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BIRDS IN CORK OAK WOODLANDS:

IMPROVING MANAGEMENT FOR BIODIVERSITY

ANA ISABEL CAMOEZ LEAL DA ENCARNAÇÃO MARTINS

DOUTORAMENTO EM BIOLOGIA
(ECOLOGIA)
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Nota Prévia

A presente tese apresenta resultados de trabalhos já publicados ou em preparação para publicação (capítulos 2 a 5), de acordo com o previsto no nº 1 do artigo 41º do Regulamento de Estudos Pós-Graduados da Universidade de Lisboa, publicado no Diário da República II série nº 209 de 30 de Outubro de 2006. Tendo os trabalhos sido realizados em colaboração, a candidata esclarece que participou integralmente na concepção dos trabalhos, obtenção dos dados, análise e discussão dos resultados, bem como na redacção dos manuscritos.

Lisboa, Novembro de 2011

Ana Isabel Camoez Leal da Encarnação Martins

Ao Ricardo e ao Miguel

Aos meus pais

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"…When uncorking a bottle of a good wine or using any of the dozens of products made from natural cork, have you ever stopped to wonder where it comes from? If so, (let us know more about) the Cork Oak (Quercus suber), one of the most extraordinary trees on Earth. Whether fully clothed, in its arm-thick, fissured, light gray bark, or with brick red trunks recently undressed by a once-a-decade harvest of its corky clothing, the tree has great beauty, mystery, and charm, as writers and travelers have long recounted. The landscapes where it occurs have the same charm, or even more to those who know how to read them…"

Aronson J., Pereira J.S., Pausas J.G.
***in* "Cork Oak Woodlands on the Edge: Conservation, Adaptive Management and Restoration"**

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Abstract

Cork oak woodlands (*montados*) are agro-forestry-pastoral systems that, in general, conciliate social and economical value with a rich biodiversity, representing remarkable components of Mediterranean landscapes.

The overall goal of this thesis was to investigate the effects on biodiversity of management practices widely used in *montados.* Passerine birds were used as models, since they are a prominent group in *montados,* occupy a broad diversity of ecological niches, and are strongly responsive to changes in the environment. Starting with management practices applied to trees, we investigated (1) the impact of cork extraction, and found that only birds that forage directly on cork are affected by this activity. Consequently, cork extraction is compatible with maintaining a rich bird community. We also analysed (2) the consequences of tree pruning and concluded that it does not have an effect on overall species diversity, although foliage-gleaning species tend to be considerably less abundant in recently-pruned areas. On a landscape scale, we assessed (3) the effect of the presence of fragments of olive groves and riparian vegetation in *montados* dominated landscapes, and found that it would be desirable to reverse the decline of such habitats. Finally (4) we manipulated the extension of riparian vegetation and olive groves using spatially-explicit modelling to generate future scenarios, and concluded that simple measures like protecting riparian habitats and traditional olive groves could have positive effects on birds of *montados* landscapes.

Montados are threatened by an increasing number of factors that extend from the lack of natural regeneration, to pressure from the decreasing market share of cork bottle stoppers, which can lead to changes in their structure and thus threaten biodiversity. The results of this study are a contribution for a science based improvement of management practices of *montados*, aiming to preserve this system by facilitating the conciliation between economic exploitation and wildlife conservation.

Keywords: *Montados*; Agro-silvo-pastoral systems; Management; Conservation; Birds; Sustainability

Resumo

Os montados de sobro (*Quercus suber*) são sistemas de uso múltiplo agro-silvo-pastoril, que resultam da intervenção humana continuada sobre as florestas de carvalhos originais, sendo uma paisagem comum no Mediterrâneo. São assim sistemas geridos pelo Homem nos quais, dependendo da componente que se quer valorizar (agricultura, pastorícia ou floresta), podem ser aplicadas várias práticas de gestão, tanto à escala da árvore como à da paisagem. Os montados de sobro têm ainda a particularidade de muito do seu rendimento económico ser obtido através de uma prática sustentável que é aplicada directamente à árvore: a extracção da cortiça.

Apesar do seu elevado valor económico, os montados são tradicionalmente sistemas de uso extensivo que conciliam desenvolvimento económico e social com conservação da natureza. Os montados de sobro são reconhecidos pelos elevados níveis de biodiversidade que suportam, sendo um habitat importante para inúmeras espécies de plantas, insectos, mamíferos e aves. Na verdade, são um dos mais ricos habitats para as aves na Península Ibérica, suportando uma grande variedade de espécies (onde se inclui um grande número de Passeriformes) durante a reprodução e também no Inverno.

Apesar do seu enorme valor, não só económico mas também natural, os montados estão hoje em dia ameaçados por um crescente e variado número de factores que vão desde uma reduzida regeneração natural, até à diminuição do valor da cortiça devido à competição com materiais sintéticos para vedantes de garrafas. Estas ameaças podem levar a alterações a nível da estrutura deste sistema, que por sua vez podem afectar a elevada biodiversidade que dele depende.

Esta tese tem como principal objectivo o estudo das consequências sobre as aves de práticas de gestão comuns em montados. Esta questão foi abordada partindo de práticas que são dirigidas à árvore, como a extracção da cortiça e a poda, indo até práticas que têm

consequências a nível da paisagem, como a gestão dos diferentes habitats que existem nos montados. Os Passeriformes foram usados como modelo porque, além de serem um grupo muito abundante nos montados, são largamente reconhecidas como bons indicadores ecológicos.

Capítulo 2. Impacto da extracção da cortiça nas Aves: relevância para a conservação da biodiversidade no Mediterrâneo

Em grande parte da vasta região em que o sobreiro ocorre, esta árvore é uma parte essencial da economia. Apesar do sistema montado incluir múltiplas actividades económicas, que vão desde a pastorícia, à agricultura e caça, a maior parte do seu valor económico advém da extracção da cortiça. Sem o rendimento que deriva desta actividade, muitas explorações dominadas por sobreiro tornar-se-iam economicamente inviáveis o que teria graves consequências sociais. Estima-se que em todo o Mediterrâneo milhares de pessoas dependam de actividades relacionadas com a cortiça. Portugal é o maior produtor mundial de cortiça, correspondendo este material a cerca de 2,3% do total das exportações Portuguesas.

A cortiça é periodicamente extraída da árvore, em intervalos mínimos de 9 anos, entre Maio e Agosto. Após ser retirada esta camada da casca, a árvore tem a capacidade de regenerar uma nova sem prejuízo para a sua vitalidade. Apesar de ser uma prática corrente, a extracção implica potenciais alterações a nível do sistema que não foram até agora estudadas. O objectivo principal deste capítulo foi avaliar qual o impacto da extracção da cortiça para a biodiversidade dos montados, usando as aves como modelo. Se esta prática afectar as aves, é esperada uma redução da sua densidade e riqueza em áreas onde as árvores foram recentemente descortiçadas.

A comparação de comunidades de aves entre zonas com árvores recentemente descortiçadas (cortiça com 0 anos) e zonas com árvores com cortiça desenvolvida (cortiça com 7 anos), revelou uma menor densidade das espécies que se alimentam directamente na casca das árvores em zonas com cortiça nova (ex. trepadeira-comum (*Certhia brachydactyla*) e trepadeira-azul (*Sitta europaea*)). A avaliação da comunidade de artrópodes (que constituem as principais presas destas aves) existentes em cortiça de diferentes idades permitiu concluir que existe uma menor disponibilidade de presas potenciais em cortiça mais nova, o que deve justificar a diminuição da densidade daquelas espécies. No entanto, os resultados revelam que a riqueza específica e a densidade da grande maioria das espécies de aves não são afectadas por esta prática. Para além disso, a extrapolação destes resultados para toda a área de estudo revelou que, mesmo as espécies localmente afectadas, mantêm populações potencialmente estáveis a nível da paisagem e ao longo dos anos.

Actualmente, os montados correm o risco de se tornar economicamente inviáveis devido à enorme pressão de mercado imposta pelos produtores de vedantes sintéticos. Ao demonstrar que a extracção da cortiça é compatível com a manutenção do elevado valor ornitológico do montado, estes resultados confirmam que é uma actividade que deve ser mantida em benefício da biodiversidade.

Capítulo 3. Qual a influência da poda dos sobreiros para as aves que se alimentam na copa das árvores?

A poda das árvores, que corresponde ao corte de ramos, é uma prática silvícola comum em montados de sobro e apresenta objectivos múltiplos. Em sobreiros jovens, a poda pretende geralmente maximizar a altura de descortiçamento; em árvores adultas, pretende sobretudo melhorar o estado fitossanitário da árvore livrando-a de ramos secos ou doentes. As podas podem também ter o efeito de aumentar a produção regular de fruto e ainda permitir a obtenção de lenha. Todas estas intervenções na árvore têm como consequência uma simplificação da sua estrutura, nomeadamente por redução da área de copa e folhagem. No entanto, o impacto desta intervenção nas comunidades animais foi ainda pouco estudado, sabendo-se contudo que pode afectar algumas espécies de aves florestais. Neste capítulo pretendeu-se avaliar se a poda afecta as comunidade de aves do montado de sobro, particularmente as espécies que utilizam as copas das árvores, como os chapins (*Parus sp*.) ou as felosinhas (*Phylloscopus collybita*), tendo-se para tal comparado a comunidade de aves em zonas não podadas e em zonas recentemente podadas.

No geral, a poda não parece ter um efeito significativo nos padrões gerais de densidade e riqueza da comunidade de aves do montado de sobro. No entanto, tal como previsto, as espécies de aves que se alimentam sobretudo na copa tendem a ser menos abundantes naquelas zonas, especialmente no Inverno.

Os resultados indicam assim que a poda é compatível com a manutenção da rica comunidade de aves nos *montados*. No entanto, dado o seu impacto em algumas espécies, deverão ser evitadas podas de grande intensidade que causem uma redução forte da densidade da copa. Outra medida importante será a alteração do limite do período autorizado de poda de Março para Fevereiro, uma vez que em Março o corte dos ramos pode levar à destruição de ninhos de algumas espécies de aves residentes que tendem a nidificar mais cedo, sobretudo no sul da Península Ibérica.

Capítulo 4. Influência de fragmentos de habitat não-matriz para a comunidade de aves do montado de sobro.

As paisagens extensivas de montados de sobro no sul da Península Ibérica são frequentemente interrompidas por fragmentos de outros habitats, que podem ter origem antropogénica ou natural. Entre estes habitats incluem-se frequentemente fragmentos de olivais tradicionais e galerias de vegetação ripícola associadas a linhas de água. Muitos destes olivais estão presentemente a degradar-se devido ao seu abandono e a vegetação ripícola é frequentemente afectada por medidas de gestão agressivas. No entanto, na matriz de montados de sobro estes fragmentos contribuem para gerar interrupções na continuidade do habitat que podem originar interacções ecológicas importantes.

Neste trabalho analisou-se a influência da presença de fragmentos de olivais tradicionais e galerias ripícolas na estrutura da comunidade de aves da matriz de montado de sobro. Os resultados da análise das contagens de aves realizadas em áreas de montado a distâncias crescentes dos fragmentos sugerem que a diversidade de aves da matriz é maior perto destes. De facto, cinco das dezassete espécies estudadas reagiram positivamente à presença de olivais ou galerias (ex. tentilhão *Fringilla coelebs* e chapim-azul *Parus caeruleus*). Este efeito é mais notório no Inverno possivelmente porque os fragmentos funcionam como habitats complementares de alimentação, compensando a baixa disponibilidade de frutos com polpa que existe na matriz de montado.

Será assim importante incluir na gestão dos montados de sobro medidas que resultem na preservação destes fragmentos, os quais parecem assumir um papel ecológico importante para a comunidade de aves deste sistema. Neste sentido será desejável limitar as práticas de destruição da vegetação associada às linhas de água e evitar o abandono dos olivais tradicionais.

Capítulo 5. Heterogeneidade espacial na gestão de florestas mediterrânicas: o uso de cenários de futuro espacialmente explícitos para a conservação das aves.

A gestão dos montados de sobro tem sofrido diversas alterações ao longo do tempo, havendo um claro investimento nas práticas com maior rendimento económico (como a extracção da cortiça) e o abandono de algumas práticas de agricultura tradicional. Estas alterações no sistema levam a mudanças na estrutura da paisagem que podem ter consequências para a biodiversidade.

A aplicação de cenários de futuro tem sido indicada como uma ferramenta importante para avaliar as implicações de diferentes opções de gestão dos habitats. Esta técnica permitiu a construção de cenários simulados para a Serra de Grândola, em que a extensão da área de fragmentos de vegetação ripícola e olivais tradicionais foi manipulada para avaliar quais as suas potenciais consequências para a comunidade de aves do montado de sobro. Foram simulados cenários em que as áreas destes dois biótopos foram aumentadas, e outros em que foram reduzidas. Para a construção das diferentes simulações de extensão dos fragmentos e suas consequências potenciais sobre cada espécie, foram utilizados modelos espacialmente explícitos.

Os resultados sugerem que um aumento de galeria ripícola teria um efeito muito positivo na densidade de várias espécies de aves (ex. rouxinol (*Luscinia megarhynchos*) e felosa-poliglota (*Hippolais pollyglota*)). Por outro lado as manipulações das áreas de olival não parecem ter um efeito tão marcado e o seu aumento parece até poder ser prejudicial, pelo menos para quatro espécies que são comuns na matriz de sobro. Com base nos resultados obtidos são feitas recomendações de gestão que, sendo compatíveis com a manutenção do valor económico dos montados, poderão ter efeitos positivos para a comunidade de aves da paisagem de sobro. É o caso, por exemplo, do restabelecimento da vegetação ripícola ao longo das linhas de água que, envolvendo apenas uma reduzida área de montado, deverá ter consequências positivas para várias espécies de aves, incluindo algumas que são actualmente das menos abundantes nesta paisagem.

Esta tese permitiu investigar e quantificar os impactos de algumas das mais importantes práticas de gestão do montado de sobro nas populações de diversos Passeriformes. Apesar de se ter utilizado as aves como modelo, muitos dos resultados e conclusões aqui obtidos poderão ser extrapolados para outros grupos animais. Espera-se assim ter contribuído para a produção de bases científicas que permitam elaborar regras para o melhoramento das práticas de gestão, contribuindo para a sua melhor conciliação com a conservação da biodiversidade dos montados.

Palavras-chave: Montado; Sistemas agro-silvo-pastoris; Gestão; Conservação; Aves; Sustentabilidade

CHAPTER 1

General Introduction

1. General Introduction

1.1. Cork oak trees and woodlands

The cork oak (*Quercus suber*) tree is a long-living evergreen Mediterranean oak that has an extremely rare characteristic in the plant kingdom: a corky bark of suberized cells up to 15-20 cm thick (Hidalgo *et al.* 2008). This cork layer constitutes an important protective barrier against fire (Pausas 1997) and has some remarkable features, such as being light-weight, exhibiting lower conductivity for heat and noise, possessing a high capacity to recover after being compressed and being highly impermeable to liquids and gases (Natividade 1950; Mendes & Graça 2009). Because of these properties cork has many applications and has been exploited by Man for centuries.

Cork oak woodlands are functional landscapes that have been managed for centuries and represent remarkable components of Mediterranean landscapes (Pereira *et al.* 2009). The Mediterranean basin is one of the richest and most complex regions on Earth, geologically, biologically, and culturally (Blondel *et al.* 2010; Pascual *et al.* 2011), and it has been considered one of the world's 25 biodiversity hotspots (Myers *et al.* 2000; Brooks *et al.* 2006). Cork oak woodlands are considered High Nature Value Farmlands (HNVF) (Hoogeveen *et al.* 2004), and are included in Annex I of the European Union Habitats Directive (92/43/CEE).

Currently, the estimated global cork oak woodland area is approximately 2.3 million ha, all of which are in the western Mediterranean (Figure 1.1). Its distribution is very patchy and includes a narrow band in North Africa (Morocco, Algeria and Tunisia), the south of France, the western Italian coast, some Mediterranean islands like Corsica, Sardinia and Sicily, and the southern Iberian Peninsula. Cork oak trees exist in regions with average annual precipitation above 600 mm and optimal average annual temperatures near 15^{o}C (Blanco *et al.* 1997; Costa & Pereira 2007a). They usually grow in acidic soils on granite, schist or sandy subtracts (Pausas *et al.* 2009b). Although they are well-adapted to hot and dry weather, and poor soil conditions, they are less tolerant to frost and drought than the more widespread holm oak (*Quercus ilex*) (Larcher 2000). In Europe, low winter temperatures appear to set the geographic distribution limits for this species, and to some extent this explains why most cork oak woodlands are located in areas below 800 m in altitude (Pausas *et al.* 2009b).

In Portugal, cork oak occupies an area of about 737 000 ha (DGRF 2007) dominating the landscape in much of the southern part of the country. This distribution is a response not only to soil and climate conditions, but also to human actions. In fact, with the exception of some high and humid regions, cork oak has conditions that allow its existence across most of Portugal (Costa & Pereira 2007a). However, the current distribution of cork oak is mostly restricted to areas in the south of the country, mostly in Ribatejo, Alentejo and Algarve. It has been relegated to this range largely due to human pressure against oak forests, especially in the north of Portugal, where oak forests have been extensively destroyed. It can exist in pure woodlands where it is the main tree species; but it also commonly coexists in mixed woodlands with other Mediterranean tree species, like holm oak or stone pine (*Pinus pinea*).

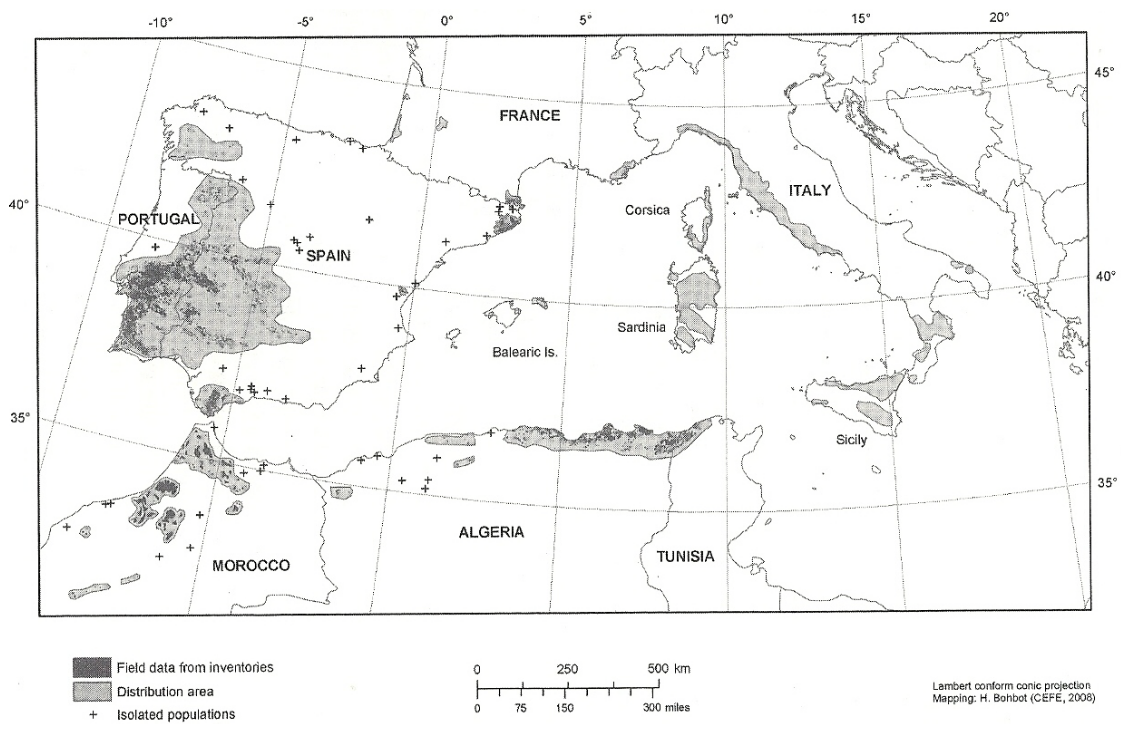


Figure 1.1. World current distribution of cork oak (*Quercus suber*) (adapted from Pausas *et al.* 2009b).

In Portugal, conservation of cork oak woodlands dates back to the XIII century, when King D. Dinis declared the protection of the trees against inappropriate uses mainly to protect the hunting of certain species within those woodlands (Natividade 1950). Since then laws for the protection of the cork oak woodlands have improved, focusing not only on the protection of the tree itself, but also on the adequate management of the forests. Nowadays, cork oaks are protected nationally. Activities and management actions applied to cork oak woodlands - such as cuts, soil usage, cork extraction and pruning - are regulated by Law decree nº 169/2001. For example, it is illegal to cut down a cork oak tree without special justification and permission; a 9-year or longer interval is mandatory between cork extractions in the same area of a tree; and pruning is not allowed during the two years before or after cork extraction. However, there is still a need to regulate other activities and management interventions, like grazing pressure and distribution, cleansing methods, and the harvesting of complementary resources (Pinto-Correia & Fonseca 2009).

1.2. Ecological importance and biodiversity in cork oak woodlands: the case of birds

Cork oak landscapes are one of the best examples of a managed agro-forestry-pastoral system that balances social and economical development with nature conservation, with obvious contributions to both human welfare and nature (APCOR 2009). Traditionally, cork oak woodlands are low-input management systems (Bugalho *et al.* 2011), some of which are included in Natura 2000 network of protected sites. According to the Millennium Ecosystem Assessment (MA 2005), cork oak woodlands provide important key ecosystem services in all four categories analysed: provisioning, regulating, cultural and supporting services (Table 1.1). These contributions include products like cork and acorns, but also soil conservation, carbon sequestration, and even the preservation of cultural heritage (WWF 2006; APCOR 2009).

Table 1.1. Ecosystem services provided by cork oak woodlands according to the terminology of the Millennium Ecosystem Assessment (adapted from MA 2005; Berrahmouni *et al.* 2009).

Service	Description	Examples
Provisioning	Products obtained from the ecosystem	Food (acorns), fodder, firewood, cork, other nontimber forest products
Regulating	Benefits obtained from regulation of the ecosystem processes	Soil conservation, water retention, watershed protection, erosion control, fire risk, carbon sequestration
Cultural	Nonmaterial benefits obtained from ecosystems	Cultural heritage (landscape amenity), recreation, tourism
Supporting	Services necessary for the production of all other ecosystem services	Soil formation, nutrient cycling, primary production

In addition to those services, cork oak woodlands are of key importance for a wide range of *taxa*, including an enormous variety of vertebrates. This biodiversity is commonly attributed to the traditional and low-intensity use of the system, to the long-term stability of habitat conditions, to its extension, and to the large variety and complex structures of habitats that co-exist within the cork oak woodlands matrix (Tellería 2001). Open patches of cork oak woodlands are unusually rich in plants species (Díaz-Villa *et al.* 2003; Bugalho *et al.* 2009a). Cork oak woodland landscapes also provide an important habitat for many insect species, such as butterflies and beetles (e.g. da Silva *et al.* 2009), and mammals like wild boars (*Sus scrofa*), deer (*Cervus elaphus* and *Capreolus capreolus*) (Díaz 2009), European badgers (*Meles meles*) (Rosalino *et al.* 2008) and remnant populations of the extremely endangered Iberian lynx (*Lynx pardinus*) (Fernández & Palomares 2000; Berrahmouni *et al.* 2009).

Cork oak woodlands also harbour nearly a hundred other animal species listed in the annexes of the EU Habitats and Birds Directives. In fact, they are the richest habitat for breeding birds in the Iberian Peninsula (Tellería 2001), and are important breeding areas for large-sized endangered species like the Spanish imperial eagle (*Aquila adalberti*), black vulture (*Aegypius monachus*) and black stork (*Ciconia nigra*) (Carrete & Donazar 2005). Outside the breeding season, they are a key habitat for many migratory wintering species, like the common crane (*Grus grus*), wood pigeon (*Columba palumbus*), and passerines (Díaz *et al.* 1996; Díaz *et al.* 1997).

