural Resources Conservation Service, United States Department of Agriculture, p. 75

SVAP elements	10	9	8	7	6	5	4	3	2	1	0
Channel condtion **Note:** “Stage” refers to the stage of the Schumm Channel Evolution Model (CEM): Schumm, S.A., Harvey, M.D., and Watson, C.C. 1984. Incised channels: morphology, dynamics, and control. Water Resource Publications, Littleton, CO.	There are no discernible signs of incision (such as vertical banks) or aggradation (such as very shallow multiple channels). If channel Stage I or Stage V - Score 10.		There is evidence of past incision and some recovery. The active channel and the flood plain are connected in most areas. Streambanks may be low or appear to be steepening. If channel Stage I: Score 8, Stage V: Score 7–8 and Stage IV: Score 6.			There is active incision and plants are dying or falling into the channel. The active channel is disconnected from the flood plain. The banks ate steep and there are iminent or evident failures. If channel the channel Stage IV: Score 5 Stage III: Score 4 and Stage II: Score 3.			The are headcuts or surface cracks on banks and active incision. The vegetation is very sparse. There is little or no connection between the flood plain and the stream channel. The streambanks are steep and there are prominent failures. If the channel is Stage II or III, the scores should range between 2 and 0.		

Hydrologic alteration	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Bankfull or higher flows occur according to the flow regime that is characteristic of the (every 1-2 years)site, and there are no dams, dikes, or development in the flood plain.		Bankfull or higher flows occur every 3-5 years. There are development areas in the floodplain, water withdrawals, flow augmentation or water control structures, but they don't significantly alter the natural flow regime.			Bankfull or higher flows occur only once every 6 to 10 years. There are development areas in the floodplain, stream water withdrawals, flow augmentation, or water control structures that alter the natural flow regime.			Bankfull or higher flows rarely occur. Stream water withdrawals completely dewater the channel and/or the flow augmentation resulting from stormwater or urban runoff discharges severely alters the natural flow regime.		
Bank condition	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Note: Both margins were surveyed and scores sepparately.	The banks are stable and are protected by the roots of natural vegetation, wood, and rock. There are o fabricated structures present, no excessive erosion or bank failures or evidence of recreational or livestock access.		The banks are moderately stable, protected by roots of natural vegetation, wood, or rock and there is a limited number of structures present on thebank. There is evidence of erosion or bank failures but on some the vegetation is reestablishing itself. Recreational use and/or grazing do not negatively impact bank condition.			The banks are moderately unstable and there is little protection of banks by roots of natural vegetation, wood or rock. Fabricated structures cover more than half of the entire bank. There is excessive bank erosion or active bank failures. Recreational and/or livestock use are contributing to bank instability.			The banks are unstable and there is no bank protection by vegetation roots, wood or rock. Riprap and/or other structures dominate the banks. There are numerous active bank failures andr ecreational and/or livestock use are contributing to bank instability		

Riparian area quantity	10	9	8	7	6	5	4	3	2	1	0
Note: Both margins were surveyed and scored sepparately.	The natural plant community extends at least two bankfull widths or more than the entire active flood plain and is generally contiguous throughout the property. Each margin is scored separately.		The natural plant community extends at least one bankfull width or more than 1/2 to 2/3 of active flood plain and is generally contiguous throughout property. Vegetation gaps do not exceed 10% of the estimated length of the stream on the property. Each margin is scored separately.		The natural plant community extends at least 1/2 of the bankfull width or more than at least 1/2 of active flood plain. Vegetation gaps do not exceed 30% of the estimated length of the stream on the property.		The natural plant community extends at least 1/3 of the bank- full width or more than 1/4 of active flood plain. Vegetation gaps exceed 30% of the estimated length of the stream on the property			The Natural plant community extends less than 1/3 of the bankfull width or less than 1/4 of active flood plain. Vegetation gaps exceed 30% of the estimated length of the stream on the property	

Riparian area quality	10	9	8	7	6	5	4	3	2	1	0
Note: Both margins were surveyed and scores sepparately.	There is natural and diverse riparian vegetation with composition, density and age structure appropriate for the site. There are no invasive species or concentrated flows through the area.		There is natural and diverse riparian vegetation with composition, density and age structure appropriate for the site. There is little or no evidence of concentrated flows through the area. Invasive species are present but in small numbers (<20% cover).			The natural vegetation is compromised and there are concentrated flows running through the riparian area. Invasive species are common (20-50% cover).			There is little or no natural vegetation. There's evidence of evidence of concentrated flows running through the riparian area and invasive species are widespread (>50% cover).		