Passerines are a prominent group in cork oak woodlands (Almeida & Granadeiro 2000; Cherkaoui *et al.* 2009; Godinho & Rabaça 2011). They occupy very different ecological niches within the woodland, taking advantage of the complex physiography of this system. Under relatively open conditions (i.e., a poorly developed understory), ground feeders like chaffinches (*Fringilla coelebs*), woodlarks (*Lullula arborea*) and corn buntings (*Miliaria calandra*) dominate (Rabaça 1990; Tellería 2001). On the other hand, some warbler species like the Sardinian warbler (*Sylvia melanocephala*) and wrens (*Troglodytes troglodytes*) are more abundant in areas with developed understory vegetation (Rabaça 1990; Tellería 2001). With these co-exist other bird species that depend upon the resources provided directly by the trees. This is the case of blue tits (*Parus caeruleus*), great tits (*Parus major*) and the wintering chiffchaffs (*Phylloscopus collybita*) (Almeida & Granadeiro 2000) that feed mainly on the canopy, and of nuthatches (*Sitta europaea*) and treecreepers (*Certhia brachydactyla*) that feed mostly on cork, the bark of the tree (Almeida 1992) (Figure 1.2).

Birds are often considered a good model by which to assess the broad status of an ecosystem, for both scientific and practical reasons (Gregory *et al.* 2005). In fact, birds present certain characteristics that make them good bio-indicators. First they are relatively easy to detect, identify and census. Secondly, birds are wide-ranging in habitat distribution, moderately abundant, and have an intermediate body size (Gregory *et al.* 2005). These characteristics result in population responses to environmental changes at moderate spatial and temporal scales (Gregory *et al.* 2005) that are easily perceived and suitable for use by managers and decision makers. In some situations, birds can reflect changes in other groups and are responsive to environmental changes (Hutto 1998; Stattersfield *et al.* 1998). There are several examples of cases in which birds have been used as general indicators of environmental health. At a national level (e.g., in Portugal and the UK), the population trends of common breeding birds is used by governments as an indicator of the progress of attempts to safeguard and enhance biodiversity. At a wider scale, the Pan-European Common Bird Monitoring Scheme uses multi-species indices based upon data from 25 national breeding bird surveys. This programme has, for example, demonstrated that farmland birds in Europe have declined steeply over the last two decades, which correlates well with the increase in agricultural intensification (PECBMS 2009).

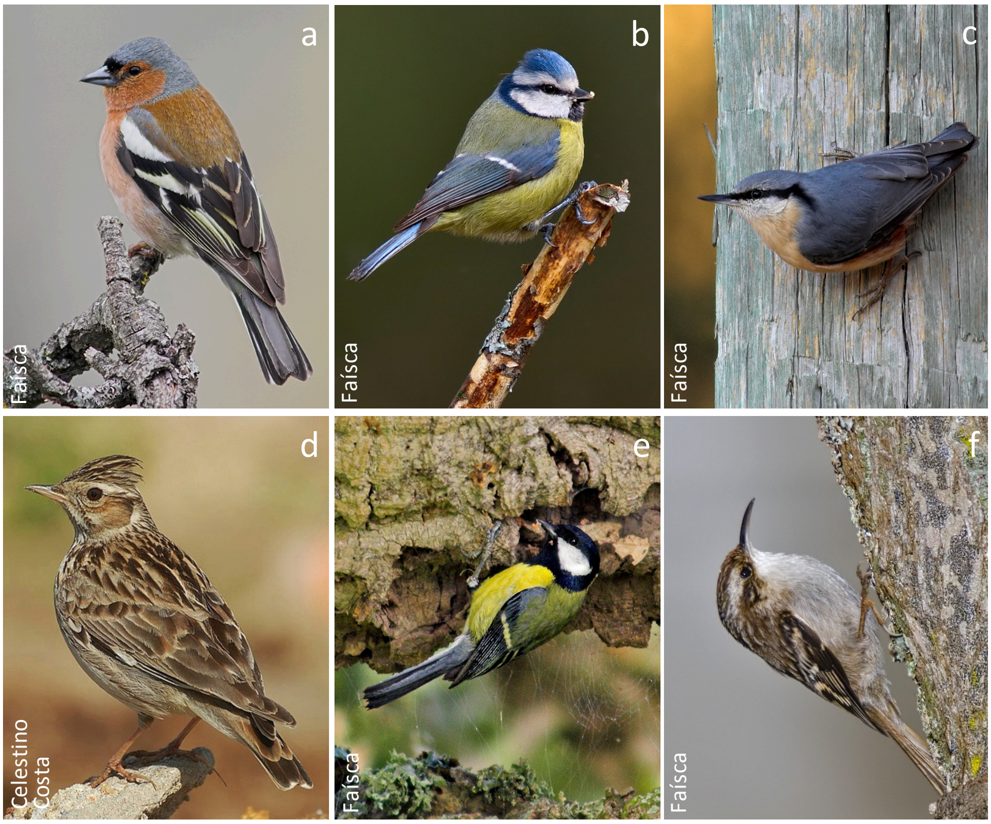


Figure 1.2. Examples of six common passerine bird species in cork oak woodlands: (a) chaffinch (*Fringilla coelebs*), (b) blue tit (*Parus caeruleus*), (c) nuthatch (*Sitta europaea*), (d) woodlark (*Lullula arborea*), (e) great tit (*Parus major*) and (f) treecreeper (*Certhia brachydactyla*).

Birds, and especially passerines, are therefore a suitable model with which to study the impacts of cork oak woodland management practices on biodiversity, since they are one of the most abundant vertebrate groups in this habitat and make diverse uses of both trees and woods. In this study, the focus was especially on common passerine birds. However, some of the information obtained studying this group can probably be generalised to rarer species and taxa other than passerines. Overall, very few bird species depend exclusively on cork oak woodlands; rather, they use mosaic landscapes where forest and open habitats coexist at several spatial scales (Díaz *et al.* 2003; Díaz 2009).

1.3. Cork oak woodlands management: multi-scale approaches

Cork oak woodlands have been managed for centuries to provide multiple goods and services. These include livestock rearing, cereal cropping, firewood, charcoal, fruits, berries, mushrooms, honey production and, especially in the last two centuries, cork (Pinto-Correia & Mascarenhas 1999; Bugalho *et al.* 2009b). In actuality, cork oak trees can be found mostly in two main types of forest stands: *sobreirais* and *montados*. *Sobreirais* are managed mostly for forestry use and tend to be dense forests with a well-developed shrub layer. *Montados* (in Portugal) or *dehesas* (in Spain) are agro-forestry-pastoral systems dominated by cork oak and/or holm oak trees, usually with a groundcover of pastures, agricultural fields or scrub (Díaz *et al.* 1997; Pinto-Correia 2000). As *montados* occupy most of the cork oak distribution area, especially in the Iberian Peninsula, we will hereafter mostly use this term when referring to cork oak woodlands.

Montados can be considered semi-natural systems, and their characteristics are a consequence of sustained and low-intensity human intervention in the original forests. Depending upon the system component to be valued (agriculture, pasture or forestry), a set of different management practices are applied to these woodlands at the landscape level and directly at the tree level. Regardless of the main management target, they are a widely-recognized excellent example of a balance between socio-economic development and biodiversity conservation. To conciliate economic productivity with high biodiversity value, *montados* must be managed correctly, and this requires information on how different management options influence biodiversity.

In *montados*, some of the most important management interventions are applied directly to the tree. Indeed, when the advantages of cork as a stopper for champagne bottles were discovered in France, in the late XVII century, by a Benedictine monk named Pierre Perignon, a major change in cork oak woodlands management was triggered. Since then, a vital cork industry has developed, the economic value of cork has increased, and became the second most important marketable non-wood forest product in the western Mediterranean (Mendes & Graça 2009).

Cork is periodically extracted from the tree by stripping off long portions of bark from the trunk and large branches, when they reach a minimum perimeter of at least 70 cm. When cork is removed, the bark has the ability to regenerate, because cork oaks have a phellogen, the cell layer that is responsible for the production of cork, active throughout the life of the tree (e.g. Natividade 1950; Moreira *et al.* 2007). The first cork debarking takes place when trees are about 25-years old (Costa & Pereira 2007b), with subsequent debarking performed at 9 to 12-year intervals, between May and August. This means that a single tree may yield fifteen to twenty harvests of cork over the course of two and a half centuries (Mendes & Graça 2009). Although cork has a great variety of industrial uses (e.g., flooring, insulation material, clothes and accessories), wine bottle stoppers are its main use and they justify the major economic importance of *montados* in the vast region where they occur. Portugal produces approximately 160 000 tons of cork per year, which corresponds to more than 50% of the world’s production, followed by Spain (with 30%), Italy, France, Morocco, Tunisia and Algeria. Cork production represents 2.3% of all Portuguese exports and 30% of Portuguese forestry product exports. It is estimated that roughly 28 000 Portuguese residents are employed in activities related to cork, and 100 000 across the seven cork-producing Mediterranean countries (WWF 2006). Cork extraction, and the maintenance of cork economic value, is therefore a fundamental activity for the preservation of *montados* ecosystems.

As cork extraction does not destroy the tree and is only performed at prolonged time intervals, it usually has been assumed to be a non-damaging activity for cork oak ecosystems and biodiversity (e.g. Pereira & Fonseca 2003). However, this intervention changes important aspects of the system that may influence biodiversity, so it is surprisingly that, to our best knowledge, no study has quantitatively evaluated its potential consequences. The impacts of cork extraction on *montados* biodiversity are analysed in Chapter 2, using birds as a model.

Pruning is another common silvicultural activity in *montados*, typically entailing the removal of side branches and multiple leaders from a standing tree (Keer 2004). In *montados*, the pruning of young trees is largely used to direct growth of the trunk so as to facilitate cork extraction, thereby increasing the future value of cork. Adult trees also are pruned to promote more regular and abundant fruit production, to balance the canopy, and to eliminate dead, old or sick branches (LPN 2007). Moreover, this practice enhances cereal production, as it contributes to an increased amount of radiation reaching the ground (Natividade 1950). Current Portuguese legislation only allows cork oak pruning between November and March. The removed material is often used to obtain charcoal and cork (which is removed from branches after they are cut). Pruning reshapes and resizes canopies; consequently it potentially affects animal species that depend on them, such as the many woodland birds that forage on canopies and benefit from the protection of this substrate. However, this potential impact remains poorly understood, so this question is addressed in Chapter 3.

At a landscape scale, some studies have already addressed the consequences to biodiversity of certain management interventions in *montados*. This is the case with the consequences of practices like mechanical fuel reduction and understory cleansing (e.g.

Santana *et al.* 2011) or even with the effects of fire (Díaz-Delgado *et al.* 2002; Acácio *et al.* 2009). Some knowledge also already exists about how differences in shrubby understory (e.g. Rabaça 1990) or fragmentation (Cherkaoui *et al.* 2009) affect bird communities. However, many landscape factors and dimensions still remain to be studied.

Extensive *montados*, especially in south-western Iberia, often include scattered patches of other habitats of natural or anthropogenic origin. These include lines of riparian vegetation along water lines, shrub areas, productive or abandoned orchards, and olive groves *(Olea europaea*) (Rosalino *et al.* 2009). These elements have traditionally been distinctive and prominent characteristic of *montados* and can play important roles in this ecosystem. However, the extent to which these patches influence the biodiversity of *montados* warrants further study. Furthermore, the importance for people of these habitats within the cork oak matrix has evolved over time, following changes in the economic and social contexts and variations in land-use policies. This is the case of riparian habitats that, although recognized as valuable high diversity habitats in Mediterranean landscapes (Corbacho *et al.* 2003), often are subject to aggressive interventions such as the excessive removal of riparian vegetation (Aguiar *et al.* 2000). Traditional olive groves, also have been recognized as having a positive impact on certain taxonomic animal groups, such as carnivores; but their extent and health have suffered from years of land abandonment that have led to changes in the structure of these habitats due, for example, to the invasion of understory vegetation species (Duarte *et al.* 2008).

These different habitats patches contribute not only to *montado*s fragmentation, but also to the landscape heterogeneity. In fact, in landscapes composed of a matrix with embedded fragments of distinct habitats, there are relevant ecological interactions between the fragments and matrix. The effects of the matrix on islands of embedded habitat have been studied extensively (e.g. Sisk *et al.* 1997; Gascon *et al.* 1999; Antongiovanni & Metzger 2005), but reverse analyses (i.e., the influence of fragments on the species assemblages of the matrix at several spatial scales) remain scarce (Tubelis *et al.* 2004). It is therefore of great management interest to determine if habitat fragments promote the diversity or abundance of *montados* species or, alternatively, exert negative effects for matrix species due to, for instance, an increase in predation near the edges (e.g. Gates & Gysel 1978; Andrén & Angelstam 1988; Morris & Gilroy 2008) or the expansion of generalist species (e.g. Heske *et al.* 1999).

As previously stated, the physical structure of riparian galleries and olive groves are subject to continuous change. These changes can have important consequences not only for the animal communities that depend on them, but also for the diversity and ecological value of the *montados* landscapes in which they are included. Well-informed and adequate management of *montados* landscapes partly depends upon identifying the potential impacts of any ongoing changes in those habitat fragments. The ecological effects of management measures must be identified, particularly regarding those activities that are compatible with the maintenance of the economic value of the system. The impacts of olive grove and riparian gallery fragments on *montados* bird communities, as well as the consequences of different management options, are addressed in Chapters 4 and 5.

1.4. Study areas

As noted in the first part of this introduction, Portugal has nearly 737 000 ha of cork oak woodlands, which corresponds to almost one third of the world’s total area of this type of woodland, most of which are in the form of *montados*. For the choice of study areas, we considered factors like woodland conservation, understory features, silvicultural practices, and matrix fragmentation.

Analyses of the impacts of management interventions directed at the tree itself were conducted in a well-maintained cork oak area on a large farm managed by the state-owned

"Companhia das Lezírias" (38° 48' N – 8° 49' W) (Figure 1.3a). The farm covers 11 071 ha, 6 100 ha of which are occupied by cork oak *montados*. In addition to cork production and non-intensive livestock rearing, the area includes pine and eucalyptus plantations, cereal fields, and rice paddies. The density of trees in the cork oak fields is about 35 trees/ha, and shrubs are periodically cleaned across most of the area. The cork oak woodlands of the farm form a mostly continuous area that is organized into fields, with cork removal rotating from field to field. In this way, cork age tends to be relatively constant within any given field, though a few fields have trees with a mixture of cork ages (see Chapters 2 and 3).

Studies directed towards interventions affecting the overall landscape were carried out on Serra de Grândola (38° 07'N - 8° 36' W), in Southern Portugal (Figure 1.3b). The area is characterized by a Mediterranean climate (Santos-Reis & Correia 1999) and is within one of the largest and better-preserved areas of mostly-continuous cork oak woodlands in Portugal. Human density is low, and nowadays the area is primarily used for cork and wood extraction, cattle raising and hunting (Rosalino *et al.* 2005). As in other *montados* areas, the cork oak matrix is interrupted by fragments of other habitats, which include traditional olive groves and patches of riparian vegetation along water lines (see chapters 4 and 5). Olive groves are present in the area in small patches; and, while most of them are subject to a low-intensity management regime, some have been abandoned by farmers (Santos-Reis & Correia 1999). The area also is crossed by four watercourses that often have only small residual pools of water during the summer; and the integrity of these riparian corridors varies significantly across the area, from sections with well-developed woods, to some that only have shrubs, usually blackberries (*Rubus ulmifolius*). Traditional olive groves and riparian vegetation are common in Mediterranean habitats and can play important roles in a *montados* ecosystem. Management interventions in both habitats have changed over time, for both social and economic reasons. Consequently, studies on the ecological function of these habitats in this biodiversity-rich system are of increasing importance.

Both study areas present rich and diverse communities of flora and fauna (e.g. Santos-Reis & Correia 1999; Gonçalves *et al.* 2011). Typically, as in most *montados* areas, birds are a particularly abundant group, characterized by a rich and diverse passerine community both in spring and winter (pers. obs). Previous studies on Serra de Grândola have identified more than 50 passerine species (Vicente *et al.* 1999).

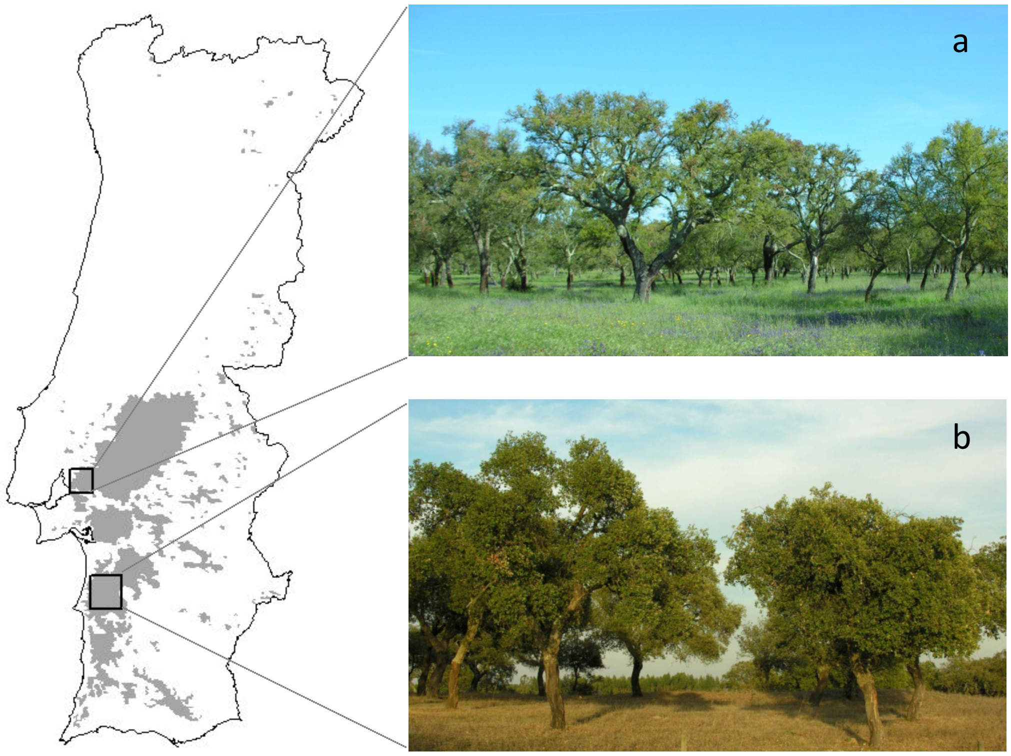


Figure 1.3. Portugal map with the indication of the study areas (black squares): (a) Companhia das Lezíras, (b) Serra de Grândola. Cork oak distribution areas in Portugal are indicated in shade in the country map.

1.5. Main aims and outline of the thesis

This thesis aims to analyse the consequences of some of the most traditional cork oak woodland management measures on biodiversity, using birds as a model group. Different approaches were used to study practices that are directed towards different aspects of the system, at different spatial scales. Starting with management procedures that target the tree itself, the work addresses the potential consequences of cork extraction and cork oak tree pruning on bird populations. On a broader scale, the extent to which the occurrence of other habitat fragments influences the presence and distribution of birds in the cork oak matrix was evaluated. Finally, at a landscape scale, it was examined the effect on birds of major habitat management that are compatible with the maintenance of the economic value of cork oak woodlands. The specific objectives and main methodological approaches of each chapter are described below.

Chapter 2. Impact of cork extraction on birds: Relevance for conservation of Mediterranean biodiversity

The study described in this chapter examines the impact of cork extraction on biodiversity, focusing on consequences on the abundance and distribution of common bird species. Bird point counts were conducted in areas with different cork ages, sampling a gradient from recently-extracted cork, to areas with old cork. This allowed for analysis of the response of different functional groups (like foliage gleaners, bark gleaners and ground foragers) to cork extraction. It was also analysed, through focal observations, how birds use trees with different cork ages in areas that had a mixture of just-debarked trees and trees with 7-year old cork.

To estimate differences in the availability of food resources for insectivorous birds, relative to cork age, arthropods were sampled from the bark of the trees in the same fields as bird counts. Finally, considering that cork extraction activities often lead to the establishment of mosaic landscapes of fields with trees of different cork ages, the total impact of cork extraction on the abundance of birds was modelled at a landscape level.

This study was published in *Biological Conservation (Leal et al. (2011) 144: 1655-1662)*.

Chapter 3. Does canopy pruning affect foliage-gleaning birds in cork oak woodlands?

The main objective of this study was to evaluate the ecological consequences of pruning in cork oak woodlands by examining its impact upon bird assemblages. As pruning reduces foraging substrates and cover for birds that forage on the canopy, we tested whether these species would have lower densities in pruned areas.

To determine which bird species could potentially be affected by pruning, the foraging behaviours of several species were characterized by means of focal observations. Transects were carried out several times in winter and spring and, for all birds detected in a tree, behaviour and precise foraging site were recorded. Furthermore, 15 counting stations were established in areas that had been recently pruned and another set of 30 stations in areas that had not been pruned in recent years, the latter acting as a control. Point counts were carried out in the spring immediately after the intervention and in the following winter, in order to compare the relative abundance and behaviour of birds in different contexts.

Chapter 4. Influence of habitat fragments on bird assemblages in cork oak woodlands

In the study described in this chapter the impacts of the presence of olive groves and riparian vegetation on the birds of cork oak woodland matrix were assessed. Bird point counts were performed at increasing distances (0, 50, 150, 250 and 350 m) from olive groves and from sections of riparian vegetation embedded in a matrix of cork oak woodland. Several characteristics of bird communities at different distances from these habitats are investigated, and the potential impacts of these fragments on cork oak woodland bird assemblages are discussed.

This study was published in *Bird Study (Leal et al. (2011) 58: 309–320)*

Chapter 5. Managing spatial heterogeneity in Mediterranean woodlands: The use of spatially-explicit future scenarios for bird conservation.

This study assessed the effects on birds of major habitat management measures aimed at maintaining the economic value of cork oak woodlands, at landscape level. In particular, the potential consequences of management-induced variations in the extent of riparian vegetation and traditional olive groves were modelled. All the olive groves and the main sectors of riparian vegetation present in the study area were identified, digitalized and geo-referenced, using aerial photographs and ground checks.

A total of 40 squares of 1 km^2 were selected within the study area, separated into four categories, ranging from squares with almost pure cork oak woodland to squares with extensive riparian vegetation within a cork oak matrix or fragments with traditional olive groves. Breeding bird censuses were conducted in each square using 1 km line transects. Spatially-explicit models were used to select the most suitable areas for habitat management and quantify the population response of birds to the management of riparian vegetation and olive groves. Finally, these models were used to quantify the consequences of different management scenarios which included both the expansion and elimination of olive groves and riparian vegetation.

The main findings of this work are discussed and integrated in a General Discussion, in ***Chapter 6***. Implications of the major findings for the conservation and management of cork oak woodlands and bird populations are presented, and a prospect for future work is made. Except for the Introduction and General Discussion, the chapters have been accepted for publication in international journals or are in preparation for submission. Consequently, chapter formats may vary slightly.

Chapter 2

Impact of cork extraction on birds: Relevance for conservation of Mediterranean biodiversity

Ana I. Leal, Ricardo A. Correia, José P. Granadeiro & Jorge M. Palmeirim. 2011.
Biological Conservation, 144: 1655-1662

2. Impact of cork extraction on birds: Relevance for conservation of Mediterranean biodiversity

2.1. Abstract

Montados are Mediterranean agro-forestry-pastoral systems recognized as an excellent example of balance between socio-economic development and biodiversity conservation. The economic viability of *montados* dominated by cork oak (*Quercus suber*) depends on the extraction of cork (the bark of trees), usually in 9 year cycles, which is mostly used for production of bottle stoppers. This study evaluated the impact of cork extraction on biodiversity, using birds as indicators.