Canopy cover **Note:** For this element we the scoring-matrix for warm-water streams.	The percentage of shaded water surface within the length of the stream reach is >75%.		50-75% of the water surface is shaded within the length of the stream.			49–20% of the water surface is shaded within the length of the stream.			<20% of water surface is shaded within the length of the stream.		
Water appearance	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	The water is very clear or its clarity is appropriate to the site. Submerged features in stream (rocks, wood) are visible at depths of 0.9 - 1.8 m. There is no motor oil sheen on the surface and no evidence of metal precipitates.			The water is slightly turbid, especially after a storm event, but clears after the weather clears. Submerged features (rocks, wood) are only visible at depths of 0.3-0.9 m. There is no motor oil sheen on the surface and no evidence of metal precipitates.			The water is turbid most of the time and submerged features in stream (rocks, wood) are visible at depths of only .0.15-0.45 m. Or there is motor oil on the water surfac/areas of slackwater. Or there is evidence of metal precipitates in the stream.			The water is very turbid most of the time. Submerged features in stream (rocks, wood) are visible only within 0.15 m below the surface. Or there is motor oil the water surface/ areas of slackwater.	
Nutrient enrinchment	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	The water is clear along the entire reach. Little algal growth present.		The water is fairly clear or slightly greenish. Moderate algal growth on substrates.			The water is greenish particularly in slow sections. Abundant algal growth, especially during warmer months. Or there's a slight odor of ammonia or rotten eggs. Or sporadic growth of aquatic plants within slack water areas.			The water is pea green and thick algal mats dominate the stream. Or there is a strong odour of ammonia or rotten eggs. Or there are widely dispersed dense stands of aquatic plants.		
Manure and human waste	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**

	Livestock do not have access to stream. There are no pipes or concentrated flows discharging animal waste or sewage directly into stream.	The livestock access to stream is controlled and/or limited to small watering or crossing areas. There are no pipes or concentrated flows discharging animal waste or sewage directly into stream.	Livestock have unlimited access to the stream during some portion of the year and manure is noticeable in stream. Or there are pipes or concentrated flows discharging treated animal waste or sewage directly into the stream.	Livestock have unlimited access to the stream during the entire year and manure is noticeable in the stream. Or there are pipes or concentrated flows discharging untreated animal waste or sewage directly into the stream.
Pools	**10** **9**	**8** **7** **6**	**5** **4** **3**	**2** **1** **0**
Note: we used the scoring-matrix for low gradient streams and considered a "pool" as an area with lower water velocity and a depth two times the normal depth of the river. The depth was measured using a stick.	More than two deep pools separated by riffles, each with greater than 30% of the pool bottom obscured by depth, wood, or other cover. Shallow pools are also present.	One or two deep pools separated by riffles, each with greater than 30% of the pool bottom obscured by depth wood, or other cover. At least one shallow pool present.	Pools present but shallow (<2 times maximum depth of the upstream riffle). Only 10–30% of pool bot- toms are obscured due to depth or wood cover	Pools absent, but some slow water habitat is available and there's no discernible cover. Or the reach is dominated by shallow continuous pools or slow water.
Barriers to aquatic species movement	**10** **9**	**8** **7** **6**	**5** **4** **3**	**2** **1** **0**
	No artificial barriers that prohibit movement of aquatic organisms during any time of the year.	Physical structures, water withdrawals and/ or water quality seasonally restrict movement of aquatic species.	Physical structures, water withdrawals and/ or water quality restrict movement of aquatic species throughout the year	Physical structures, water withdrawals and/ or water quality prohibit movement of aquatic species.
Fish habitat complexity	**10** **9**	**8** **7** / **6** **5**	**4** **3**	**2** **1** **0**
Fish habitat features: logs/large wood, deep pools, other pools (scour,	Ten or more habitat features available, at least one of which is	Eight to nine habitat features available. / Six to seven habitat features available.	Four to five habitat features available.	Less than four habitat features available.

plunge, shallow, pocket) overhanging vegetation, boulders, cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, backwater pools, and other off-channel habitats.	considered optimal in reference sites (large wood in forested streams).				
Aquatic invertebrate habitat	**10** **9**	**8** **7** **6**	**5** **4**	**2** **3**	**3** **2** **1**
Habitat types: logs/large wood, leaf packs, fine woody debris, overhanging vegetation, aquatic vegetation, undercut banks, pools, and root mats. These habitat features were assessed in a representative subsection of the reach that is five times the activel channel width (10 meters).	At least 9 types of habitat present. A combination of wood with riffles should be present and suitable in addition to other types of habitat.	8 to 6 types of habitat. The site may be in need of more wood or reference habitat features and stable wood-riffle sections.	5 to 4 types of habitat present.	3 to 2 types of habitat present.	None to 1 type of habitat present.