Comparing bird assemblages of areas with recently extracted cork and older cork revealed that only two species of bark gleaners and two of bark-foliage gleaners had lower densities in recently debarked areas. Arthropod sampling revealed that, in the first years after cork extraction, the bark has less prey, suggesting that the reduction in bark gleaners densities is a result of the decreased food availability. Focal observations confirmed that the affected species were those that foraged mostly on cork. However, our data demonstrated that bird richness and the density of the majority of species were unaffected by debarking, and that at the landscape level even bark gleaners had potentially stable populations.

Pressure from the synthetic bottle stopper industry threatens to render *montados* economically unviable, and consequently be replaced by land uses much less valuable for biodiversity. Showing that cork extraction is compatible with the maintenance of the great ornithological value of *montados*, our results confirm that it is an economic activity that should be promoted for the benefit of biodiversity.

2.2. Introduction

There is increasing evidence that the preservation of biodiversity depends not only on the maintenance of networks of protected sites, but also on the condition of the habitats present in the matrix, usually economically exploited (e.g. Lindenmayer & Franklin 2002). In fact, biodiversity rich farmland and forestry habitats can be critical to maintain interconnection among protected areas, and may harbour important populations of many species of conservation concern (e.g. Tucker 1997; Child *et al.* 2009). Consequently, it is very important to promote land uses that are simultaneously economically valuable and biodiversity friendly.

Montados (Portugal) or *dehesas* (Spain), are agro-forestry-pastoral systems dominated by cork oak (*Quercus suber*) or holm oak (*Quercus ilex*) trees, usually with a groundcover of grazed grasslands (Pinto-Correia 2000), which are recognized as an excellent example of balance between socio-economic development and biodiversity conservation. They are considered High Nature Value Farmlands (HNVF) (Hoogeveen *et al.* 2004), and are included in Annex I of the European Union Habitats Directive (92/43/CEE). However, the area of *montado*s currently protected is considered insufficient to maintain the favourable conservation status of this system (Underwood *et al.* 2009; Santos & Thorne 2010), as required by the Habitats Directive.

Montados are very important for Mediterranean birds as they are the habitat with the highest richness in breeding birds in the Iberian Peninsula (Tellería 2001), and are important breeding areas for endangered species like Spanish imperial eagle (*Aquila adalberti*) and black stork (*Ciconia nigra*). Outside of the breeding season they are a key habitat for a great number of migratory species (Díaz *et al.* 1996; Díaz *et al.* 1997).

Montados dominated by cork oak cover a large area in European and North African Mediterranean countries, over half of which is in the Iberian Peninsula. In Portugal, cork oak occupies almost 740 000 ha, dominating the landscape in much of the southern part of the country. In the vast region where they occur, cork oak *montados* are an essential part of the economy. The system includes multiple economic activities, such as livestock rearing, hunting, mushroom recollection and honey production (Pinto-Correia & Mascarenhas 1999; Pinto-Correia & Fonseca 2009), but most of its economic value derives from the extraction of cork, which is the bark of the cork oak trees. Without the cork revenue, local communities in areas dominated by *montados* would collapse economically, and this would have serious ecological and social consequences. It is estimated that around 28 000 people are employed in Portugal in activities related with cork, and 100 000 in the seven Mediterranean cork-producing countries (WWF 2006).

In this exploitation system, developed mainly in the 18th century, cork is periodically extracted by stripping off long portions of bark from the trunk and large branches at ca. 9 years intervals. The first cork debarking takes places when trees are around 25 years old (Costa & Pereira 2007b) and the bark regenerates because cork oaks have a phellogen, the cell layer responsible for the production of cork, active during the full life of the tree (e.g. Natividade 1950; Moreira *et al.* 2007).

In spite of the high potential of the cork oak *montados* system for the sustainable use of Mediterranean areas, these habitats are nowadays highly threatened. Managed ecosystems last as long as their products are valuable to society (Aronson *et al.* 2009) and the economic viability of *montados* depends on cork extraction, mostly used for the production of bottle stoppers (about 70%). However, makers of synthetic bottle stoppers, mainly located outside the cork production regions, have been internationally promoting their products and this is resulting in a decrease of the demand for cork. Promotional campaigns for synthetic bottle stoppers have used unproven arguments, such as that the demand for cork stoppers was leading to an over stripping of trees with negative consequences for *montados* and their biodiversity. International environmental organizations responded to this with high profile counter campaigns in defence of the use of natural cork. For example, WWF (2006) argued that the survival of those landscapes is important for Mediterranean biodiversity and dependent on the maintenance of the market value of cork, which is currently linked to the wine stopper market.

Although debarking has been usually assumed to be a non-damaging activity (e.g. Pereira & Fonseca 2003), it does imply a potential change in the *montados* ecosystem. This may indeed influence biodiversity, but to our best knowledge nobody has objectively evaluated this potential impact. Such evaluations are necessary to understand the real impact of the cork industry, providing the scientific background required to make management decisions on the future of the exploitation of *montados*. Birds are a suitable model to study the biodiversity consequences of cork extraction because they are very diverse and abundant in the *montados*, and are known to be good biodiversity indicators (e.g. Hutto 1998; Gregory *et al.* 2003; Díaz 2008).

The overall objective of this study is to determine if cork extraction affects the biodiversity of *montados,* using birds as a model. If cork extraction influences birds, we would expect lower species richness and abundance in areas with younger cork. *Montados* are home to a variety of bird functional groups, such as foliage gleaners, bark gleaners, and ground foragers (e.g. Díaz 2009), and we predict that they will be differentially affected by cork extraction. To identify factors that may determine how cork extraction potentially affects birds, we analysed how birds use trees with different cork ages and studied the abundance of potential arthropod prey. Finally, considering that cork extraction activities often lead to the establishment of mosaic landscapes of fields with trees with different cork ages, we quantified the total impact of cork extraction on birds at a landscape level.

2.3. Methods

Study area

The study was carried out in Portugal, in a large farm managed by the state owned "Companhia das Lezírias" (38^o 48' N – 8^o 49' W) (Figure 2.1). It covers 11 071 ha, 6 100 of which are occupied by cork oak *montados*. In addition to cork production and non-intensive livestock rearing, the area includes pine and eucalyptus plantations, cereal fields, and rice paddies. In most of the cork oak areas all trees have the cork removed in the same year, although a few fields still have trees with a mixture of cork ages. The density of trees in the cork oak fields is about 35 trees/ha, and shrubs are regularly cleared in most of the area.

Bird assemblages in areas with different cork age

To study the influence of cork age on the bird assemblages we estimated the density of all bird species present in areas with 0, 3, 6 and 9-year old cork (Figure 2.1). For each of these four ages we established 30 counting stations, separated by at least 200 m from each other, which were our sampling units. In addition, we established 30 stations in areas that had a mixture of trees with 0 and 7-year old cork, hereafter designated as mixed-age areas. As previous studies demonstrated that *montados* vegetation structure influences bird community parameters (e.g. Pulido & Díaz 1992; Pulido & Díaz 1997), all the stations were located in areas with similar management, tree density and age, and had a minimal shrub cover (less than 1%). A total of 150 stations were sampled during winter (December 2007 and January 2008), and again in spring (April and May 2008).

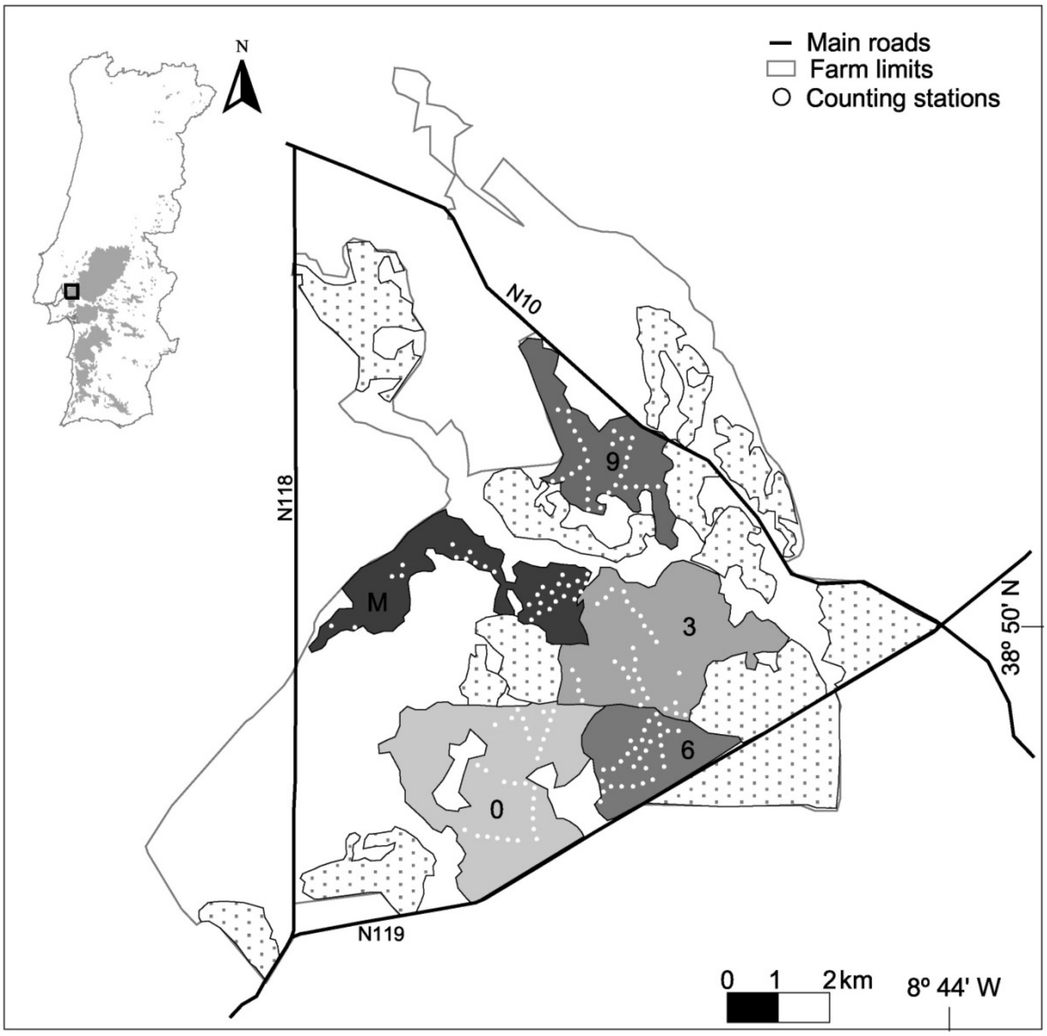


Figure 2.1. Study area with the indication of cork oak (*Quercus suber*) fields. The studied areas are marked in solid grey with the indication of the age of cork (0, 3, 6 and 9 year-old cork, or M for mixed-age fields that had a mixture of trees with 0 and 7-year old cork). White dots indicated the bird counting stations. Cork oak distribution areas in Portugal are indicated in shade in the country map.

Bird counts were carried out within four hours after sunrise, always by the same observer, using 10 minute point counts (Bibby *et al.* 1992; Sutherland *et al.* 2004). We recorded all bird contacts and estimated their distance to the observer in 10 meters distance bands, up to 100 meters. Over-flying birds were excluded from the analyses.

Bird densities were estimated using the DISTANCE software (Thomas *et al.* 2006). Since the structure of the habitat in all the sampled areas was similar, we used the same detection function for all the density estimates of the same species. We did not estimate densities for the species that did not reach the recommended minimum of about 60 detections to use DISTANCE with accuracy (Buckland *et al.* 1993; Somershoe *et al.* 2006). We fitted uniform, hazard-rate and half-normal functions, all with cosine adjustments, and chose the model with the lowest value of Akaike´s Information Criterion (Buckland *et al.* 1993; Burnham & Anderson 2002).

Coleman individual-based rarefaction curves, calculated with EstimateS (Colwell 2006), were used to compare species richness in areas with different cork age. The influence of the age of cork on the total density of birds was tested using GLM with Poisson error distribution and a log-link. The slope obtained in the log-linear models was used to test the significance of the relationship between cork age and bird density.

Bird use of trees with different cork age

To determine if birds have a preference for using trees with cork of different ages we made observations in the mixed-age areas. These trees were intermixed, so birds always had a choice of different cork ages within a small area. Between February and June 2008, we carried out focal observations in early morning and late afternoon in two transects (1400 m and 800 m long). An observer walked along the transect searching both trunks and canopies for birds, within a band of 30 m from the transect line.

When a bird was detected, we registered the age of the cork of the tree where the bird was first detected. Each bird was then followed for as long as possible, and its behaviour was recorded for a maximum of 60 seconds (Morrison 1984; Adamík & Kornan 2004). When the bird was actively foraging we registered the foraging technique (bark and foliage glean, hover/hawk, hang and hammer) (Airola & Barrett 1985; Remsen & Robinson 1990).

The availability of trees with different cork ages was estimated by counting all the trees located within the 30 m band from the transect line. Selection of cork age by birds was determined by comparing use with availability, using a Chi-square test. All the statistical computations were carried out using the R statistical software (R Development Core Team 2007).

Abundance of arthropod prey on trees with different age

To estimate differences in the availability of food resources for insectivorous birds in relation to cork age, we sampled arthropods in the same fields where we made bird counts, i.e. 0, 3, 6, and 9-year old cork. We also sampled arthropods on trees in the mixed-age areas. Sampling was carried out in winter and spring.

Trunks of cork oak trees are usually high, especially in the case of trees that have been prepared since young age for cork extraction, and usually split in two or three main branches. The cork is extracted both from trunk and main branches, when they achieve the minimum allowed perimeter of 70 cm. To estimate arthropod availability, in each tree we sampled a 0.25 m^2 area of the surface of debarked main branches for 120 s, using an adapted electric vacuum cleaner (1600 Watts, 3 cm^2 suction area). For each cork age we sampled debarked branches of 10 different trees in winter and 30 in spring. We also sampled the availability of arthropod prey in 30 squares of non-debarked main branches in each of the five studied cork age classes, which we used as reference. All arthropods specimens were kept in 70^o alcohol for identification to Class or Order.

For the analysis of the arthropod availability for birds on cork with different ages, we used the arthropod groups that are often in the diet of the species that usually feed directly on the cork (following Obeso 1988; Blondel *et al.* 1991; Orsini & Ponel 1991; Pulido & Díaz 1994; Cramp & Perrins 1998): treecreeper (*Certhia brachydactyla*), nuthatch (*Sitta europaea*), blue tit (*Parus caeruleus*) and great tit (*Parus major*). This resulted in the following orders: Aranae, Coleoptera, Diptera, Hemiptera, Hymenoptera and Lepidoptera.

GLM with Poisson error distribution was used to test the influence of the age of cork on the total density of arthropods.

Landscape level impact of cork extraction on birds

Landscapes dominated by *montados* can be organized in mosaics of fields where all the trees have the same age of cork, as happens in most of our study area. To estimate the landscape level impact of cork extraction in the studied *montados*, throughout a complete nine years cork rotation cycle, we first estimated the total surface of each cork age that will be available in each year of the cycle in the study area. We then used our density estimates for each cork age to project the likely size of the total bird population inhabiting the studied *montados* in each of the next nine years of the cycle. Finally, we compared each of these estimates with those that would be expected if cork was not exploited in any of the *montados* fields. Ideally, in this comparison we would use bird densities in *montados* where cork had never been exploited. However, as such fields do not exist in the study region, we used as a reference the closest available approximation to this situation, i.e. densities in fields with the oldest cork (9 years). The difference between the two values was considered as the likely landscape level impact of the cork exploitation on the populations of birds.

2.4. Results

Comparison of bird assemblages in areas with different cork age

A total of 63 species were identified in spring and 56 in winter. There were no differences in species richness between the five cork age groups in either season, according to the rarefaction curves analysis. However, the overall density of birds increased slightly from the younger to the older cork (Figure 2.2a) in both seasons (spring: slope= 0.02, $p < 0.001$; winter: slope= 0.03, $p < 0.001$). Functional groups responded to cork age differently. Bark gleaners and bark-foliage gleaners were both affected, and had lower abundance in the areas with younger cork (bark gleaners, spring: slope= 0.23, $p < 0.001$; winter: slope= 0.29, $p < 0.001$; bark-foliage gleaners, spring: slope= 0.08, $p < 0.001$; winter: slope= 0.07, $p < 0.001$; Figure 2.2b and c). The overall density of the remaining bird species was unaffected by cork age (spring: slope= -0.006, $p = 0.51$; winter: slope= 0.003, $p = 0.8$) (Figure 2.2d).

Seventeen bird species had samples large enough to test for density responses to cork age. The two bark gleaners, treecreeper and nuthatch, had a substantially lower density in areas with younger cork (Figure 2.3a and b). This effect was weaker, but still important, in the bark-foliage gleaners blue tit and great tit (Figure 2.3c and d). In the mixed-age area these four species presented high densities, usually with values similar or higher than those of fields with 6-year old cork.

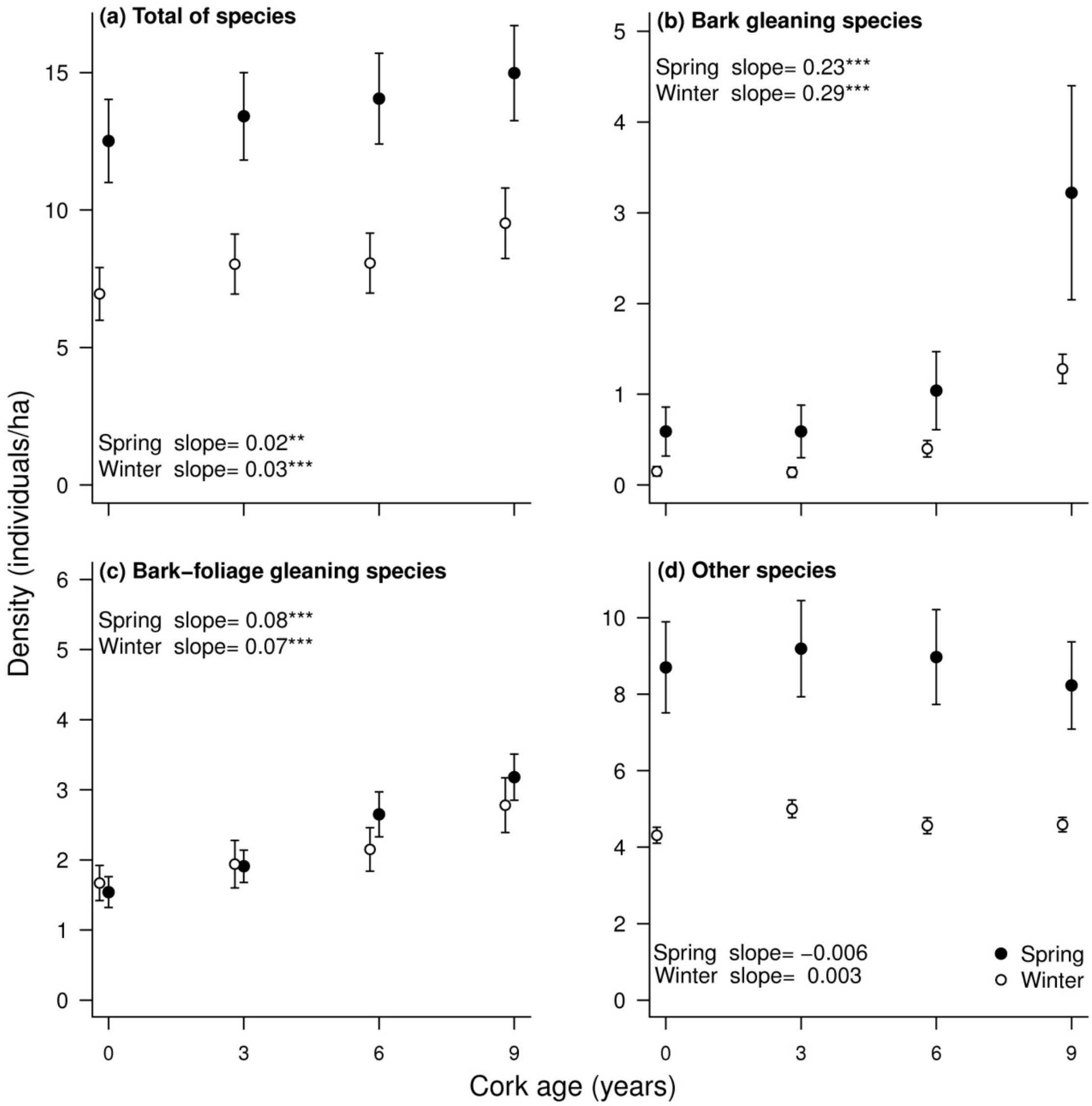


Figure 2.2. Density of birds (individuals/ha ± SE) in *montados* with different cork ages (0, 3, 6 and 9 years), in spring (black dots) and winter (white dots): (a) all species pooled, (b) bark gleaning species, (c) bark-foliage gleaning species, and (d) all other species, which mainly forage on the foliage or ground. The slope was obtained using GLM with Poisson error distribution (*p< 0.05, **p< 0.01, ***p< 0.001).

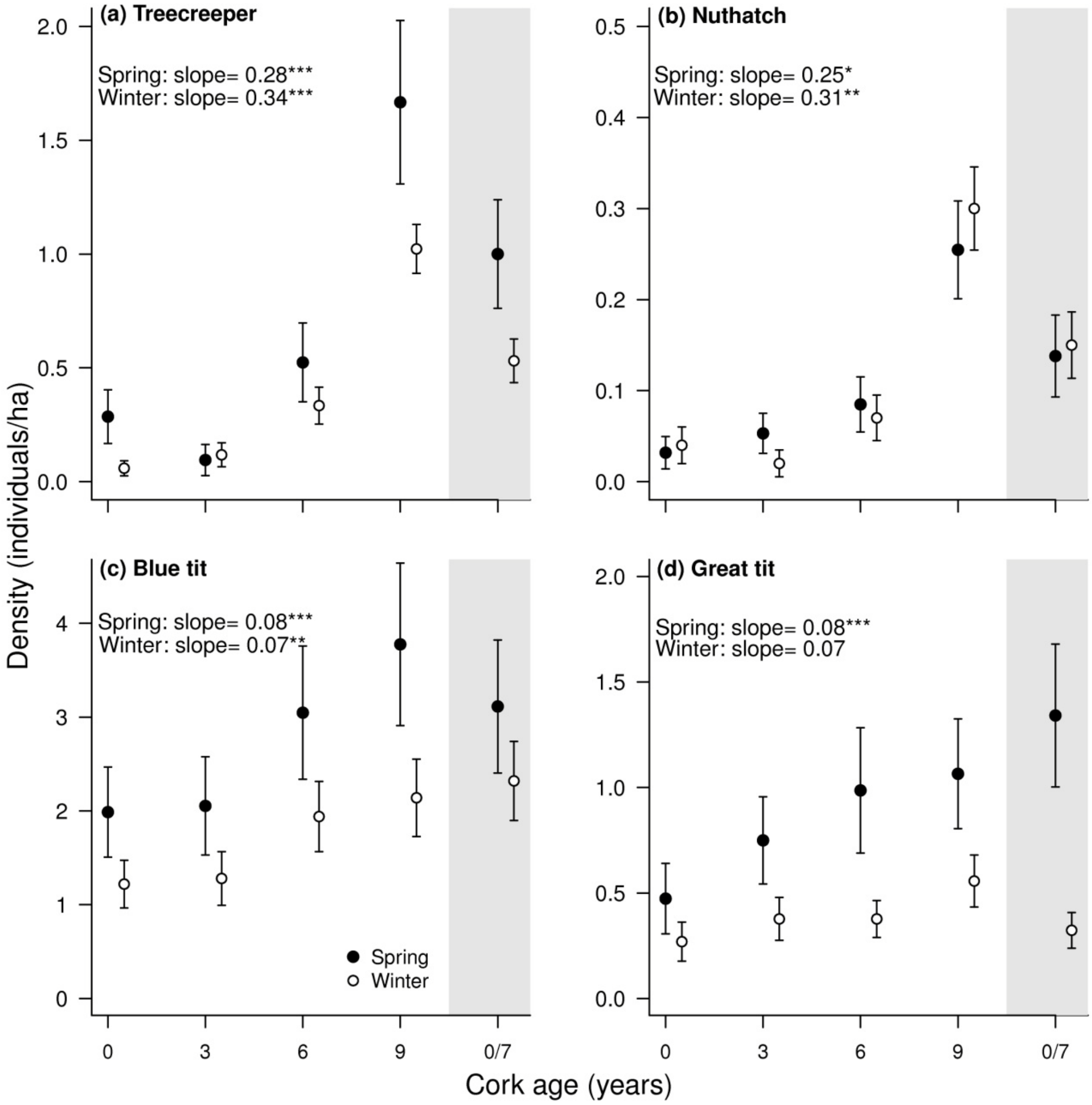


Figure 2.3. Density of the four bird species (individuals/ha ± SE) that were influenced by debarking in areas with different cork ages (0, 3, 6 and 9 years), in spring (black dots) and winter (white dots). The shaded bar corresponds to the mixed-age areas, which had trees with 0 and 7-year old cork. The slope was obtained using GLM with Poisson error distribution (*p< 0.05, **p< 0.01, ***p< 0.001).