2.2 Tables

Table S1 – Summary table with the estimated regression parameters, standard errors (SE), t-values and *P*-values of the linear mixed effects models. The two columns on the right indicate whether a variance structure and a spatial correlation structure were added to the model and specify its type. *P*-values < 0.05 are printed in bold. Non certified - NC, certified for three years - 3C, certified for five years - 5C and least-disturbed - LD.

	Variable	Estimate	SE	t-value	*P*-value	Variance structure	Spatial correlation structure
SVAP index	Intercept	7.23	0.21	34.75	**0.000**		linear
	C3	-0.08	0.19	-0.42	0.679		
	C5	1.44	0.16	8.92	**0.000**		
	LD	1.26	0.40	3.17	0.019		
Channel condition	Intercept	6.66	0.56	11.96	**0.000**	varIdent	gaussian
	C3	-1.12	0.55	-2.04	**0.044**		
	C5	1.70	0.53	3.21	**0.002**		
	LD	2.17	1.02	2.12	0.078		
Hydrologic alteration	Intercept	9.39	0.38	24.43	**0.000**		
	C3	-0.29	0.53	-0.55	0.583		
	C5	0.73	0.46	1.57	0.120		
	LD	-0.61	0.68	-0.91	0.400		
Bank condition	Intercept	7.39	0.34	21.59	**0.000**	varIdent	rational quadratic
	C3	0.31	0.43	0.72	0.473		
	C5	2.02	0.37	5.52	**0.000**		
	Ref	2.07	0.50	4.13	**0.006**		
Riparian quantity	Intercept	6.36	0.43	14.63	**0.000**	varIdent	rational quadratic
	C3	-0.39	0.68	-0.56	0.574		
	C5	3.47	0.44	7.83	**0.000**		

	LD	3.55	0.49	7.24	**0.000**		
Riparian quality	Intercept	6.00	0.50	12.06	**0.000**		linear
	C3	-0.45	0.52	-0.88	0.382		
	C5	3.37	0.45	7.49	**0.000**		
	Ref	3.09	0.93	3.31	0.016		
Canopy cover	Intercept	8.44	0.44	19.35	**0.000**		rational quadratic
	C3	-0.97	0.46	-2.09	0.039		
	C5	1.79	0.51	3.48	**0.001**		
	LD	1.32	0.78	1.70	0.140		
Water appearance	Intercept	7.47	0.25	30.24	0.000		gaussian
	C3	-0.04	0.15	-0.28	0.778		
	C5	-0.75	0.15	-4.93	**0.000**		
	LD	-0.47	0.48	-0.97	0.371		
Nutrient enrichment	Intercept	8.89	0.57	15.55	**0.000**		exponential
	C3	0.07	0.39	0.18	0.855		
	C5	0.50	0.33	1.50	0.137		
	LD	-0.55	1.12	-0.49	0.642		
Manure and human waste	Intercept	8.08	1.10	7.32	**0.000**	varIdent	exponential
	C3	2.07	0.55	3.78	**0.000**		
	C5	0.44	0.29	1.54	0.127		
	Ref	-2.30	2.19	-1.05	0.334		
Pools	Intercept	5.92	0.80	7.44	**0.000**		gaussian
	C3	0.74	0.51	1.44	0.152		
	C5	2.19	0.67	3.27	**0.002**		
	LD	3.21	1.55	2.07	0.083		
Barriers to fish	Intercept	10.00	0.13	79.86	**0.000**		

movement							
	C3	-0.27	0.23	-1.17	0.247		
	C5	0.00	0.20	0.00	1.000		
	LD	-0.30	0.18	-1.63	0.155		
Fish habitat complexity	Intercept	4.37	0.43	10.12	**0.000**		linear
	C3	0.00	0.05	0.01	0.994		
	C5	1.68	0.43	3.87	**0.000**		
	LD	3.34	0.84	3.99	**0.007**		
Aquatic invertebrate habitat	Intercept	4.40	0.42	10.49	**0.000**		gaussian
	C3	0.00	0.00	0.00	0.998		
	C5	1.48	0.26	5.65	**0.000**		
	LD	2.43	0.82	2.95	**0.026**		

Table S2 – Results of the multiple comparisons performed with all groups of stream reaches using Tukey's test: non certified (NC), certified for three years (3C), certified for five years (5C) and least-disturbed (LD). Estimate – parameter estimate, SE – standard error. *P*-values < 0.05 are printed in bold.