Comparison of bird use of trees with different cork age

We checked if species had a preference for foraging in older cork comparing their choice between 0 and 7-year old cork trees (Figure 2.4). We made a total of 265 focal observations of 18 bird species during winter and 365 of 21 species in spring. Eight species were observed actively foraging on the trees. More than half of the observations of treecreeper, nuthatch, blue tit, great tit and chiffchaff (*Phylloscopus collybita*) corresponded to individuals actively foraging. Robin (*Erithacus rubecula*), chaffinch (*Fringilla coelebs*) and serin (*Serinus serinus*) were excluded from the analyses due to the low number of foraging observations.

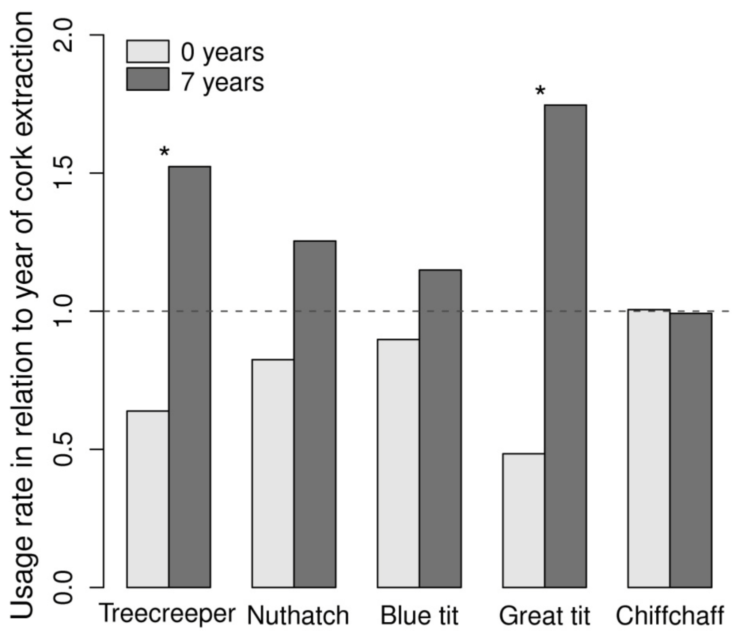


Figure 2.4. Foraging preferences for trees with 0 and 7-year old cork, by five species of birds. Values near 1.0 indicate usage levels proportional to availability, above 1.0 indicate a use greater than expected, and less than 1.0 a use lower than expected. N= 141 observations for 0-year old, and n= 134 for 7-year old. Significant results of Chi-square test are marked with *.

Table 2.1. Percentage of time spent in different foraging techniques for five of the studied species. Number of birds foraging (*N.birds*) and total time of observation (*observ.time*) are indicated.

	Treecreeper	Nuthatch	Blue tit	Great tit	Chiffchaff
Bark-glean	100.0	91.2	21.7	45.4	---
Foliage-glean	---	4.7	70.2	54.6	86.4
Hover/Hawk	---	---	---	---	13.5
Hammer	---	4.0	---	---	---
Hang	---	0.1	8.1	---	0.1
(N.birds; observ.time)	*(61; 1575s)*	*(40; 1267s)*	*(82; 2225s)*	*(23; 667s)*	*(69; 1802s)*

Treecreeper and great tit used older cork significantly more often than expected by chance. The chiffchaff, mainly a canopy gleaner, used trees with the two cork ages proportionally to their availability.

The analysis of the foraging behaviour (Table 2.1) shows that bark gleaning was by far the most common foraging technique used by treecreeper and nuthatch, and was also common in great tit and blue tit. The chiffchaff is also a gleaner, but was only observed using this technique in the foliage.

Arthropod prey abundance in relation to cork age

We caught a total of 10 804 arthropods in winter and 25 582 in spring. Excluding ants, roughly 50% of all the caught arthropods belonged to taxa known to be consumed by the bird species that forage on bark, including Aranea (Class Arachnida), Coleoptera and Lepidoptera (Class Insecta).

There was a significant increase in the abundance of these potential prey from 0 to 9-year old cork in debarked branches, in both seasons (winter: slope= 0.09, $p < 0.01$; spring: slope= 0.06, $p < 0.001$) (Figure 2.5). Abundances in spring were roughly twice those in winter, regardless of the age of cork.

In spring we also sampled arthropods in branches with virgin cork (i.e. branches which were never debarked), in fields with different cork ages, to test for the presence of effects other than that of the age of cork. This control using virgin cork, demonstrated that there were no significant differences in the abundance of arthropods in relation to the age of cork in the fields (slope= 0.006, p= 0.57) and, in general, it had more arthropods than the branches that had been debarked. However, the abundance of arthropods in 9-year old cork reached that observed in the virgin cork (Figure 2.5).

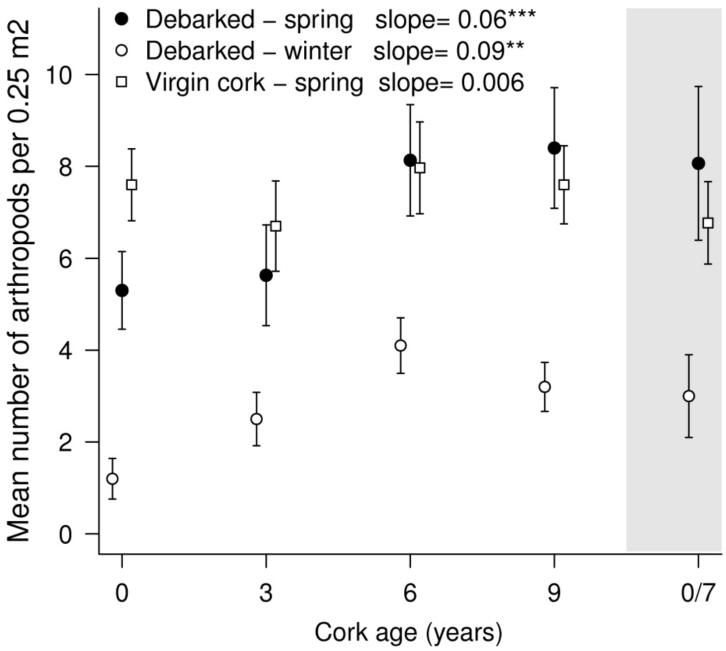


Figure 2.5. Abundance of arthropods (mean per 0.25m^2 of cork ± SE) in main cork oak branches in fields with cork with 0, 3, 6 and 9 years of age. The shaded bar corresponds to the mixed-age areas which had trees with 0 and 7-year old cork. The slope was obtained using GLM with Poisson error distribution (*p< 0.05, **p< 0.01, ***p< 0.001).

Landscape level impacts of cork extraction on birds

The predicted impact of the exploitation of cork on the populations of birds along the nine years cycle varied substantially from species to species, and in some cases also varied from year to year (Figure 2.6). The overall reduction in total bird abundance due to cork exploitation is of 13% (SD= 0.02). However, in the case of the bark gleaners, treecreeper and nuthatch, this predicted reduction is much greater, ranging between 48 and 75%. This reduction should reach a maximum in 2015, year when the overall age of the cork in the study area is expected to be at its lowest level. In the case of the bark-foliage gleaners, great tit and blue tit, the reduction should range between 14 to 33%.

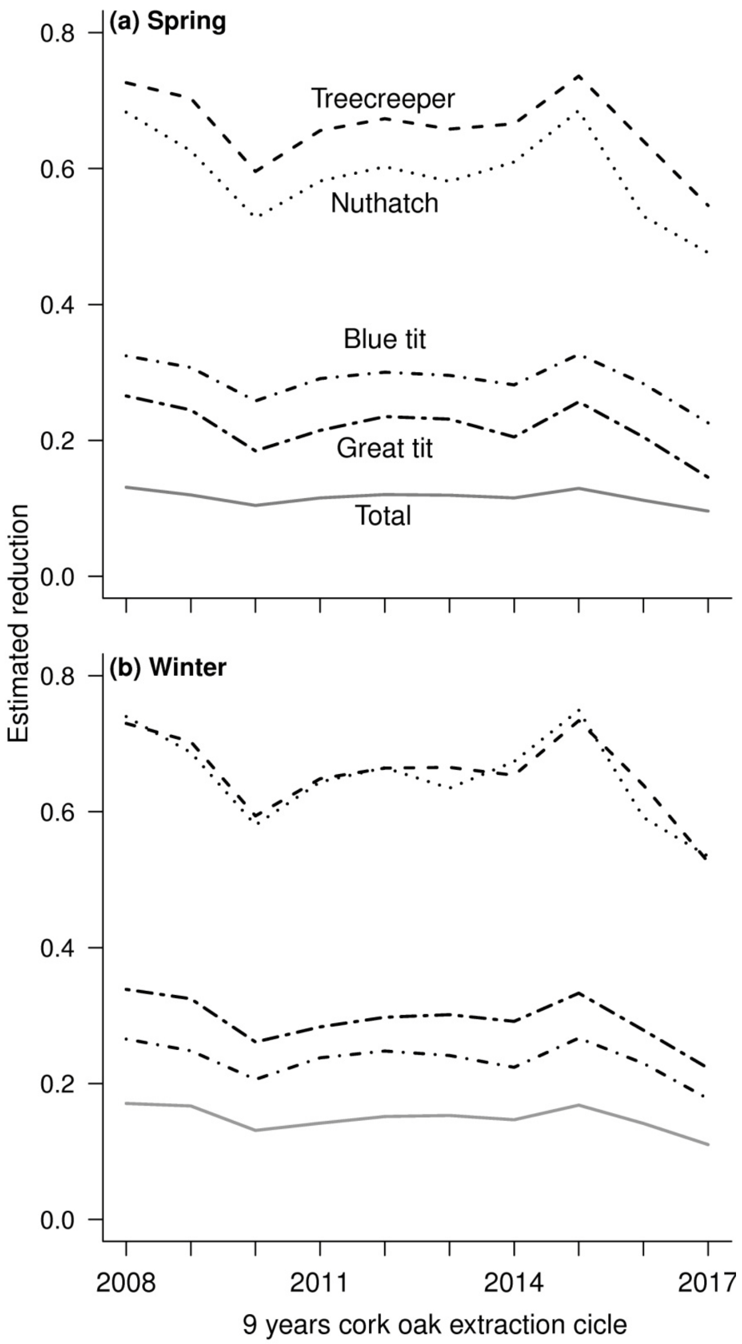


Figure 2.6. Predicted reduction in bird densities in the entire study area resulting from the extraction of cork, throughout a typical nine year extraction cycle, in spring and winter. Lines are shown for all species pooled and for the four species affected by debarking.

2.5. Discussion

The results of the rarefaction analyses demonstrate that cork age does not influence the species richness of the bird assemblages of the *montados*, neither in spring nor winter. However, age influences the overall density of birds, which in spring and winter increases in areas with older cork.

The analysis of functional groups showed that only bark gleaners and bark-foliage gleaners are affected by cork extraction. These groups are a relatively small proportion of the assemblage, which explains why the impact of debarking on the total density is quite minor, albeit statistically significant.

The lower abundances of bark gleaners and bark-foliage gleaners that we observed in areas with younger cork reflect the likely impact of debarking on treecreeper, nuthatch, blue tit and great tit. If this decrease is due to debarking, then we would predict that the affected species would show a preference to forage on trees with older bark.

Our results clearly confirmed this prediction, since the species with lower densities in debarked areas tended to have a preference for trees with older cork, although this tendency was not statistically significant in all species. Furthermore, behavioural observations confirmed that the most affected species, treecreeper and nuthatch, foraged almost exclusively on cork. In addition, they tend to forage on the trunk and main branches (pers. obs.), which are those used for cork extraction. The blue tit and the great tit were also often observed feeding on the cork, but to a lesser extent than the previous species. Finally, the chiffchaff was not observed feeding on the cork. These behavioural observations are in line with those reported in previous studies (e.g. Carrascal & Tellería 1989; Nour *et al.* 1997; Almeida & Granadeiro 2000).

As the influence of debarking on birds is closely related with their foraging strategy, we predicted that arthropod prey availability in bark would be higher where bark gleaners are more abundant, i.e. in older cork. This was indeed confirmed by our results, as trees with older cork had the highest densities of arthropod prey both in spring and winter, suggesting that debarking affects the abundance of arthropods. This is most likely due to differences in the structure of the bark. The surfaces that have recently been debarked are more homogeneous than those covered with older bark. As bark develops, its structural complexity increases and, in many cases, numerous cracks appear (e.g. Natividade 1950; Pereira 2007).

To make sure that the observed differences in prey abundance were due to the age of cork and not to uncontrolled area effects, in spring we sampled the arthropod communities of branches with virgin cork in all the fields. The results confirmed that there were no significant area effects.

Since the observed bird declines parallel those of bark arthropod prey, and the affected birds are bark and bark-foliage gleaners, we can conclude that the lower bird abundances are a consequence of a reduction in prey availability due to cork extraction. Bird species that do not depend on bark arthropods, which were the great majority of the species studied, were apparently not affected by this activity.

It is also worth noting that the density of arthropod prey in 9-year old cork is similar to that in virgin cork. This suggests that at the end of the nine year cycle the exploited *montados* are just as good for foraging bark gleaners as if they had never been subjected to cork extraction.

Our results indicate that a few bird species are affected by cork extraction, having depressed densities in fields that have recently been debarked. However, for the management of biodiversity, the effects on bird populations at the level of the landscape are more relevant than those at field scale. Therefore, we also estimated the potential impact of debarking at the landscape level.

We used bird densities in the 9-year old cork as a reference because, as discussed above, it is as good as virgin cork as a foraging substrate for insectivorous gleaners; prey availability seems to determine the densities of these birds, which were the only ones affected by debarking. At the landscape level the potential reduction in the bark gleaning species is 48-75% and that of the bark-foliage gleaners 14-33%. These reductions are not nearly as substantial as those observed in the recently debarked fields because, at the landscape level, there are always fields with older cork that are good habitat for those species. It is also noticeable in our results that even though the overall quality of the landscape for bark foraging species fluctuates from year to year, depending on the overall age of cork in the region, these fluctuations are not very accentuated.

At a regional scale, the habitat quality for bark gleaners remains relatively stable over time because the landscape in the study area is a mosaic of parcels with non-synchronized exploitation cycles. Land managers should promote the maintenance of this lack of synchronization, so that birds have always alternative good quality areas. Actually, in most cases it should be in the interest of the cork producers to have parcels that are being exploited at non-synchronized cycles. This allows them to avoid both years without economic income from cork exploitation (e.g. Borges *et al.* 1997), and years with a production above their selling capacity, so extensive areas with synchronized cork ages are rare.

In our study area all trees in each field are usually debarked in the same year, and consequently they all have cork of the same age. However, in many other *montados* managers keep trees with different cork ages in the same parcels (Pereira & Tomé 2004). We found that such mixed-age areas harbour high densities of bark and bark-foliage gleaning species, although usually not quite as high as the areas with just old cork. Consequently, this regime can be considered favourable to the species in these guilds.

Relevance for conservation

We found that the extraction of cork does not significantly affect the rich diversity of birds of *montados*, and that only species that are substantially dependent on foraging directly on cork are affected by this activity. However, these species are present even in the most recently debarked parcels, and their populations are likely to remain quite stable at the landscape level. In fact, even for bark gleaners, the exploited *montados* are still the most favourable habitat available in the study region (pers. obs). The quantitative data used in this study is limited to fairly common species, because of the need to have samples that are large enough to test for statistical significance. However, our results suggest that rarer species should not be affected by debarking, unless they feed mostly on the cork. In the study area this situation could only apply to woodpeckers (e.g., great spotted woodpecker (*Dendrocopus major*) and lesser spotted woodpecker (*D. minor*)), but they tend to feed higher in the tree, in parts that are not debarked (pers.obs.).

As previously mentioned, *montados* are a High Nature Value Farmland (Hoogeveen *et al.* 2004) that are under great threat due to the growing competition between cork stoppers and synthetic bottle stoppers. In fact, without the high income resulting from the production of cork stoppers (Mendes & Graça 2009), *montados* may lose their economic viability. This may result in its replacement by other types of land cover, much less valuable for birds and for other components of biodiversity (e.g. Berrahmouni *et al.* 2009). Moreover, the production of cork stoppers is more environmentally friendly because it results in less solid waste, greenhouse gases and other forms of pollution than any of the synthetic stoppers (Vallejo *et al.* 2009).

The loss of value of cork, and the consequent decline of *montados*, is also likely to have substantial consequences to local rural communities. *Montados* are complex socio-ecological systems (SESs) that are the main economic resource of vast regions in the Mediterranean. The loss of the economic viability of the system can lead to land abandonment, which is already affecting areas in Spain, Portugal, France and Italy (Bugalho *et al.* 2009b). An analysis of the sustainability of *montados* using the SESs framework proposed by Ostrom (2007, 2009), identified rural exodus as a problem for the conservation of European *montados* (Santos & Thorne 2010). The reduction of land abandonment can be achieved by giving clear signs to rural residents that their land is economically, ecologically and culturally valuable and viable using traditional land management practices, and applying agro-environmental incentives (Santos & Thorne 2010).

By demonstrating that cork extraction is compatible with the maintenance of the rich bird community of *montados*, our results confirm that it is an economic activity that should be maintained and promoted for the benefit of biodiversity. In *montados* dominated landscapes it is important to promote the maintenance of a mosaic of fields with different cork ages, or in alternative the coexistence of cork of different ages in the same fields. It is unfortunate that *montados* are now so threatened by market changes, and if cork does lose its economic value, then agro-environmental schemes may become necessary to maintain this ecologically and socially valuable Mediterranean system.

CHAPTER 3

Does canopy pruning affect foliage-gleaning birds in cork oak woodlands?

Manuscript

3. Does canopy pruning affect foliage-gleaning birds in cork oak woodlands?

3.1. Abstract

Semi-natural cork oak woodlands are a biodiversity rich system that covers large areas in the Mediterranean region. The canopies of the adult oaks are often pruned, but nothing is known about the consequences of this treatment on biodiversity. We evaluated the impact of pruning on birds that forage in cork oak canopies in an area of southern Portugal. The use of trees by foraging birds was characterized with focal observations, and the effects of pruning on density with point counts on recently pruned and control areas. As pruning reduces the foraging substrate for foliage gleaners, we predicted that these species would have lower densities in pruned areas.

Pruning did not have a significant effect on overall bird density or species richness. However, as predicted, the density of species that foraged mostly by gleaning in the canopy tended to be lower in pruned areas, especially in winter when differences were statistically significant. In this season the combined density of foliage gleaners in the pruned stations was only half of that in controls. Furthermore, a separate exam of the density of the common foliage-gleaning species revealed that they all tend to be less abundant in the pruned areas, although the difference was statistically significant only for the blue tit.

Pruning is also a common treatment in several other managed Mediterranean woodlands that are important for birds, such as holm oak woodlands and olive groves, and canopy gleaners are likely to be affected in those too. The cumulative effects of pruning on all these habitats need to be assessed, but our results already indicate that pruning does have negative consequences that should be properly considered in management decisions.

3.2. Introduction

Forests are among the most diverse habitats on earth containing at least two-thirds of the known terrestrial species (WCFSD 1999). Mediterranean woodlands cover very large areas in Southern Europe and in North African Mediterranean countries, and are considered a biodiversity hotspot (Myers *et al.* 2000; Brooks *et al.* 2006). These woodlands have been managed for centuries, but surprisingly there is a large gap of knowledge on how the management activities affect the biodiversity in these species-rich ecosystems (Marañón *et al.* 1999; Gil-Tena *et al.* 2007). In fact, the impact of silvicultural practices on biodiversity has received some attention, but most studies have focused mainly in northern European forests (e.g. Mielikäinen & Hynynen 2003; Paquet *et al.* 2006; Quine *et al.* 2007).

Pruning is a common and well-established silvicultural procedure in managed woodlands, and consists in the removal of side branches and multiple leaders from a standing tree (Keer 2004). The impacts of pruning on biodiversity are poorly documented (Torras & Saura 2008), in contrast with for example those of thinning (the artificial reduction of the number of trees growing in a stand), which have been widely studied (e.g. Hayes *et al.* 2003; Hagar *et al.* 2004; De La Montaña *et al.* 2006). De La Montaña *et al*. (2006) studied the impact of silvicultural practices in birds of Mediterranean maquis, which included pruning of the canopies. However, the treatment used also included other procedures, so it is difficult to isolate the effect of pruning. Other authors concluded that pruning significantly favors shrub species richness, but apparently not indicators such as snags, mature trees, shrub abundance, tree species richness and diversity (Torras & Saura 2008).

Pruning simplifies the structural complexity of the tree by reshaping and resizing canopies and the consequences of pruning include the reduction of canopy and tree foliage (Cañellas & Montero 2002) and the removal of existing or potential cavities (e.g. Sedgeley 2001). The impact of this intervention on animal species has not yet been studied although it may affect, for example, many woodland birds. Indeed, pruning may not only reduce the protection from predators offered by the foliage but potentially also affects the amount of prey available for birds.

Cork oak (*Quercus suber*) woodlands (called *montados* in Portugal, and *dehesas* in Spain) are agro-silvo-pastoral systems typical of many Mediterranean countries (Pinto-Correia *et al.* 2011). In these systems, the trees are often subjected to direct management procedures that include cork extraction, thinning and pruning. Pruning in young trees is considered to be an important operation to obtain clear trunk heights to facilitate cork extraction and increase the future value of cork. However, old trees are also often pruned, a practice that was introduced in *montados* when these woodlands started to be used for cattle rearing and cereal production (Natividade 1950), as it increases the amount of radiation reaching the ground. In adult trees pruning also favours a regular and abundant acorn production, balances the canopy, and eliminates dead, old or sick branches (LPN 2007). Portuguese legislation only allow cork oak pruning between November and March and the removed branches are used for the production of firewood, charcoal or virgin cork (Natividade 1950; Costa & Pereira 2007b).

In this study we investigate the ecological consequences of pruning, by examining its effect on the bird assemblages in *montados*. We hypothesised that the abundance of bird species that forage on the tree can decrease following this silvicultural treatment. This effect is likely to be more noticeable on canopy foliage-gleaning birds that are very abundant in *montados*, such as tits (*Parus sp*.) and chiffchaff (*Phylloscopus collybita*).

3.3. Methods

Study area

The study was carried out in Portugal, in a large farm managed by the state-owned "Companhia das Lezírias" (38º 48' N – 8º 49' W). It covers 11 071 ha, 6 100 of which are occupied by cork oak *montados*. In addition to cork production, the area is used for extensive livestock rearing, and includes pine and eucalyptus plantations, cereal fields, and rice paddies.

Use of trees by birds

To evaluate which bird species could be affected by pruning we carried out focal observations along two transects (1400 m and 800 m long), in winter and spring 2008. All birds seen or heard within a band of 30 m from the transect line were recorded. When a bird was detected on a tree, its behaviour (foraging, singing, calling, others) and its foraging site (trunk, main or secondary branches or foliage) were recorded (Airola & Barrett 1985). The birds were observed, up to a maximum of 60 s, and their behaviour was recorded during the full length of the scanning period.

Assessing bird populations

To study the influence of pruning on bird densities we selected cork oak areas with similar vegetation structure, tree density and cork age. We established 15 counting stations in areas that had been recently pruned and 30 counting stations in areas that were not pruned in the recent years, which acted as a control. Pruning was carried out in February-March 2008 and the counting stations were surveyed in the spring immediately after the intervention (April-May 2008, with a minimum of 1 month interval between pruning and bird surveys), and in the following winter (February 2009).

Counts were carried out within four hours after sunrise, using 10 min point counts (Bibby *et al.* 1992; Sutherland *et al.* 2004). We recorded all bird contacts and estimated their distance to the observer in 10 m distance bands, up to 100 m. Over-flying birds were excluded from the analyses.

Bird densities were estimated using DISTANCE software (Thomas *et al.* 2006). To increase the robustness of the detection function estimate for each species, we also used the data from similar point counts, carried within another study, which were surveyed simultaneously in the same study area (Leal *et al.* 2011a). Since the structure of the habitat was similar in all the sampled areas, we used the same detection function for all the estimates of the same species. We did not estimate densities for species that did not reach the recommended minimum of about 60 detections to allow the use of DISTANCE with accuracy (Buckland *et al.* 1993; Somershoe *et al.* 2006). We fitted uniform, hazard-rate and half-normal functions, all with cosine adjustments, and chose the model with the lowest value of Akaike's Information Criterion (Buckland *et al.* 1993; Burnham & Anderson 2002).

3.4. Results

Distribution of foraging birds on the tree

We made a total of 265 focal observations of 18 bird species during winter, and 365 of 21 species in spring. Ten species had a total observation time over nine minutes, eight of which were observed actively foraging on trees. More than 50% of the observations of treecreeper (*Certhia brachydactyla*), nuthatch (*Sitta europaea*), great tit (*Parus major*) and blue tit (*Parus caeruleus*) corresponded to actively foraging individuals. Robin (*Erithacus rubecula*), chaffinch (*Fringilla coelebs*) and serin (*Serinus serinus*), were excluded from the analyses due to the low number of foraging observations.

Table 3.1. Percentage of time spent foraging in different substrates for the five species more frequently observed foraging on trees (winter and spring). Number of birds foraging (*n*) and total observation time (*time*) are indicated.

	Treecreeper	Nuthatch	Blue tit	Great tit	Chiffchaff
Trunk	18.7	2.3	---	---	---
Main branches	25.0	15.4	---		---
Sec. Branches	55.1	71.3	11.5	34.0	0
Foliage branches	1.1	11.0	88.5	66.0	100
(n; time)	*(61; 26min)*	*(43; 24min)*	*(85; 39min)*	*(23; 11min)*	*(69; 31min)*

Blue tit, great tit and chiffchaff spent more than 65% of the foraging time in foliage branches, whereas the treecreeper and nuthatch, which are mainly bark gleaners, spent the great majority of the foraging time on the trunk or major branches (Table 3.1).

Comparison of bird assemblages in pruned and control areas

A total of 50 species of birds were identified in spring and 45 in winter. The overall density of birds in point counts was not significantly affected by pruning (spring: t_{43}= 0.47, p= 0.6; winter: t_{43}= 0.9, p= 0.4) (Figure 3.1a). In addition, there were no significant differences in species richness between pruned and control areas in both seasons (Figure 3.1b).

However, the density of foliage gleaners tends to be higher in control areas, especially in winter when the differences were statistically significant (spring: t_{43}= 1.2, p= 0.2; winter: t_{43}= 3.4, p< 0.01) (Figure 3.2a). In winter the combined density of foliage gleaners in the pruned stations was only half of that observed in the controls. In fact, if we examine separately the density of the most common foliage-gleaning species, blue tit, great tit and chiffchaff (in winter), it is clear that all of them tend to be less abundant in the pruned areas (Figure 3.2). However, those differences were only statistically significant for blue tit in winter (spring: U= 210, p= 0.7; winter: t_{43}= 2.6, p< 0.05) and nearly significant for chiffchaff (winter: U= 159.5, p= 0.06).

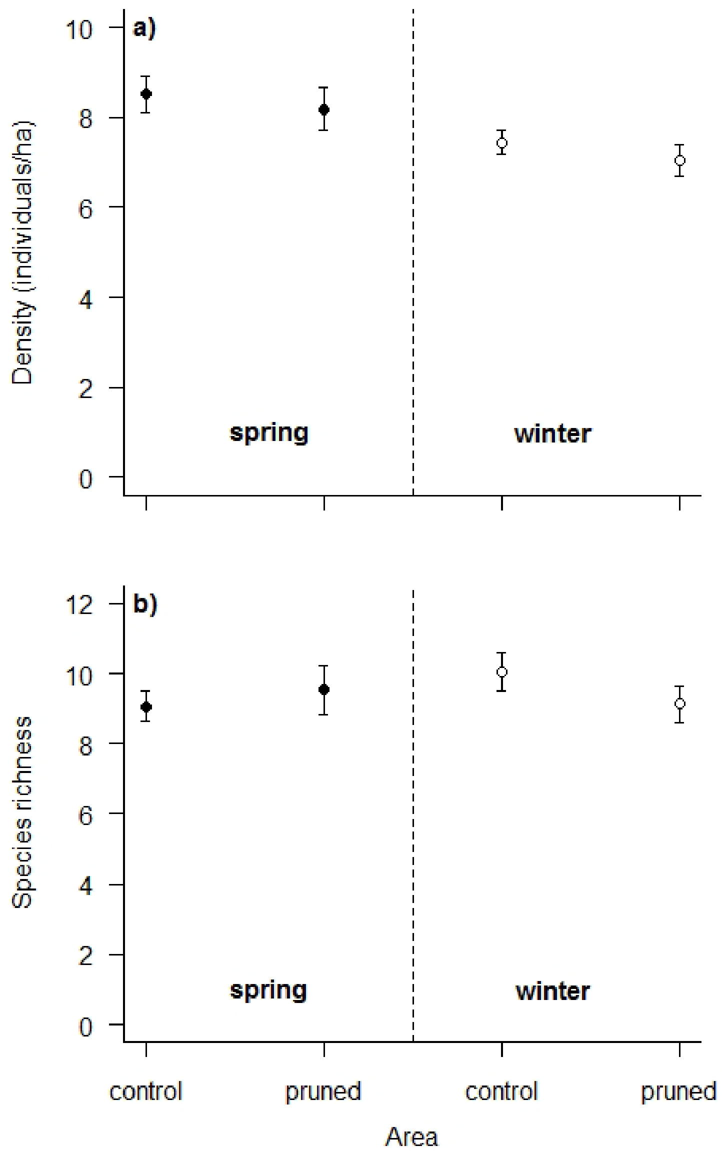


Figure 3.1. Density of all bird species (individuals/ha ± SE) (a) and species richness (mean number of species/point ± SE) (b) in control and pruned areas, in the spring and winter immediately after pruning intervention.

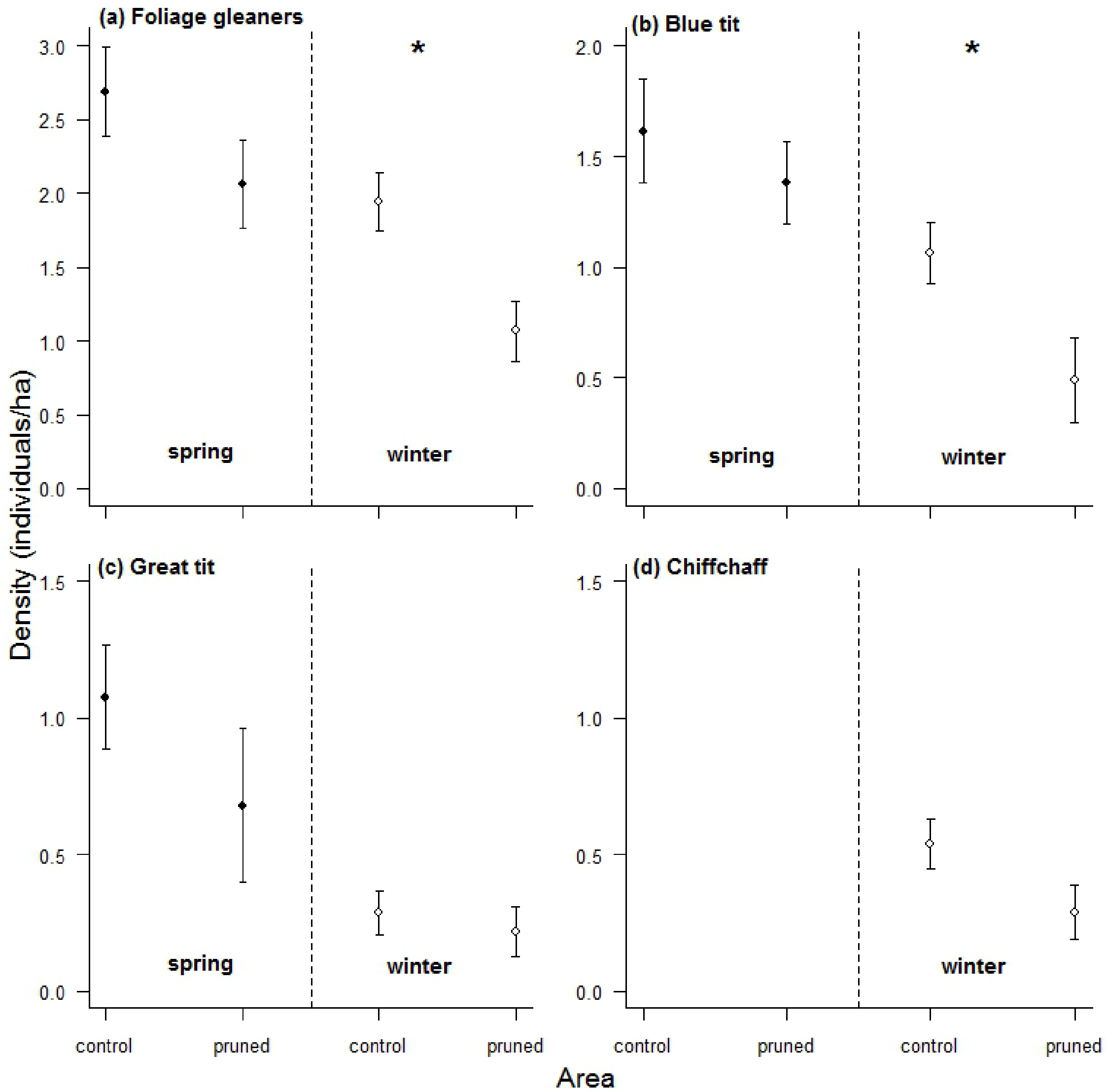


Figure 3.2. Density (individuals/ha ± SE) of all foliage gleaners combined (a), blue tit (b), great tit (c) and chiffchaff (d), in control and pruned areas, in the spring and winter immediately after pruning intervention. Significant results of t-test are marked with *.

3.5. Discussion

Which species are potentially affected by pruning?

Silvicultural activities affect bird communities through their effect on vegetation structure (King & DeGraaf 2000). Pruning may have consequences to birds, especially to species that explore the areas of the trees that suffer the intervention. The vertical distribution of birds on the trees and forests has been the focus of many studies (e.g. Macarthur 1958; Dickson & Noble 1978) which give important information about the potential vulnerability of different species to management interventions (Fernández-Juricic *et al.* 2004; Doyon *et al.* 2005). The results of our focal observations revealed a marked separation of species in terms of foraging area in the tree and consequently on their likelihood of being affected by pruning.

Blue tit, great tit and chiffchaff were the species most frequently observed foraging on the tree canopy. These results are in agreement with previous evidence that indicates that blue tit and chiffchaff forage predominantly on cork oak outer branches (diameter < 5cm), leaves, twigs and flowers (Almeida & Granadeiro 2000). Since pruning mostly affects canopy structure through a reduction in foliage branches, these are the species most likely to be affected by this intervention.

Treecreeper and nuthatch mostly fed on the trunk or principal branches. This was to be expected because both are typical bark gleaners and their dependence on trunks and principal branches for foraging has previously been demonstrated in cork and holm oak (*Quercus ilex*) trees (e.g. Tellería & Santos 1995; Almeida & Granadeiro 2000; Leal *et al.* 2011a), and other tree species (e.g. Nour *et al.* 1997; Adamík & Kornan 2004).

Does foliage gleaners density decrease in pruned areas?

Data on the distribution of foraging birds on the tree suggests that the species which are likely to be affected by pruning are those that forage mainly in the canopy. Our results confirmed a reduction in bird density in pruned areas, demonstrating that it affects foliage-gleaning birds. The reduction in these species was substantial, but pruning did not have a significant effect on the overall density of birds in the spring and winter that followed the intervention. In addition, no species were entirely lost from fields due to pruning. Bird species that do not depend on foliage branches for foraging were not affected by pruning, and these included ground searchers such as chaffinch, woodlark (*Lullula arborea*) and corn bunting (*Miliaria calandra*). We also did not find any effect on bark gleaners, treecreeper and nuthatch.

Our conclusion that low/medium intensity pruning of cork oaks affects the densities of some foliage gleaners may also be valid for other species that were absent or rare at our study site, but are known to depend on the canopy foliage. This is for example the case of crested tit (*Parus cristatus*), long-tailed tit (*Aegithalus caudatus*) and firecrest (*Regulus ignicapillus*)*,* all known to use branches for foraging (Tellería & Santos 1995).

Pruning, generally lead to a reduction in tree foliage (James 2004), since foliage branches correspond to the largest proportion of the biomass removed by pruning. However, this seems to be a short term effect since in the long run pruning may strengthen the cork oaks and stimulates the production of new foliage and more fruit (Natividade 1950; González & Cayon 1990). González-Varo *et al*. (2008) found a positive effect of pruning on nuthatch abundances on chestnut (*Castanea sativa*) woods, presumably due to an increase in chestnut crop and, as pruning produces chestnut trees with thicker trunks and more branches, higher abundance of arthropods in the bark, and holes suitable for nuthatch nests (González-Varo *et al.* 2008).

Pruning has long been a controversial practice (Cañellas *et al.* 2007), even from a silvicultural perspective. Light or moderate pruning, i.e. that affects less than 30% of the canopy biomass (González & Cayon 1990; Cañellas *et al.* 2007), appears to be good for the health of the tree, ridding it of overshadowed or weak branches with a negative energy balance, and for increasing the acorn yield (Cañellas & Montero 2002). It has been suggested that this increase in acorns may have a positive effect of some bird species, especially those that have wintering populations that feed on acorns, such as cranes (*Grus grus*) and wood pigeons (*Columba palumbus*) (e.g. Díaz *et al.* 1996; Plieninger & Wilbrand 2001) and the Eurasian jay (*Garrulus glandarius*) that is a widely recognized as an acorn feeder and disperser (e.g. Pons & Pausas 2007a; Pons & Pausas 2007b). This possibility should be taken into consideration when managing areas that are important for such species. However, as the economic costs of light or moderate pruning can be very high, it has been an attempt to compensate costs by obtaining incomes from charcoal, virgin cork and firewood (Cañellas *et al.* 2007) through an increase in the intensity of pruning. Yet, this increase can cause serious damage to the tree (Natividade 1950; Pinto-Correia & Mascarenhas 1999).

Relevance for conservation

In the Mediterranean region, the structure and functioning of most native ecosystems, including cork oak woodlands, have been dramatically altered by human activities (Plieninger 2007). The conservation of the wildlife linked to such altered habitats depends on the quality of the management, which is usually mostly driven by economic and production objectives (e.g. Díaz *et al.* 1997). The overarching objective of conservation in many of these habitats is to keep them productive, while maintaining or improving their value for biodiversity.

Our results suggest that pruning is compatible with the maintenance of a diverse and abundant bird community since it does not seem to have a significant impact on the overall bird assemblages in pruned areas. However, pruning does cause a substantial reduction in the density of foliage-gleaning bird species that feed mainly in the tree canopy, and therefore we recommend the avoidance of high intensity pruning to minimize these potential harmful effects. This is also beneficial for the health of the tree since severe pruning can cause damage to the trees (e.g. Pinto-Correia & Mascarenhas 1999; Cañellas *et al.* 2007) and, in fact, the international code of cork oak silviculture practices (Proyecto Subernova - Interreg III A 2005) advises against maintenance pruning.

Another negative consequence of pruning in cork oak woodlands for birds may be the destruction of nests of early breeders, such as some resident species. Therefore we propose that, where possible, pruning should be done before the onset of the breeding season of all species. In the case of southern Iberia all pruning should be completed before the end of February.

While we have been able to evaluate the short term impacts of pruning on the birds breeding and wintering in cork oak habitat, further research is needed to quantify this impact at longer timescales. This presumably depends mostly on the time that it takes for canopies to recover from pruning, and on the lengths of the periods between pruning interventions.

Canopy pruning is a common procedure not only in the management of cork oak woodlands but also of other wooded Mediterranean habitats, such as holm oak woodlands (Alejano *et al.* 2008; Gea-Izquierdo *et al.* 2009) and olive groves (Duarte *et al.* 2008), which cover large extensions, and they are known to be important for a great variety of resident and wintering bird species (Díaz *et al.* 1997; Tellería 2001). It is quite likely that in these habitats canopy gleaners are also negatively affected by canopy reductions due to pruning. This possibility deserves to be investigated, as the cumulative effects on several important habitats may be a relevant limiting factor for canopy gleaner bird species across large geographic regions.

CHAPTER 4

Influence of habitat fragments on bird assemblages in cork oak woodlands

Ana I. Leal, Ricardo C. Martins, Jorge M. Palmeirim & José P. Granadeiro. 2011.
Bird Study, 58(3): 309-320

4. Influence of habitat fragments on bird assemblages in cork oak woodlands

4.1. Abstract

Capsule Fragments of olive groves and riparian galleries have a positive influence on bird assemblages in cork oak woodlands.

Aim Assess the impact of fragments of olive groves and riparian vegetation on the birds of the matrix of cork oak woodlands.

Methods We carried out bird point counts at increasing distances (0, 50, 150, 250 and 350 m) from 15 olive groves and 13 sectors of riparian vegetation embedded in a matrix of cork oak woodland.

Results A total of 72 bird species were recorded during the spring, and 61 in winter. The diversity of the bird assemblages of the cork oak matrix was somewhat greater near fragments. The density of six out of the 17 most abundant bird species varied due to the presence of olive groves or riparian vegetation. Of those, five were more abundant near the fragments and only one was less abundant. The type of response could be mostly predicted from the species density in the fragments and depended on the season.

Conclusions Our results demonstrate that in Mediterranean landscapes dominated by cork oak woodlands, the maintenance of the existing networks of olive grove fragments and riparian galleries has a positive effect on the bird assemblages of woodland matrix. The increase in abundance of birds near olive groves and riparian galleries was probably due to the additional fruit resources provided by the fragments, especially in winter. Consequently, we conclude that the active maintenance of the existing fragments should be included in the management of this valuable agro-silvo-pastoral system.

4.2. Introduction

Much of the western end of the Mediterranean region is covered by an extensive agro-silvo-pastoral system dominated by either holm oak (*Quercus ilex*), or cork oak (*Quercus suber*), or a combination of the two species, known as *montados* in Portugal and *dehesas* in Spain (Díaz *et al.* 1997). This system is the result of the transformation of the original forest by man (Moreno & Pulido 2009), and is now protected under European Legislation (92/43/CEE) because of its high biodiversity value (Díaz *et al.* 2003; Díaz 2008). *Montado* is a semi-natural habitat where the traditional economic activities have proved to be mostly compatible with the maintenance of a rich wildlife (Plieninger & Wilbrand 2001), although in some cases this is not completely clear (Díaz 2008; Moreno & Pulido 2009). The diverse community of breeding and wintering birds of the *montado,* and the endangered bird species that to a great extent depend on this habitat (e.g. Díaz *et al.* 1997; Almeida & Granadeiro 2000; Tellería 2001) demonstrate its importance to the preservation of biological diversity.

To conciliate economic productivity with a high biodiversity value, the *montados* have to be correctly managed, and this requires information on how the different management options impact biodiversity. There are some studies focused on the effects of diverse management practices on bird communities of *montados* dominated by holm oak (e.g. Tellería 1992; Santos *et al.* 2002), but much less information is available for those dominated by cork oak (e.g. Cherkaoui *et al.* 2009; Díaz 2009).

Extensive cork oak *montados* in south-western Iberia often include scattered patches of productive or abandoned orchards, riparian vegetation and scrubland (Rosalino *et al.* 2009). Little is known about how these structures influence the biodiversity of cork oak woodlands, but they are often the object of aggressive management interventions, such as the extensive removal of riparian vegetation (Aguiar *et al.* 2000). The small fragments of traditional olive

(*Olea europaea*) groves are progressively being abandoned leading, for example, to the invasion of understory vegetation species (Duarte *et al.* 2008).

In landscapes composed of a matrix with imbedded fragments of distinct habitats, there are relevant ecological interactions between the fragments and the matrix. The effects of the matrix on islands of imbedded habitat have been extensively studied (Sisk *et al.* 1997; Gascon *et al.* 1999; Antongiovanni & Metzger 2005), but the reverse analyses, i.e. the influence of fragments on the species assemblages of the matrix, are still scarce (Tubelis *et al.* 2004). In this study we examined how fragments of olive groves and riparian galleries influence the structure of bird assemblages in adjacent cork oak woodlands. We focused on passerines because they are good bioindicators and one of the most abundant and diverse vertebrate groups in cork oak woodlands, so they are very convenient to study the influence of management practices on biodiversity. However, other bird groups, such as birds of prey, may relate differently to the studied habitat fragments (e.g. Carrete & Donazar 2005).

The potential outcomes of the presence of habitat islands on the bird species assemblages of the cork oak matrix are diverse. (i) Habitat islands may allow an increase in the diversity or abundance of species (e.g. Lay 1938; Reino *et al.* 2009) but they can also have negative effects, such as: (ii) nest predation along their edges can be higher (e.g. Gates & Gysel 1978; Andrén & Angelstam 1988; Morris & Gilroy 2008) contributing to the decline of birds in the adjacent matrix; (iii) edge effects can make the habitat less suitable for matrix species, thus decreasing the amount of habitat available to them (e.g. Brand & George 2001; O'Dea & Whittaker 2007); and (iv) anthropogenic habitat islands may facilitate the penetration of generalist species into the matrix (e.g. Heske *et al.* 1999).

The objective of this study was to assess the impact of the presence of fragments of olive groves and riparian vegetation on the birds of the matrix of cork oak woodland. To do this we (i) compared bird assemblages of fragments of olive groves and riparian galleries with that of the surrounding cork oak matrix, (ii) determined up to what distance the bird community of the matrix is influenced by that of the fragments, and (iii) studied how different species respond to the presence of the two types of fragments. We use the conclusions of the study to formulate recommendations for the management of riparian vegetation and patches of olive groves in cork oak woodland landscapes.

4.3. Methods

Study area

This study was carried out in Grândola mountain (38° 07’N - 8° 36’ W), Southern Portugal (Figure 4.1). The area is characterized by a Mediterranean climate (Santos-Reis & Correia 1999) and is within one of the largest and best preserved areas of mostly continuous cork oak woodland in Portugal. Human density is low, and nowadays the area is mainly used for cork and wood extraction, cattle raising and hunting (Rosalino *et al.* 2005), as observed in other areas dominated by cork oak (Aronson *et al.* 2009).