		5C-3C	**NC-5C**	**NC-3C**	**LD-3C**	**LD-5C**	**LD-NC**
SVAP Index	**Estimate**	1.744	-1.431	0.313	1.504	0.045	1.191
	SE	0.320	0.263	0.207	0.424	0.434	0.401
	z-value	5.453	-5.437	1.515	3.546	-0.554	2.972
	***P*-value**	0.000	0.000	0.409	0.002	0.941	0.014
Channel condition	**Estimate**	2.889	-1.507	1.382	3.260	0.371	1.878
	SE	0.759	0.634	0.606	1.054	1.072	1.059
	z-value	3.808	-2.376	2.281	3.093	0.346	1.774
	***P*-value**	0.000	0.077	0.097	0.010	0.985	0.275
Hydrologic alteration	**Estimate**	1.021	-0.728	0.293	-0.321	-1.342	-0.614
	SE	0.655	0.464	0.532	0.766	0.736	0.677
	z-value	1.558	-1.570	0.551	-0.419	-1.823	-0.907
	***P*-value**	0.391	0.384	0.944	0.974	0.253	0.794
Bank condition	**Estimate**	2.079	-2.118	-0.039	1.935	-0.145	1.974
	SE	0.435	0.457	0.504	0.422	0.327	0.453
	z-value	4.781	-4.633	-0.077	4.580	-0.443	4.354
	***P*-value**	0.000	0.000	1.000	0.000	0.970	0.000
Riparian quantity	**Estimate**	4.454	-3.558	0.896	4.430	-0.024	3.533
	SE	0.945	0.553	0.851	0.988	0.381	0.643
	z-value	4.713	-6.431	1.053	4.481	-0.063	5.492
	***P*-value**	0.000	0.000	0.697	0.000	1.000	0.000
Riparian quality	**Estimate**	3.858	-3.025	0.833	3.903	0.045	3.070
	SE	0.825	0.641	0.596	1.033	1.031	0.952
	z-value	4.674	-4.720	1.397	3.778	0.043	3.224
	***P*-value**	0.000	0.000	0.486	0.000	1.000	0.006
Canopy cover	**Estimate**	2.827	-1.988	0.839	2.204	-0.623	1.365
	SE	0.792	0.610	0.594	0.855	0.842	0.747
	z-value	3.571	-3.260	1.413	2.579	-0.740	1.827
	P-value	0.002	0.006	0.481	0.047	0.876	0.252
Water appearance	**Estimate**	-0.489	0.577	0.088	-0.375	0.114	-0.463
	SE	0.305	0.240	0.205	0.463	0.468	0.440
	z-value	-1.601	2.403	0.431	-0.810	0.244	-1.051
	***P*-value**	0.355	0.069	0.971	0.838	0.994	0.700

Nutrient enrichment	**Estimate**	0.406	-0.405	0.002	-0.479	-0.885	-0.480
	SE	0.651	0.486	0.449	1.201	1.212	1.157
	z-value	0.624	-0.833	0.004	-0.399	-0.730	-0.415
	***P*-value**	0.916	0.822	1.000	0.976	0.872	0.973
Manure and human waste	**Estimate**	-1.645	-0.505	-2.150	-4.466	-2.821	-2.316
	SE	0.942	0.483	0.782	2.610	2.391	2.422
	z-value	-1.746	-1.046	-2.751	-1.711	-1.180	-0.956
	***P*-value**	0.257	0.682	0.023	0.274	0.593	0.739
Pools	**Estimate**	1.169	-1.579	-0.410	2.714	1.545	3.124
	SE	0.937	0.685	0.676	1.526	1.523	1.450
	z-value	1.248	-2.304	-0.606	1.779	1.015	2.154
	***P*-value**	0.572	0.086	0.923	0.261	0.721	0.123
Barriers to fish movement	**Estimate**	0.267	0.000	0.267	0.333	-0.300	-0.300
	SE	0.250	0.205	0.229	0.234	0.211	0.184
	z-value	1.065	0.000	1.166	-0.142	-1.423	-1.628
	***P*-value**	0.709	1.000	0.645	0.999	0.481	0.360
Fish habitat complexity	**Estimate**	1.468	-1.498	-0.030	3.415	1.948	3.446
	SE	0.454	0.360	0.293	0.834	0.842	0.809
	z-value	3.230	-4.155	-0.103	4.096	2.131	4.261
	***P*-value**	0.005	0.000	1.000	0.000	0.083	0.000
Aquatic invertebrate habitat	**Estimate**	1.458	-1.482	-0.023	2.448	0.989	2.471
	SE	0.398	0.310	0.259	0.817	0.823	0.797
	z-value	3.669	-4.775	-0.090	2.994	1.202	3.100
	***P*-value**	0.001	0.000	1.000	0.012	0.595	0.008