Traditional olive groves are present in the area in small patches (mean patch size: 1.06 ha ± 1.2), and while most of them are subject to a low intensity management regime, some have been abandoned by farmers (Santos-Reis & Correia 1999). Low intensity grazing, mainly by sheep, favors the maintenance of rich therophitic grassland communities with species from *Helianthemetea guttati* communities, like *Aira caryophyllea*, *Ornithopus compressus*, *Hypochaeris glabra*, *Rumex bucephalophorus* and *Xolantha guttata*. All the olive groves where we worked were under minimal management and had similar density of trees and groundcover. The area is also crossed by four watercourses that often keep just small pools of water during the summer, bordered by riparian vegetation of *Populion albae* and *Osmundo-Alnion* communities over much of their length (mean width of riparian corridors of 15 m). We worked in patches of well developed riparian vegetation but the integrity of these riparian corridors varies significantly across the area, from wooded forest with *Alnus glutinosa* and *Fraxinus angustifolia* to riparian shrublands dominated by *Rubus ulmifolius*.

Assessing bird populations at different distances from fragments

We used aerial photographs followed by ground visits to select 15 olive groves and 13 sectors of riparian vegetation, all within a matrix of cork oak woodland with a relatively homogeneous density of trees and groundcover. One counting point was located in the centre of each of these habitat fragments. We then marked four counting points at increasing distances from the edge of the fragment (at 50, 150, 250 and 350 m). Where the homogeneity of the matrix habitat surrounding a fragment permitted, we set two transects of counting points running in opposite directions. This resulted in a total of 26 transects of five points each for olives groves, and 14 for riparian galleries.

Bird censuses were carried out in spring (from April to June 2006) and in winter (December 2006 and January 2007) using 10 min point counts (Bibby *et al.* 1992; Sutherland *et al.* 2004). Counts were carried out within the four hours after sunrise by two experienced observers. All point counts were sampled at least twice in each season, switching the observers to avoid any observer effect. In the spring the points in riparian galleries were counted three times, also switching the observers. The results of all counts in the same season were combined using their average. We recorded all bird contacts within a 100 m radius, and estimated their distance to the observer in 10 m distance bands. In the counts that included the boundaries between habitats we made sure that each detected bird was assigned to the correct habitat. This was quite easy because both olive groves and cork oak woodlands are relatively open habitats, and the riparian galleries were narrow. Over-flying individuals were later excluded from the analysis. No surveys were conducted under rainy or windy conditions.

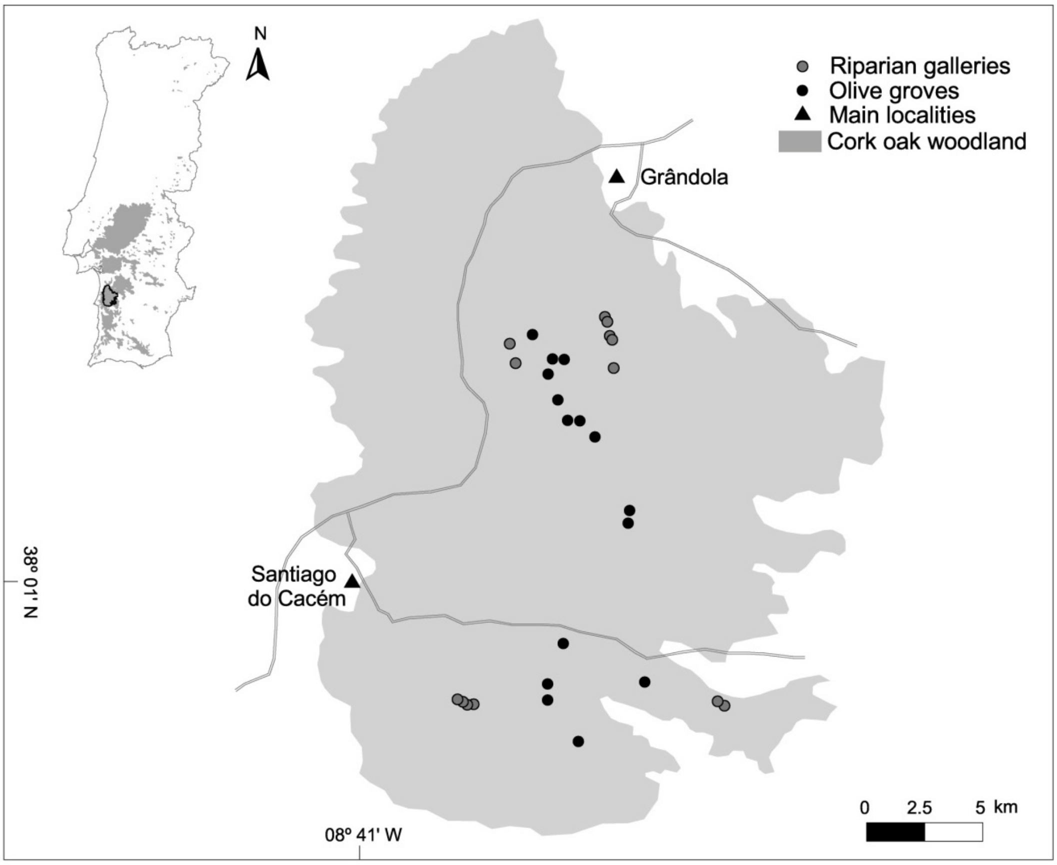


Figure 4.1. Study area and sampling stations in Grândola mountain, Alentejo, Portugal. Shaded area corresponds to cork oak (*Quercus suber*) woodland.

Data analysis

Bird densities were estimated using DISTANCE software (Thomas *et al.* 2006) and only included birds detected within 50 m from the observer to avoid overlap between consecutive sampling points. We used a global detection function for all the density estimates of the same species and fitted uniform, hazard-rate and half-normal functions, all with cosine adjustments, and chose the model with the lowest value of Akaike´s Information Criterion (Buckland *et al.* 1993; Burnham & Anderson 2002). Points located in olive grove and riparian gallery patches (0 m points), only included birds detected within the patches (birds in the adjacent cork oak matrix were excluded from calculations). In these cases, the densities were calculated using the proportion of the area of the sampled point that was occupied by the habitat patch (areas of the fragments were calculated with a Geographical Information System). Cork oak woodland bird communities were characterised using data from the 350 m point count, to minimize any potential influence of the fragments on the estimates.

Differences between the structure of assemblages of cork oak woodlands, olive groves and riparian galleries were assessed with an analysis of similarity (ANOSIM), a non-parametric permutation test of significance between groups. Variation in diversity with distance was examined by calculating Shannon-Wiener H diversity indices for all the survey points. Bootstrap 95% confidence intervals were computed with 1 000 random samples.

The influence of fragments on bird abundance was examined using the results of the densities of species along the distance gradient (50 to 350 m). Variation in the number of individuals in relation to the distance to fragments was tested with Spearman Correlation Tests (r) and these statistical computations were carried out using the R statistical software (R Development Core Team 2007).

4.4. Results

Bird assemblages of fragments and matrix

A total of 72 bird species were recorded during the spring, and 61 in winter. Table 4.1 presents the densities of the most common species. The densities of birds in cork oak woodlands presented in Table 4.1 were calculated using only data from the 350 m point count, to minimize any potential influence of the fragments on the estimates.

There were significant differences in the structure of cork oak assemblages and those of olive groves and riparian galleries in both seasons (Table 4.2). However, 89% percent of the species present in cork oak woodlands were also present in olive groves in spring, and 86% in winter. Riparian galleries shared 73% of the species with the cork oak matrix in spring, and 50% in winter. Few species were present in the fragments but not in the matrix. In spite of this similarity in the species composition of the assemblages, there were some marked differences at the level of the density of some of them.

In olive groves (0 m) there were about 50% more birds per point in winter (U= 245.5, p= 0.007), whereas in riparian galleries (0 m) birds were significantly more abundant in spring (t_{62}= 2.9, p= 0.005) (Figure 4.2).

Table 4.1. Density (individuals/ha) of birds in the cork oak woodlands (350 m), riparian galleries and olive groves (0 m), in spring and winter. Species are ordered by abundance in cork oak woodlands in spring, and separated by residents, summer and winter visitors.

	Spring			**Winter**		
	Cork oak woodlands	Olive groves	Riparian galleries	Cork oak woodlands	Olive groves	Riparian galleries
Parus major	0.77	0.30	0.08	0.71	0.49	0.39
Parus caeruleus	0.65	0.38	0.07	0.95	1.18	0.41
Fringilla coelebs	0.46	0.04	0.04	0.54	0.82	0.19
Certhia brachydactyla	0.34	0.03	0.06	0.36	0.02	0.04
Sitta europaea	0.31	0.01	0	0.62	0.04	0.04
Petronia petronia	0.24	0.06	0	---	---	---
Parus cristatus	0.24	0.07	0.02	0.27	0.04	0
Lullula arborea	0.22	0.02	0	0.19	0.03	0
Milaria calandra	0.20	0.26	0.02	---	---	---
Carduelis carduelis	0.14	0.63	0.21	0.08	0.14	0
Saxicola torquata	0.13	0.29	0.03	0.23	0.24	0.05
Sturnus unicolor	0.10	0.01	0	---	---	---
Turdus merula	0.08	0.12	0.18	0.02	0.13	0.05
Dendrocopos major	0.05	0	0.01	0.08	0.01	0
Passer domesticus	0.05	0.52	0	---	---	---
Sylvia atricapilla	0.05	0.06	0.75	---	---	---
Serinus serinus	0.04	0.09	0.03	0.08	0.28	0.02
Carduelis chloris	0.02	0.05	0.09	---	---	---
Troglodytes troglodytes	0.01	0.02	0.64	0.01	0.04	0.33
Erithacus rubecula	0	0.06	0.32	0.66	1.44	1.90
Sylvia melanocephala	0	0.22	0.29	---	---	---
Luscinia megarhynchos	0.68	1.20	10.74	---	---	---
Lanius senator	0.23	0.29	0	---	---	---
Phoenicurus phoenicurus	0.18	0	0.03	---	---	---
Hippolais polyglotta	0.08	0.03	0.62	---	---	---
Phylloscopus ibericus	0	0.04	0.67	---	---	---
Phylloscopus collybita	---	---	---	0.83	0.19	0.29
Anthus pratensis	---	---	---	0.15	0.26	0
Sturnus sp.	---	---	---	0.06	0.03	0

Table 4.2. Average dissimilarity values based on the Bray-Curtis similarity index on bird species between habitats in winter and spring (***p< 0.001).

	Spring	**Winter**
Cork oak and olive groves	0.59***	0.57***
Cork oak and riparian galleries	0.85***	0.61***
Olive groves and riparian galleries	0.73***	0.17***

Diversity in cork oak woodlands close to fragments (50 m) was significantly different than in points furthest away (350 m). Olive groves had a positive effect on cork oak diversity in both seasons (spring: t= 2.2, p= 0.026 and winter: t= 3.7, p< 0.001), whereas the positive effect of riparian galleries was only noticeable in spring (spring: t= 2.2, p= 0.028 and winter: t= -3.5, p< 0.001) (Figure 4.3).

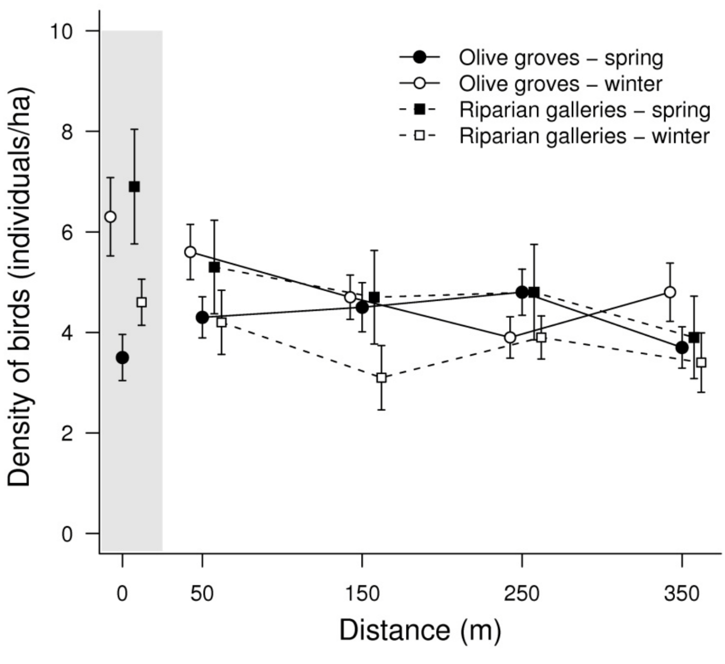


Figure 4.2. Density of birds (individuals/ha ± SE). The point 0 m (shaded bar) refers to counts carried out inside the fragments (olive groves and riparian galleries), and the remaining values to counts in the cork oak matrix, at increasing distances (50 to 350 m) from the edge of the fragments, in spring and winter.

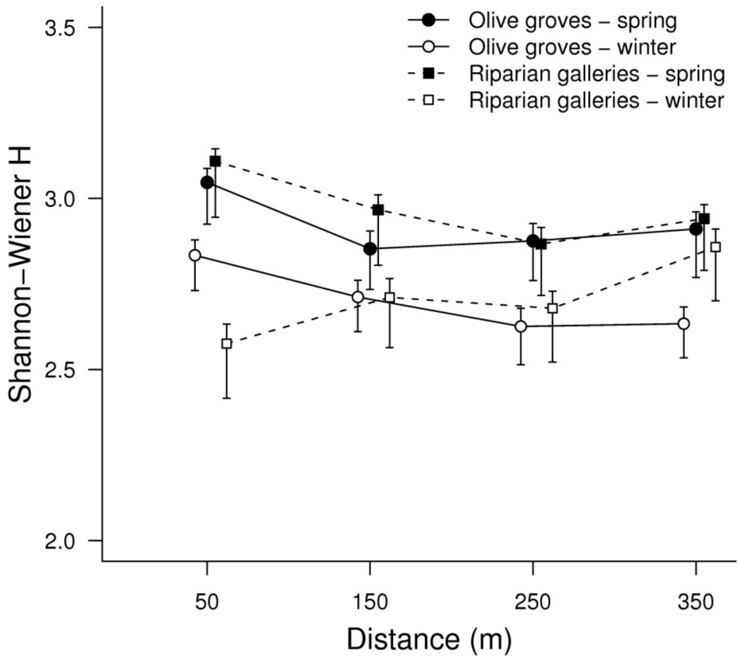


Figure 4.3. Shannon-Wiener H diversity indices (+/- 95% confidence intervals) for bird counts at increasing distances from the edge of olive groves and riparian galleries (50 to 350 m), in spring and winter.

Influence of fragments on birds in adjacent cork oak woodlands

The overall density of birds in the matrix was not significantly positively affected by the presence of fragments, except for the increase observed near riparian galleries in spring ($U = 358.5$, $p < 0.001$) (Figure 4.2).

The response of individual species to the presence of fragments varied among habitats and seasons. In spring, the density of corn buntings (*Miliaria calandra*) in cork oak woodlands decreased with distance from olive groves, although it was only nearly significant. A significant negative correlation was also observed in winter for chaffinch (*Fringilla coelebs*), robin (*Erithacus rubecula*) and blue tit (*Parus caeruleus*) (Figure 4.4). The species that did not show a significant relationship with distance to olive groves included nuthatch (*Sitta europaea*), treecreeper (*Certhia brachydactyla*), great tit (*Parus major*), woodlark (*Lullula arborea*), and chiffchaff (*Phylloscopus collybita*).

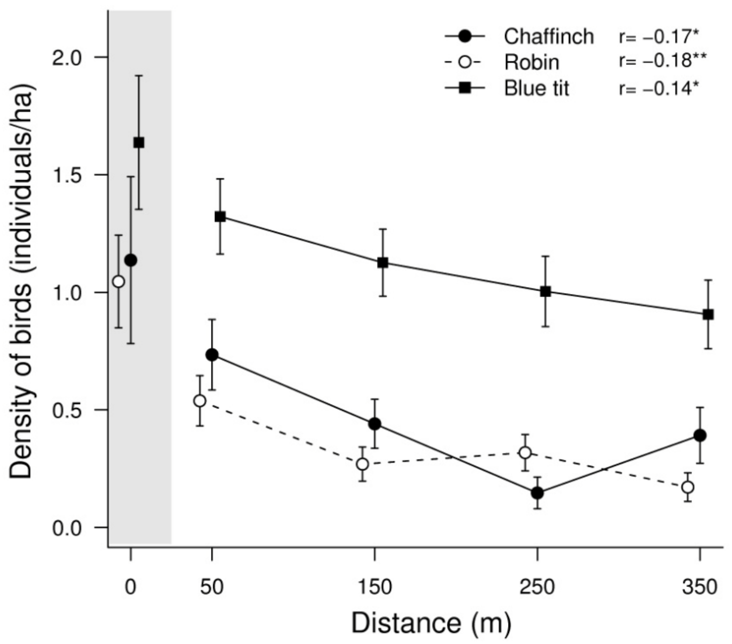


Figure 4.4. Density of three bird species (individuals/ha ± SE) in olive groves (shaded bar) and in cork oak woodlands, at four distances from the edge of the fragments, in winter. Trends between 50 and 350 m were tested with Spearman Correlation test (r) (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

Three species showed a significant relationship with distance from riparian galleries (Figure 4.5). In spring, the abundance of goldfinch (*Carduelis carduelis*) increased in cork oak areas close to riparian galleries, and the same happened with great tit in winter. The woodlark was the only species negatively influenced by the proximity of riparian galleries but only in winter. Blue tit, chaffinch, nuthatch, treecreeper and chiffchaff did not show a relationship with distance to riparian habitats.

Three resident species changed their response pattern in winter and were more abundant near fragments only during this season: chaffinch and blue tit were influenced by the presence of olive groves (Figure 4.4) and great tit by riparian galleries (Figure 4.5).

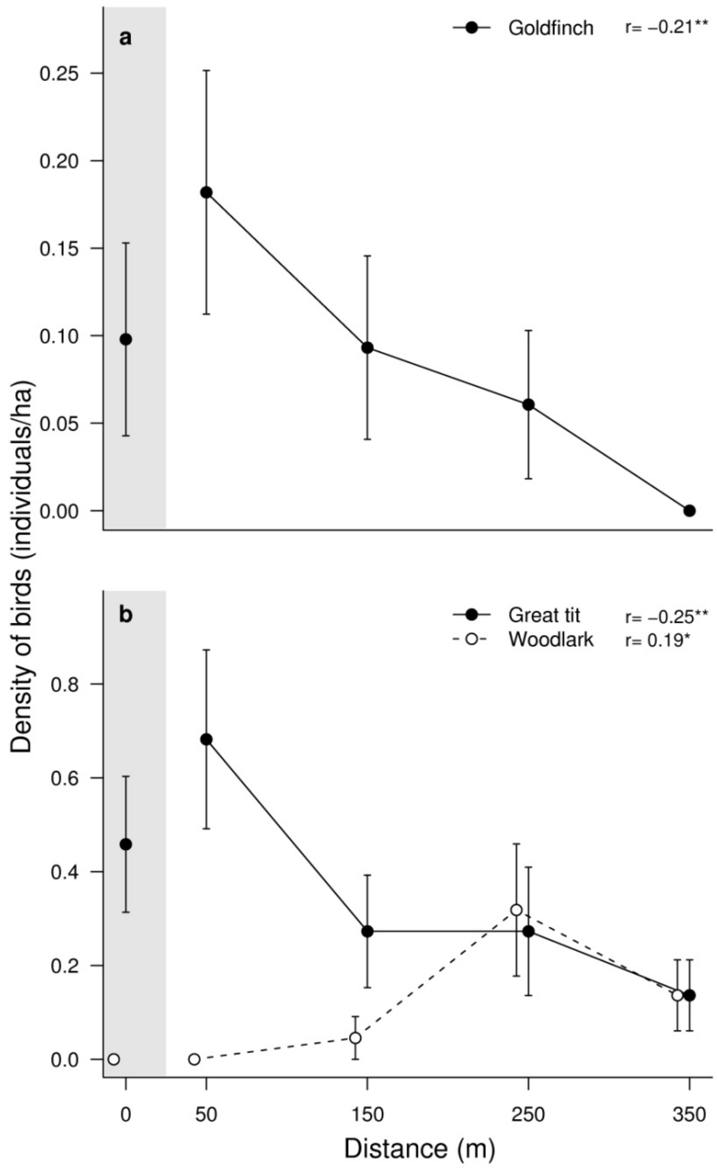


Figure 4.5. Density of three bird species (individuals/ha ± SE) in riparian galleries (shaded bar) and in cork oak woodlands, at four distances from the edge of the fragments, in spring (a) and winter (b). Trends between 50 and 350 m were tested with Spearman Correlation test (r) (*p< 0.05, **p< 0.01, ***p< 0.001).

4.5. Discussion

Bird assemblages in fragments are not very distinct from those of cork oak matrix

There were substantial differences in the relative abundance of some bird species in the matrix and fragment habitats, but the species compositions were quite similar. The assemblages that differed the least were those in olive groves and the cork oak matrix, which is probably explained by the structural resemblance of the two habitats and the small size of the patches. Indeed, they may be too small to allow a generalized presence of species that are usually common in Iberian olives groves, such as song thrush (*Turdus philomelos*) and redwing (*Turdus iliacus*) in winter (Rey 1993, 1995). Both factors may also facilitate the "penetration" in the patches of species that typically occur in cork oak woodlands, such as chaffinch and blue tit. This seems to happen mostly in winter, and explains the higher numbers of individuals in olive groves in that season. Both habitats are also important for some species of conservation concern as the woodchat strike (*Lanius senator*), whose populations have suffered a decline in Europe and is considered as "Near threatened" in Iberia (Almeida *et al.* 2005; Vořišek *et al.* 2010).

The bird assemblages of the riparian galleries showed slightly larger discrepancies, but still a great number of species was shared. Riparian galleries are recognised as rich habitats (e.g. Naiman & Décamps 1997; Palmer & Bennett 2006). In our study the highest number of species was detected in spring, due to the presence of a number of species that in southern Iberia tend to be associated with riparian vegetation, such as nightingale (*Luscinia megarhynchos*), Iberian chiffchaff (*Phylloscopus ibericus*) and melodious warbler (*Hippolais polyglotta*) (Martí & Del Moral 2004; Equipa Atlas 2008). In winter, there was an overall reduction in the number of individuals, mostly because several of the species that breed in this habitat are summer visitors.

Bird species differ in the response to the proximity of fragments

The response of species to the presence of habitat edges can be classified in three categories (Ries *et al.* 2004): (i) positive responses, when the abundance of the species increases near the edge; (ii) negative responses, when the abundance declines near the edge; and (iii) neutral responses, when the abundance shows no pattern in relation to the edge. In our study we found all three types of responses and, in general, it could be predicted from the abundance of the species in the fragments of olive groves or riparian vegetation and depended on the season. Species that were less abundant in the matrix than in the fragments tended to have a positive response to the edge, i.e. their abundance increased near the fragment. This was, for example, the case of corn bunting, chaffinch, robin and blue tit near olive groves, and of goldfinch and great tit near riparian vegetation.

The second type of response to edges, negative responses, was the least common, as we only observed it in the woodlark. Even then this pattern was only evident in the edges involving riparian galleries, and not in those of olive groves. It is worth pointing out that this negative response was observed when the species was common in the matrix but absent from the fragment.

The third type, the neutral response, was the most common and it is important to underline that most of the species that presented this pattern were less abundant or even absent from the fragment. Examples of species that showed this pattern in both seasons are the nuthatch and treecreeper near olive groves, and chaffinch and blue tit near riparian galleries.

Positive and negative consequences of the presence of the fragments on the birds of cork oak woodlands

As referred in the introduction, the impacts of the presence of habitat fragments in the bird assemblages of the matrix of cork oak woodland can be very diverse, and include both positive and negative components.

In most situations, the presence of olive groves and riparian galleries was associated with an increase in the diversity of bird species in the adjacent matrix areas. In addition, there was also an increase in the density of several species near the edges, both in spring and winter. This increase in density was noted mainly for species that are common in the cork oak matrix, rather than for those more characteristic of olive groves or riparian galleries. The relatively short penetration of the edge effects on the matrix that we observed is probably a consequence of the lack of a transition zone along the edges, because they are maintained by human management. If the edges between the fragments and matrix were natural, the vegetation would change more gradually, and this should broaden the area in which edge effects are expressed. In fact, the penetration distances that we observed are quite similar to those reported for other artificially maintained habitat edges (e.g. Tubelis *et al.* 2004; Reino *et al.* 2009). However, the positive impacts of the presence of the fragments of other habitat are probably not limited to the gains that we measured in their immediate vicinity. Actually, the high numbers of passerine birds found feeding in the olive groves (unpublished data) during the winter suggests that this habitat provides supplementary food resources for birds from larger areas, as in the winter many species are more mobile and may track the availability of resources. For chaffinch, blue tit and robin, and possibly for other less common species, this habitat seems to provide important supplementary feeding resources. Indeed, these species were commonly observed in olive groves foraging on the ground, eating fallen olives (unpublished data) which are known to be an important resource for birds wintering in Mediterranean regions (e.g. Jordano 1987; Rey *et al.* 1997). Other partly frugivorous species, like great tit (e.g. Herrera 1984b, a; Hampe 2001), were statistically more abundant in cork oak areas close to riparian habitats in winter. In fact, these birds were frequently observed in the riparian galleries feeding in bushes, especially in blackberries, which are particularly abundant in some riparian galleries but scarce in the cork oak matrix (unpublished data).

Edge effects can also potentially make the habitat adjacent to fragments less suitable for matrix species, thus decreasing the amount of good habitat available for them and leading to a decline of matrix birds near the edges. However, this should result in a decline in the abundance of matrix birds near the edges, which was not observed, except in the case of the woodlark. One possible explanation for this response is an avoidance of edges of riparian galleries to minimize the risk of predation, particularly at the nest. Indeed, nest predation tends to be higher along edges, especially for ground nesters like woodlark (e.g. Flaspohler *et al.* 2001). This species is quite common in some cork oak woodlands, as they often offer suitable areas of bare ground or short grass (Bowden 1990; Sitters *et al.* 1996).

Conclusions and relevance for management

Cork oak landscapes present a wide array of forest or woodland, shrubland, and open habitat components, as a direct consequence of human management (Berrahmouni *et al.* 2009) and the high species richness of *montados* is traditionally associated with that high heterogeneity and the diversity of land use and habitats (e.g. Díaz *et al.* 1997; Díaz *et al.* 2003). This study examined the potential impacts of the presence of riparian galleries and fragments of old olive groves on the passerine assemblages of the matrix of cork oak woodlands. The results show that the presence of both olive groves and riparian galleries had an overall positive effect on the bird assemblages of the cork oak matrix; they increased both the species diversity and the density of some species in their vicinity.

For many bird species, the benefits of the presence of the habitat islands may be related to an increase in the availability of fruit, such as berries and olives, particularly during the winter, when a great number of birds were observed feeding in those fragments (unpublished data) and food resources can be a limiting factor (Herrera 1981; McCarty *et al.* 2002). This is to be expected, because managed cork oak woodlands usually have the groundcover shrubs periodically removed. As a result, fruiting plants common in Mediterranean woodlands, such as lentisc (*Pistacea lentiscus*) and strawberry tree (*Arbutus unedo*) (Blanco *et al.* 1997), are sparse and the availability of fruits is usually low (Tellería 2001). Fruit available in riparian galleries and especially in olive groves may partly compensate this limiting factor.

As these agro-silvo-pastoral systems are actively managed, it would be desirable to plan management actions that minimize this constraint. One alternative is to allow the recovery of the fruit producing shrub layer in patches within the cork oak woodland matrix. But equally important is to maintain the existing network of old olive grove fragments and lines of riparian vegetation, which nowadays play a very relevant ecological role. In this direction, it would be very desirable to reverse the decline of these small fragments of traditional olive groves, characterized by being a low intensity farming system, which is a consequence of their abandonment by farmers (Duarte *et al.* 2008). Likewise, it would be important to stop the practices of aggressive management of riparian galleries, such as the elimination of understory vegetation (Aguiar *et al.* 2000; Corbacho *et al.* 2003), which degrade them and prevents their development into mature riparian woodlands. Instead, the establishment and recovery of riparian vegetation should be actively promoted, so that it can fulfil its important ecological role for birds and other organisms in cork oak woodland (Matos *et al.* 2009) and in similar habitats of Mediterranean landscapes.

CHAPTER 5

Managing spatial heterogeneity in Mediterranean woodlands: The use of spatially-explicit future scenarios for bird conservation

Manuscript

5. Managing spatial heterogeneity in Mediterranean woodlands: The use of spatially-explicit future scenarios for bird conservation

5.1. Abstract

Cork oak *montados* are agro-silvo-pastoral systems that have been managed for centuries. However, the importance of the different components of the system has changed throughout time in order to maximize the economic income. The increasing investment in the production of cork, together with rural exodus, led to the abandonment of some small scale agricultural practices. These changes in the management of some components of *montados* landscapes contribute to the heterogeneity of the matrix and can have serious consequences to the system biodiversity, which are still unknown.

We evaluated the effects on bird communities of different management options that are applied to patches of traditional olive groves and riparian galleries within *montados* matrix. Spatially-explicit models were used to model bird species response to variation in habitat descriptors, and to identify the most suitable areas for the establishment of the two habitats to be manipulated. This allowed the construction of predictive future scenarios to help in the quantification of the consequences of the studied habitat management measures. Riparian gallery area was the descriptor that affected the greatest number of bird species. Seven species are expected to become far more abundant in the scenarios that predicted an increase in riparian vegetation, some of which are currently less abundant in the study area. Changes in olive grove area are expected to have a much weaker effect on the bird community.

In the light of our results we conclude that restoring the riparian vegetation along major streams and drainage lines would be highly beneficial for birds in *montados* landscapes

and affect a very small proportion of cork oak area. In what respects to olive groves, although their management seems to have lower conservation implications for birds in *montados*, some bird species are known to benefit from their presence, especially in winter. Maintaining the already existing olive grove patches seems to be the most adequate alternative for the conservation of bird populations in these landscapes. The proposed management options are compatible with the maintenance of the economic value of *montados* and would contribute to maintain the its spatial heterogeneity.

5.2. Introduction

Montados are multi-use systems typical of Mediterranean landscapes dominated by cork oak (*Quercus suber*) or holm oak (*Quercus ilex*) trees, which combine agricultural, silvicultural and pastoral production lands (Díaz *et al.* 1997; Pinto-Correia & Vos 2004). They are recognized as an excellent example of balance between socio-economic development and biodiversity conservation. For example, they are the habitat with the highest richness in breeding birds in the Iberian Peninsula (Tellería 2001), and also a key habitat for a large number of migratory bird species (Díaz *et al.* 1996; Díaz *et al.* 1997).

Cork oak *montados* have been managed for centuries and the importance of its different components have changed throughout time (e.g. Pinto-Correia & Fonseca 2009). In the last decades, management procedures have mostly targeted an increase in cork production (Costa & Pereira 2007b; Pérez-Ramos *et al.* 2008), which provides most of the economic income of the system (WWF 2006; Almeida & Tomé 2010). Rural exodus also affected many cork oak areas, which experienced the abandonment of the small scale agriculture (such as crop cultivations, that used to be practiced in the *montados* dominated landscapes), and caused relatively major changes in these habitats (Pinto-Correia & Mascarenhas 1999).

Traditional olive grove (*Olea europaea*) orchards were often part of the small farmed areas that dotted many *montados* landscapes. Several still exist, in spite of some years of abandonment, but they are clearly declining and suffering the consequences of this disinvestment which leads, for example, to the invasion by understory shrubs (Duarte *et al.* 2008). However, it has been demonstrated that these extant traditional groves can have a positive impact on some taxonomic groups, such as mammals (e.g. Rosalino *et al.* 2009).

Riparian galleries are also a common feature of *montados* landscapes, and are also known to have a positive influence in the biodiversity of this system (Rosalino *et al.* 2009; Leal *et al.* 2011b). However, although galleries are recognized as valuable highly diverse habitats in Mediterranean landscapes (Corbacho *et al.* 2003), they are frequently subject to aggressive management activities, including the excessive removal of riparian vegetation (Aguiar *et al.* 2000), and therefore the quality of their services can suffer wide oscillations.

There is nowadays an increasing concern with the maintenance of the ecological value of farmland (e.g. Donald *et al.* 2002; Benton *et al.* 2003; Fahrig *et al.* 2011) and the referred changes in the structure of *montados,* olive groves and riparian galleries, can have serious consequences to animal communities that depend on them. Consequently, the impacts of ongoing changes have to be identified, so that they can be countered with suitable management. Knowledge about ecological effects of management measures needs to be gathered, particularly of those that do not affect the economic value of the system.

We studied the consequences of habitat management options on bird populations. Besides being one of the most abundant animal groups in *montados*, birds play a key functional role in forest ecosystems and are often considered good biodiversity indicators (Sekercioglu 2006).

Although it is not possible to predict future land use it is possible to explore what might happen given certain assumptions about social developments and environmental change through the construction of scenarios (Rounsevell *et al.* 2005). One of the techniques that has been suggested to evaluate the implications of management options is the development of spatially-explicit future scenarios (Boatman *et al.* 2010), which are models that combine a population simulator with a landscape map that describes the spatial distribution of landscape features (Dunning *et al.* 1995). However, in spite of its potential for understanding and quantifying the consequences of management measures, particularly those that result in changes in the landscape, this technique has been underused particularly in the Mediterranean. For example, to our best knowledge this technique has been rarely used to study the consequences of large scale management of Mediterranean woodlands.

The main objective of our study was to investigate the effects of major habitat management measures on birds, with special focus on those actions that are compatible with the maintenance of the economic value of *montados.* For that we simulated manipulations in the extension of riparian vegetation and the number of traditional olive groves and quantified its effects on bird populations. Finally, in the light of the results, we formulated advice for the management of *montados* and discuss the adequability of spatial-explicit modelling to generate future scenarios to aid in the quantification of the consequences of the studied habitat management measures.

5.3. Methods

Development of future scenarios

This study was carried out in Serra de Grândola (38° 07'N - 8° 36' W), Southern Portugal (Figure 5.1). The area is dominated by cork oak woodlands and is characterized by a Mediterranean climate. Human density is low and generally concentrated in small villages or in scattered farms. The area is presently used mainly for cork and wood extraction and for low intensity livestock rearing (mainly sheep).

Serra de Grândola is covered with cork oak woodlands, with small scattered patches of olive groves (mean patch size: 1.06 ha) and riparian vegetation along water courses (mean width of riparian vegetation corridors: 15 m). Some traditional olive groves are still explored by landowners, but many have now been abandoned by farmers. The riparian vegetation varies from a well developed wooded gallery with black alder (*Alnus glutinosa*) and narrow-leafed ash (*Fraxinus angustifolia*), to simple lines of shrubs dominated by blackberries (*Rubus ulmifolius*). We used aerial photographs and ground checks to locate olive groves and the main sectors of riparian vegetation in the study area.

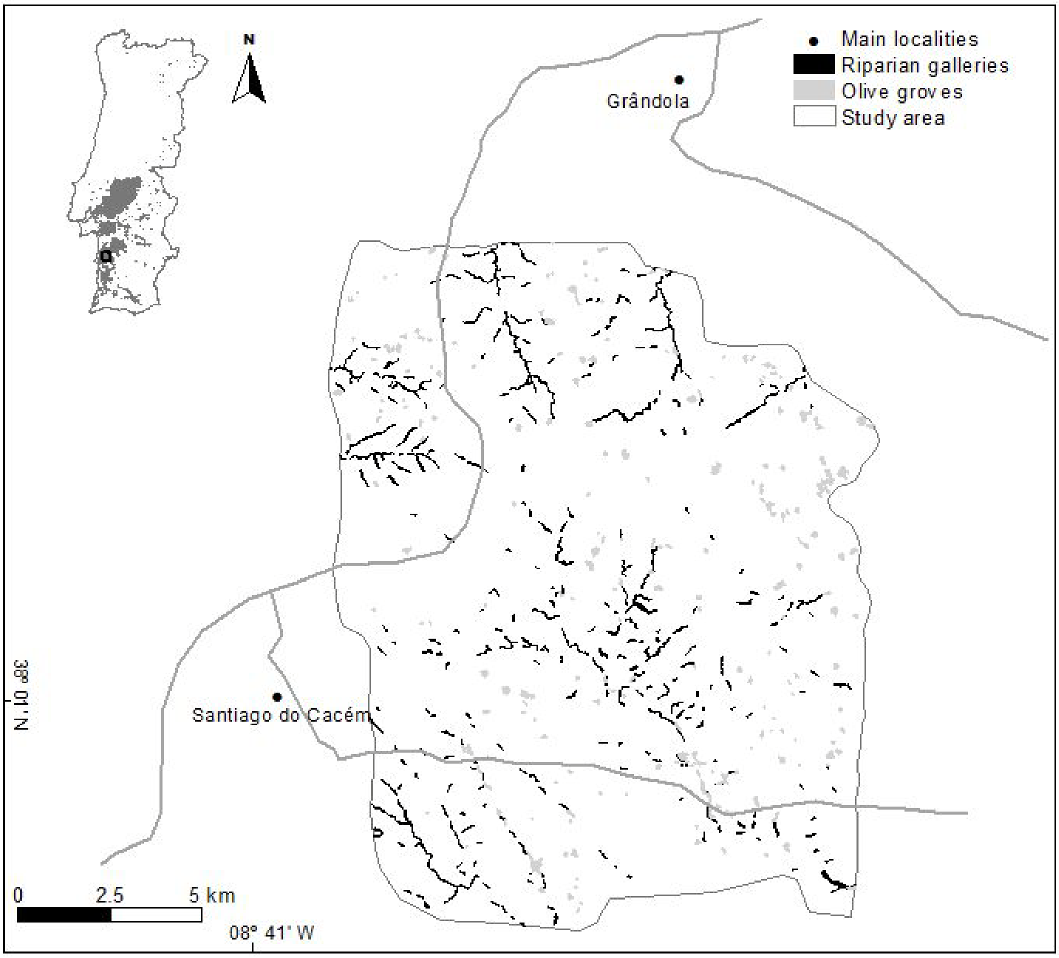


Figure 5.1. Cork oak (*Quercus suber*) woodlands study area in Serra de Grândola, Alentejo, Portugal (shaded area corresponds to cork oak woodlands in the map of Portugal). It is also represented the current distribution of olive groves and riparian galleries in the study area.

As a reference for the development of our future scenarios we used the current land cover, which is our baseline scenario. Future scenarios focused on the management of olive groves (O) and riparian gallery (G) were simulated:

(1) Baseline scenario, based on current land cover - The reference scenario assumes the maintenance of the current land cover, including the existing areas of olive groves and riparian galleries (scenario B).

(2) Scenarios involving elimination of olive groves and riparian galleries - These management scenarios assume that nothing will be done to stop the trend to maximize the production of cork by replacing the existing olive groves and riparian vegetation with cork oaks. Due to the near absence of economic value, the now unexploited olive groves may decay and be replaced by cork oak woodlands by natural regeneration, or be actively removed and replaced by cork oak trees by landowners (scenario O2). In the case of the gallery habitats the maintenance of the current aggressive interventions that eliminate the riparian vegetation, either to make room for more cork oaks or simply to clean the stream banks, would potentially result in the disappearance of this habitat (scenario G2).

(3) Scenarios involving the increase of olive groves and riparian galleries - In these scenarios managers proactively protect and promote traditional olive groves and riparian galleries. Managers may want to invest in the protection and even promotion of those habitats for conservation purposes. This would result in an increase in the number of small patches of olive groves in the region (scenario O3). In the case of riparian galleries this scenario would involve the end of massive vegetation cuts in riparian habitats, resulting in a natural recovery of the riparian vegetation, which could be accelerated by proactive management (scenario G3).

Assessing bird populations

We selected 40 squares of 1 km^2 in our study area, classified in four categories: a) 10 squares with almost pure cork oak woodland; b) 10 squares with extensive riparian vegetation in a cork oak matrix (mean length of riparian vegetation per square of 1.6 km); c) 10 squares with more than 2 ha of olive groves and d) 10 squares with less than 2 ha of olive groves. Riparian gallery and olive groves do not exist simultaneously in the studied squares. Breeding bird censuses were carried out in each square using a 1 km line transect (Bibby *et al.* 1992; Sutherland *et al.* 2004), in April and May 2007. The observer walked along the transect registering all the birds detected in 10 m bands, up to 100 m from the transect line. Over-flying individuals were excluded from the analysis. Each transect was visited twice in the season, and the results were averaged. No surveys were conducted under rainy or windy conditions.

Bird densities were estimated using DISTANCE software (Thomas *et al.* 2006). Since the structure of the habitat was quite similar in all sampled areas, we used the same detection function for all estimates of the same species. We did not estimate densities for species that did not reach a recommended minimum detections number to achieve an adequate accuracy (Buckland *et al.* 1993; Somershoe *et al.* 2006). We fitted uniform, hazard-rate and half-normal functions, all with cosine adjustments, and chose the model with the lowest value of Akaike's Information Criterion (Buckland *et al.* 1993; Burnham & Anderson 2002).

Statistical modeling

Bird data modelling

We investigated the potential role of several landscape variables as descriptors of the density of birds in the study area (Table 5.1). After a graphical exploratory analysis, we tested each variable individually using Normal Generalized Linear Models (GLM) for bird density data (Zuur *et al.* 2009). Variables with a p-level over 0.3 were excluded from further analyses

(Mickey & Greenland 1989), because there was no additional biological evidence that justified their inclusion. A Spearman correlation matrix was generated to check for collinearity between the remaining variables, but all correlation values were below 0.7 (Tabachnick & Fidell 1996).

The selected variables were then used to generate a set of candidate models for each species and indices. From each set we retained the model with the smallest Akaike's Information Criterion (AIC) corrected for small sample size (AICcmin) and all closely related models (ΔAICc< 4; Burnham & Anderson 2002). These candidates to best model were averaged in order to achieve a more stabilized inference (Burnham & Anderson 2002). Model selection and inference was done with the package Multi-model Inference (MuMIn) in the R environment (R Development Core Team 2007).

Table 5.1. Description of the variables considered as descriptors of density of birds in the study area.

Variable	**Description**
Altitude	Digital Elevation Model (DEM). Range: 81 to 282 m
Slope	Derived from DEM. Range: 0 to 31^{o}
Toposhape	Variables related to landscape features. Classes: Pits, Channels, Passes, Ridges, Peaks and Planar regions (Eastman 2006)
Soil type	Soil classification in terms of mineral content, texture, etc.
Soil capability	Measure of soil agricultural productivity. Range from A (high) to E (low productivity)
Area of cork oak	Total area (ha) of cork oak (resulting from the exclusion of other habitats as riparian galleries, olive groves, open and urban areas). Range: 90.9 to 100 ha
Area of riparian galleries	Total area (ha) occupied by riparian vegetation along water streams. Range: 0 to 9.1 ha
Area of olive groves	Total area (ha) occupied by fragments of olive groves. Range: 0 to 6.6 ha
Distance to urban areas	Distance to the nearest urban area (included the area of human influence around the villages). Range: 0 to 8.6 km

Simulating future scenarios

To evaluate how birds would react to manipulations of the availability of olive groves and riparian vegetation within the cork oak matrix, two sets of five landscape scenarios were generated, as mentioned above. They represent a gradient from total elimination of olive groves and riparian vegetation (*Elimination scenarios: O2* and *G2*, respectively*)*, to an increase of the area covered by these two habitats (*Increase scenarios: O3* and *G3*, respectively).

To generate these scenarios we first identified the areas most suitable for the expansion or contraction of the two habitats to be manipulated. For that we built models using expert knowledge and the current distribution of the two habitats in the study region as a reference. The first step was to identify the functions that better describe the relation between the presence of each of the two habitat and several landscape descriptors, using a graphic approach. These functions described how the presence for riparian vegetation or olive groves varies with slope, altitude, soil type and soil capability. The second step was to use the developed functions in fuzzy Multi-Criteria Evaluation (MCE) modeling in Idrisi (Eastman 2006). MCE works through a simple weighted linear combination of variable functions, where independent variable values indicate probability of occurrence of each habitat type analyzed to produce a map representing suitability of presence (Eastman 2006; Lippitt *et al.* 2008). Using the suitability probability classes of the generated maps, we identified the areas that would be better suited for a future expansion of each habitat type. Table 5.2 presents a summary of the projected scenarios and simulations.

To determine how birds would respond to the scenarios, the models generated for each species and indices, described in the previous section, were run using each scenario map as the new land cover descriptor. An ordination technique (Correspondence Analysis, CA) (Legendre & Legendre 1998), was used to identity groups of species that showed the same response profile (increasing, decreasing, stable), based on the predicted densities of species in each of the scenarios.

Table 5.2. Description of the studied scenarios, including the areas (ha) of relevant habitats, in the Baseline situation (scenario 1), scenarios of Elimination (scenario 2), and Increase (scenario 3) of olive groves, and riparian vegetation. Numbers in brackets indicate the percentage of each habitat area increase or decrease, in relation to the baseline.

	Olive groves (O)			Riparian galleries (G)		
Scenario	**Description**	**Area Olive**	**Area Cork Oak**	**Description**	**Area Riparian G**	**Area Cork Oak**
1	Baseline (B)	300	23340	Baseline (B)	274	23340
2	Total abandonment of olives groves with replacement by cork oak woodland	0 (-100%)	23640 (+1%)	Total elimination of riparian vegetation with replacement by cork oak woodland	0 (-100%)	23614 (+1%)
3	Increasing number of patches of olive groves (average sized):			Increase of the area of riparian vegetation along the margins of waterlines (15m):		
	a) twofold increase	599 (+200%)	22741 (-3%)	a) suitability over 0.75	375 (+50%)	23212 (-1%)
	b) threefold increase	899 (+300%)	22441 (-4%)	b) suitability over 0.65	692 (+180%)	22896 (-2%)
	c) fourfold increase	1198 (+399%)	22142 (-5%)	c) suitability over 0.60	781 (+215%)	22807 (-2%)

5.4. Results

Twenty one species (Appendix 5.1) had sufficient observations to allow for densities estimation with distance sampling methods and were thus included in the modeling process. The importance of the different variables in the bird abundance models varied among species (Appendix 5.1). The variable “riparian gallery area” showed the highest relative importance in species models, followed by “olive grove area” and “slope”.

Prediction of species density under future scenarios

We could identify five main groups, which showed similar population responses:

(1) Species that would respond positively to an increase in the availability of riparian galleries - This group includes the species that are predicted to increase with the availability of riparian gallery vegetation, but are not influenced by changes in olive groves (Figure 5.2). It includes the nightingale (*Luscinia megarhynchos*), melodious warbler (*Hippolais polyglota*), serin (*Serinus serinus*), black bird (*Turdus merula*), Iberian chiffchaff (*Phylloscopus ibericus*), blackcap (*Sylvia atricapilla*) and wren (*Troglodytes troglodytes*).

(2) Species that would respond negatively to an increase in the availability of riparian galleries - This group includes woodlark (*Lullula arbora*) and spotless starling (*Sturnus unicolor*), which are the species that are predicted to decrease with the increase in the availability of riparian gallery vegetation, but are not influenced by changes in olive groves (Figure 5.3).

(3) Species that would respond positively to an increase in the availability of olive groves - Great tit (*Parus major*) and goldfinch (*Carduelis carduelis*) are likely to increase slightly in density in the projected scenarios with greater availability of olive groves, but are not predicted to respond to riparian galleries (Figure 5.4).

(4) Species that would respond negatively to an increase in the availability of olive groves - Species in this group decline with the increase in the availability of olive groves, but are not likely to be affected by variations in the riparian gallery, and are treecreeper (*Certhia brachydactyla*), crested tit (*Parus cristatus*), stonechat (*Saxicola torquata*) and common redstart (*Phoenicurus phoenicurus*) (Figure 5.5).