3. Appendix 3 – Chapter IV

3.1 Tables

Table S1 – Candidate detection functions, with the respective ∆ AIC values, number of estimated parameter (# pars), average detection probability (p) and coefficient of variation (CV(p)). Some candidate detection functions failed to fit, such as the ones with covariates and adjustment terms. See Appendix 2 for more details.

Key	Adjustment	Covariates	AIC	Δ AIC	# pars	p	CV(p)
Hazard rate	-	Height+zone	5746.00	0.00	29.00	0.34	0.03
Half-normal	-	Height+zone	5804.99	58.99	29.00	0.41	0.02
Hazard rate	-	Height + shrub cover	5876.16	130.16	3.00	0.34	0.03
Hazard rate	-	Height	5876.96	130.96	3.00	0.34	0.03
Hazard rate	-	Height + shrub density	5878.44	132.44	3.00	0.34	0.03
Hazard rate	-	Height + Tree density	5878.69	132.69	3.00	0.34	0.03
Half-normal	-	Height+Tree cover	5899.14	153.14	3.00	0.43	0.01
Half-normal	-	Height	5900.98	154.99	2.00	0.43	0.01
Half-normal	-	Height + shrub density	5902.26	156.26	3.00	0.43	0.01
Hazard rate	-	Zone	6062.21	316.21	28.00	0.33	0.04
Hazard rate	-	Tree cover	6125.06	379.06	3.00	0.33	0.04
Hazard rate	Simple polynomial	-	6139.01	393.01	3.00	0.31	0.05
Half-normal	-	Zone	6142.94	396.94	28.00	0.45	0.02
Hazard rate	-	Shrub cover	6162.27	416.27	3.00	0.33	0.04
Hazard rate	-	Shrub density	6162.47	416.48	3.00	0.33	0.04
Half-normal	cos(2,3)	-	6176.26	430.26	2.00	0.37	0.03
Half-normal	-	Tree cover	6236.59	490.59	2.00	0.47	0.01
Half-normal	Hermite polynomial	-	6281.30	535.30	1.00	0.47	0.01
Half-normal	-	Shrub density	6283.03	537.03	2.00	0.47	0.01

Table S2 – Absolute frequency and percentage of cover of shrub species in conservation (CZ) and on non-conservation zones (NCZ). SE – standard error of the mean

Species	CZ	NCZ		CZ		NCZ	
	Absolute frequency		Total	% of cover Mean	SE	Mean	SE
Cistus salvifolius	39	30	69	3.621	0.254	2.734	0.211
Ulex sp	35	27	62	3.467	0.273	1.385	0.100
Rosmarinus offinalis	17	14	31	0.810	0.132	0.746	0.100
Cistus crispus	19	11	30	1.092	0.139	1.046	0.209
Cistus monspelliensis	13	8	21	0.509	0.069	3.157	0.919
Lavandula stoechas	13	7	20	0.277	0.040	0.237	0.050
Calluna vulgaris	6	3	9	0.527	0.192	0.074	0.018
Hallimium lasiathum	5	3	8	0.491	0.153	0.167	0.036
Cistus ladanifer	5	2	7	1.157	0.375	0.008	0.002
Daphne gnidium	4	1	5	0.088	0.026	0.049	0.018
Quercus lusitanica	1	2	3	0.130	0.040	0.439	0.154
Pterospartum tridentatum	2	0	2	0.074	0.035	0.000	0.000
Rubia peregrina	2	0	2	0.015	0.006	0.000	0.000
Hallimium ocymoides	1	0	1	0.045	0.022	0.000	0.000
Erica australis	1	0	1	0.047	0.022	0.000	0.000
Pistacia lentiscus	0	1	1	0.000	0.000	0.010	0.002
Myrtus communis	1	0	1	0.108	0.045	0.000	0.000