(5) Species least responsive to changes in the availability of olive groves or riparian galleries - Blue tit (*Parus caeruleus*), chaffinch (*Fringilla coelebs*), corn bunting (*Miliaria calandra*), rock sparrow (*Petronia petronia*), nuthatch (*Sitta europaea*) and woodchat shrike (*Lanius senator*) are not significantly affected by any of these changes (Figure 5.6).

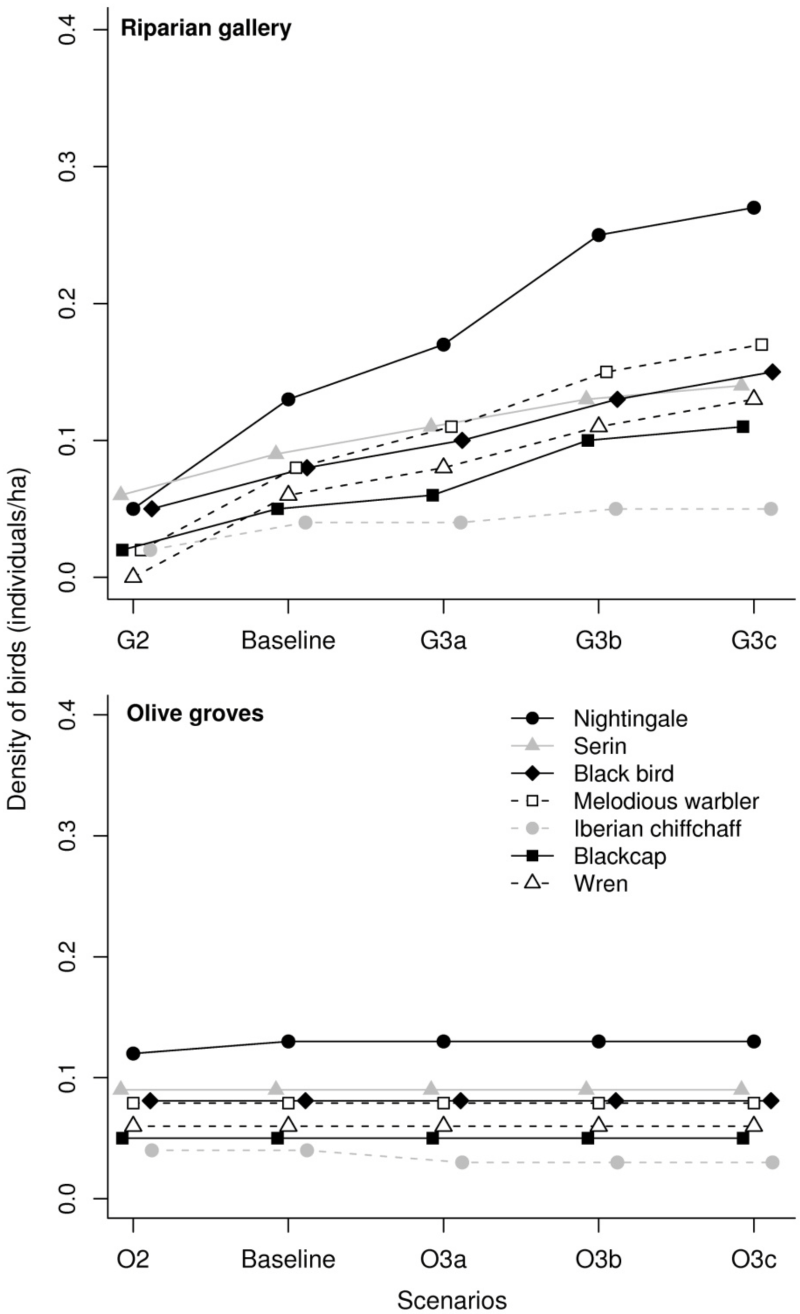


Figure 5.2. Expected densities (individuals/ha) of seven bird species in the Baseline scenario and each of the four simulations for riparian gallery (G2; G3a, b and c) and olive grove scenarios (O2; O3a, b and c). Elimination scenarios are identified by number "2"; scenarios "3a, b, c" correspond to a progressive increase of riparian galleries or olive groves.

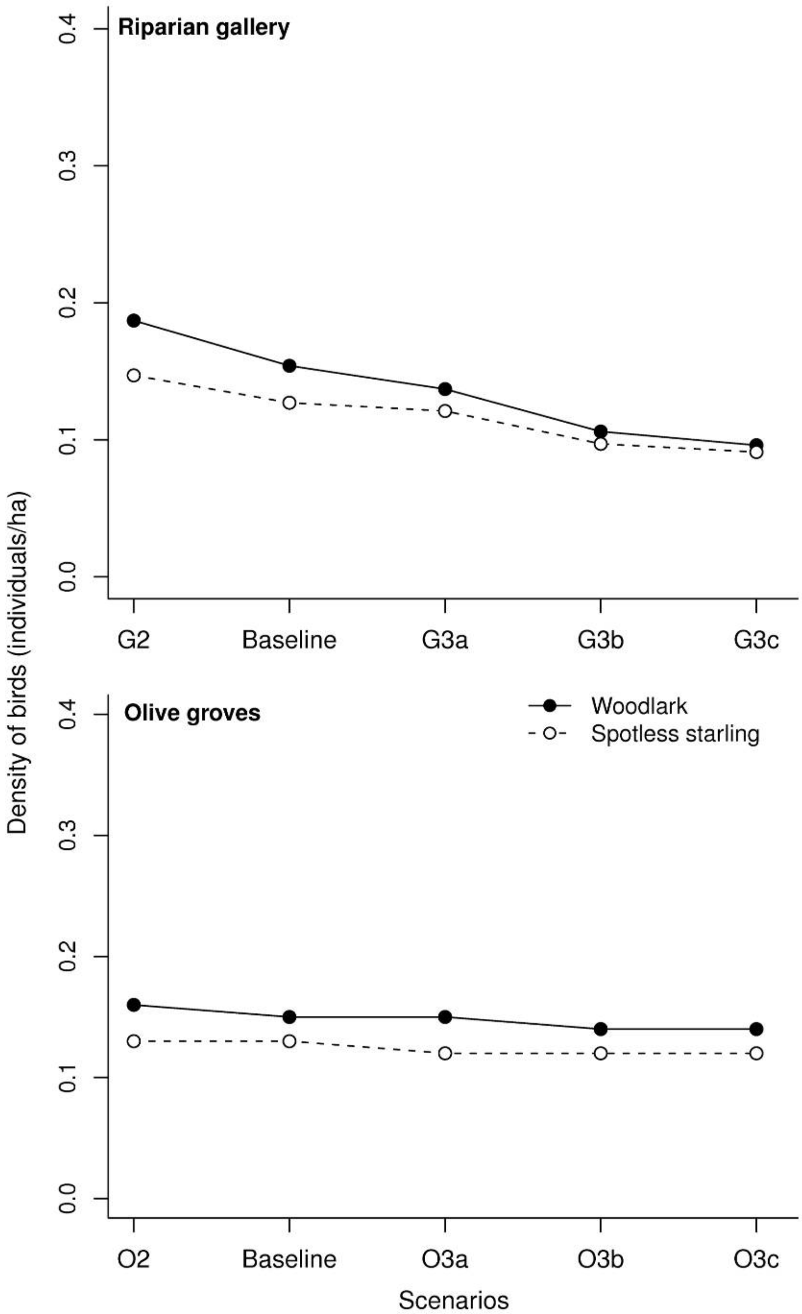


Figure 5.3. Expected densities (individuals/ha) of two bird species in the Baseline scenario and each of the four simulations for riparian gallery (G2, G3a, b and c) and olive grove scenarios (O2, O3a, b and c). Elimination scenarios are identified by number “2”; scenarios “3a, b, c” correspond to a progressive increase of riparian galleries or olive groves.

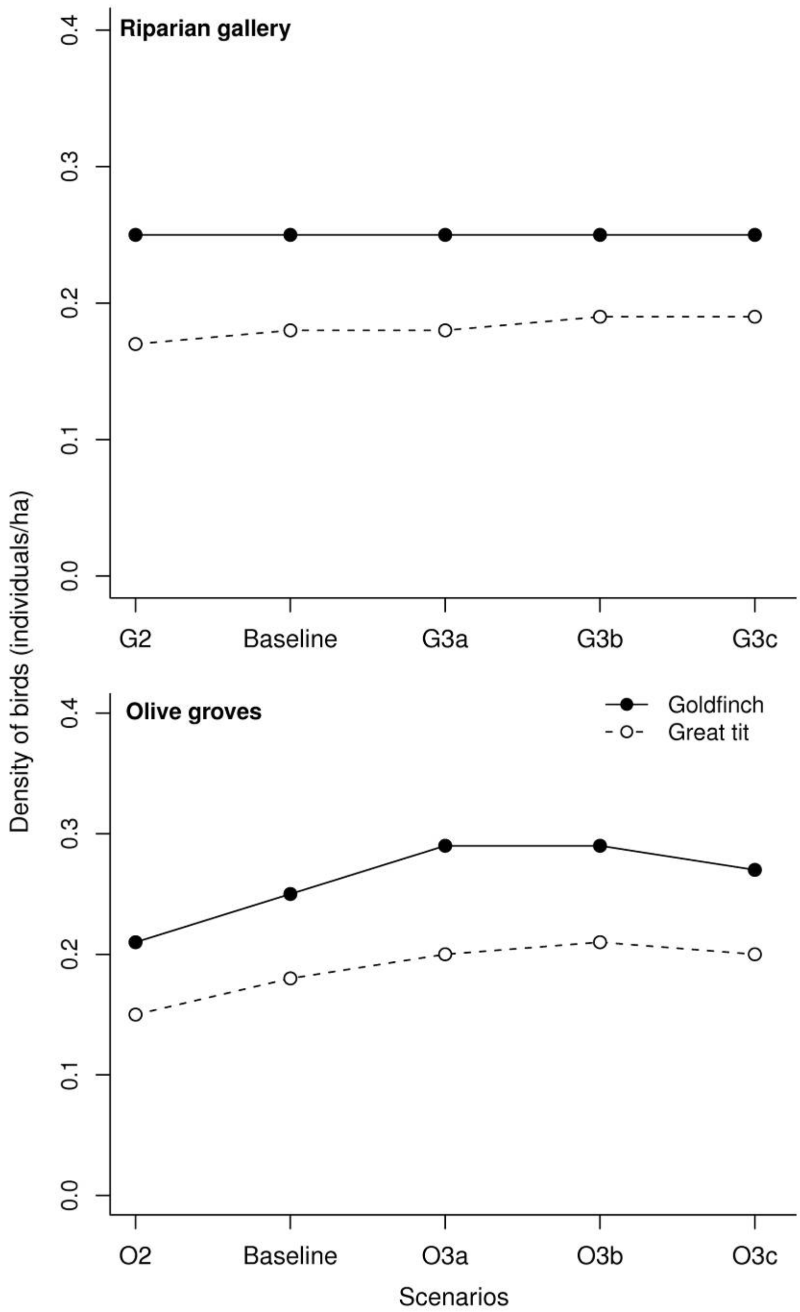


Figure 5.4. Expected densities (individuals/ha) of two bird species in the Baseline scenario and each of the four simulations in riparian gallery (G2, G3a, b and c) and olive grove scenarios (O2, O3a, b and c). Elimination scenarios are identified by number "2"; scenarios "3a, b, c" correspond to a progressive increase of riparian galleries or olive groves.

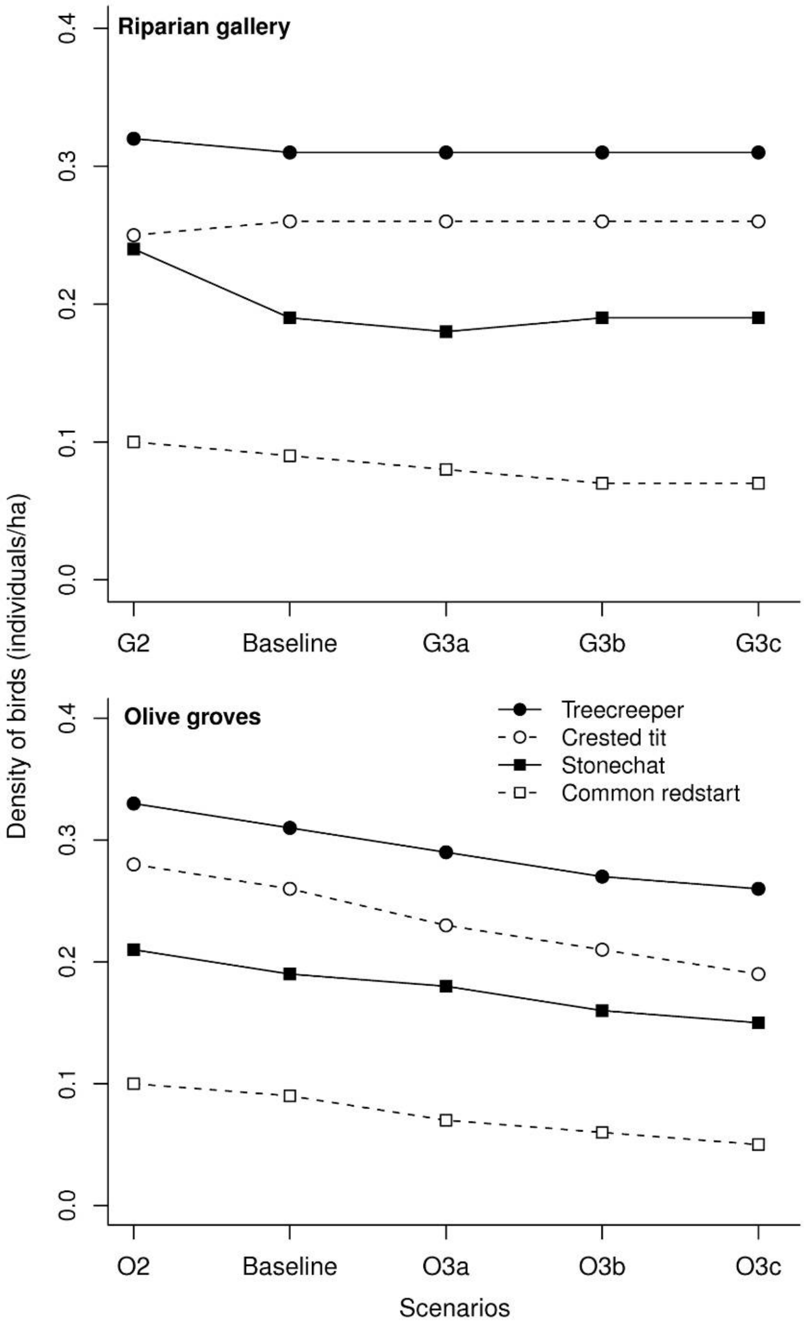


Figure 5.5. Expected densities (individuals/ha) of four bird species in the Baseline scenario and each of the four simulations in riparian gallery (G2, G3a, b and c) and olive grove scenarios (O2, O3a, b and c). Elimination scenarios are identified by number "2"; scenarios "3a, b, c" correspond to a progressive increase of riparian galleries or olive groves.

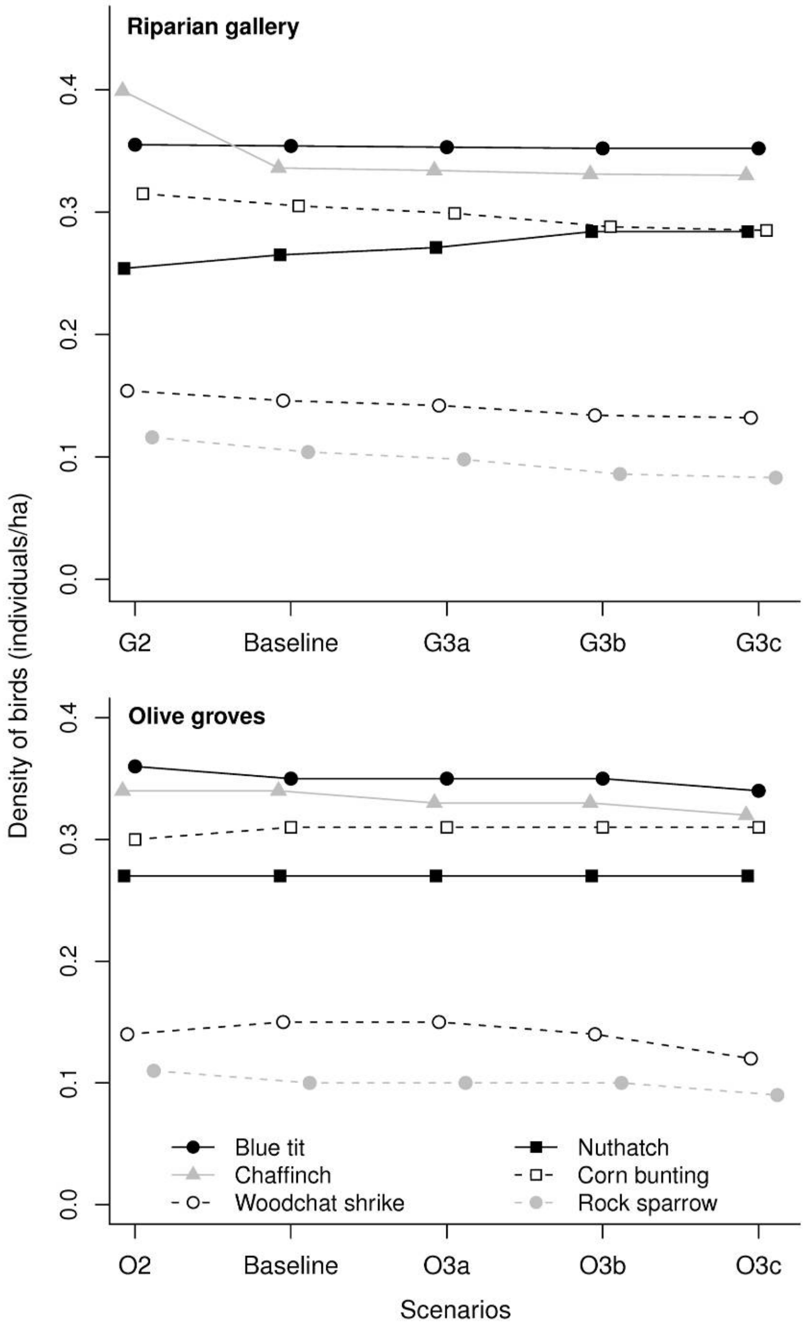


Figure 5.6. Expected densities (individuals/ha) of six bird species in the Baseline scenario and each of the four simulations in riparian gallery (G2, G3a, b and c) and olive grove scenarios (O2, O3a, b and c). Elimination scenarios are identified by number "2"; scenarios "3a, b, c" correspond to a progressive increase of riparian galleries or olive groves.

Mapping response of birds to scenarios

The response of species under the various scenarios modeled is spatially-explicit, in the sense that it includes spatial concepts in its formulation and is not invariant to relocation.

Figures 7 to 10 are examples of the first four species groups specified in the previous section. It is clear in Figure 5.7 that the elimination of the riparian galleries is expected to result in the near extinction of the melodious warbler in the study area. In this scenario its maximum expected density values would decrease to 0.16 birds/ha or less. In the increase scenarios, which correspond to a progressive restoration of riparian vegetation, the greater abundance of the species along the new areas of riparian vegetation is clearly visible. The woodlark scenarios in Figure 5.8 illustrate how the density of this species is expected to increase when we simulate a total elimination of the riparian vegetation in the study area, contrasting with the pattern observed in the increase scenarios. It is noticeable in Figure 5.9 that the elimination of olive groves is likely to lead to a general decrease in the density of the great tit, where the maximum expected density is reduced to 0.23 individuals/ha. Figure 5.10 illustrates how the overall density of the common redstart is expected to increase in the olive grove elimination scenario, particularly in the SE of the study region. This corresponds to the areas where the species decreases the most when we simulate an increase in the number of olive groves, because it has the highest suitability for this habitat.

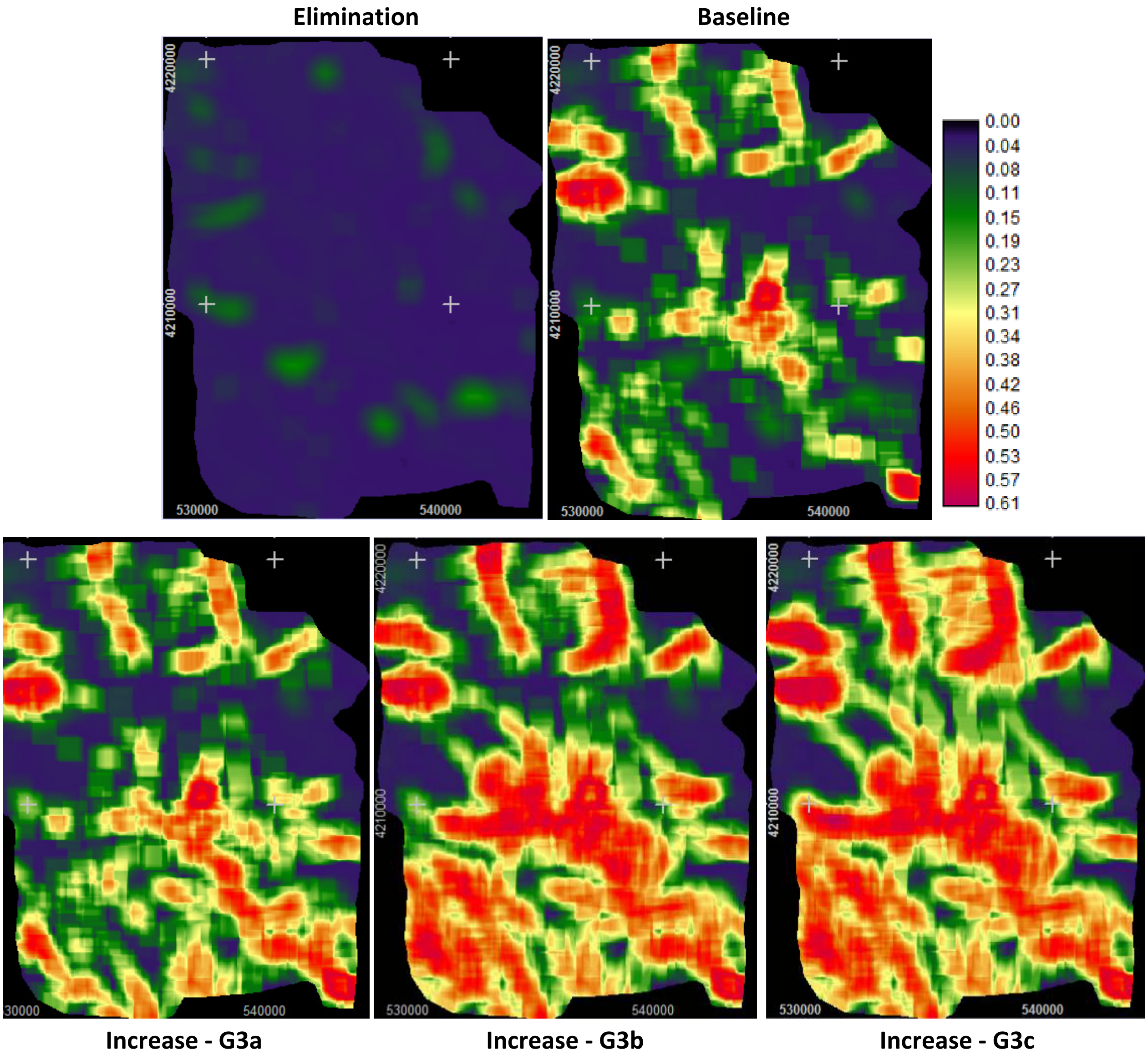


Figure 5.7. Maps of predicted melodious warbler density (individuals/ha) in Baseline, Elimination and Increase of riparian gallery scenarios. Scenarios "3a, b, c" correspond to a progressive increase of riparian vegetation (respectively +50%, +180% and +215%, in relation to the Baseline scenario).

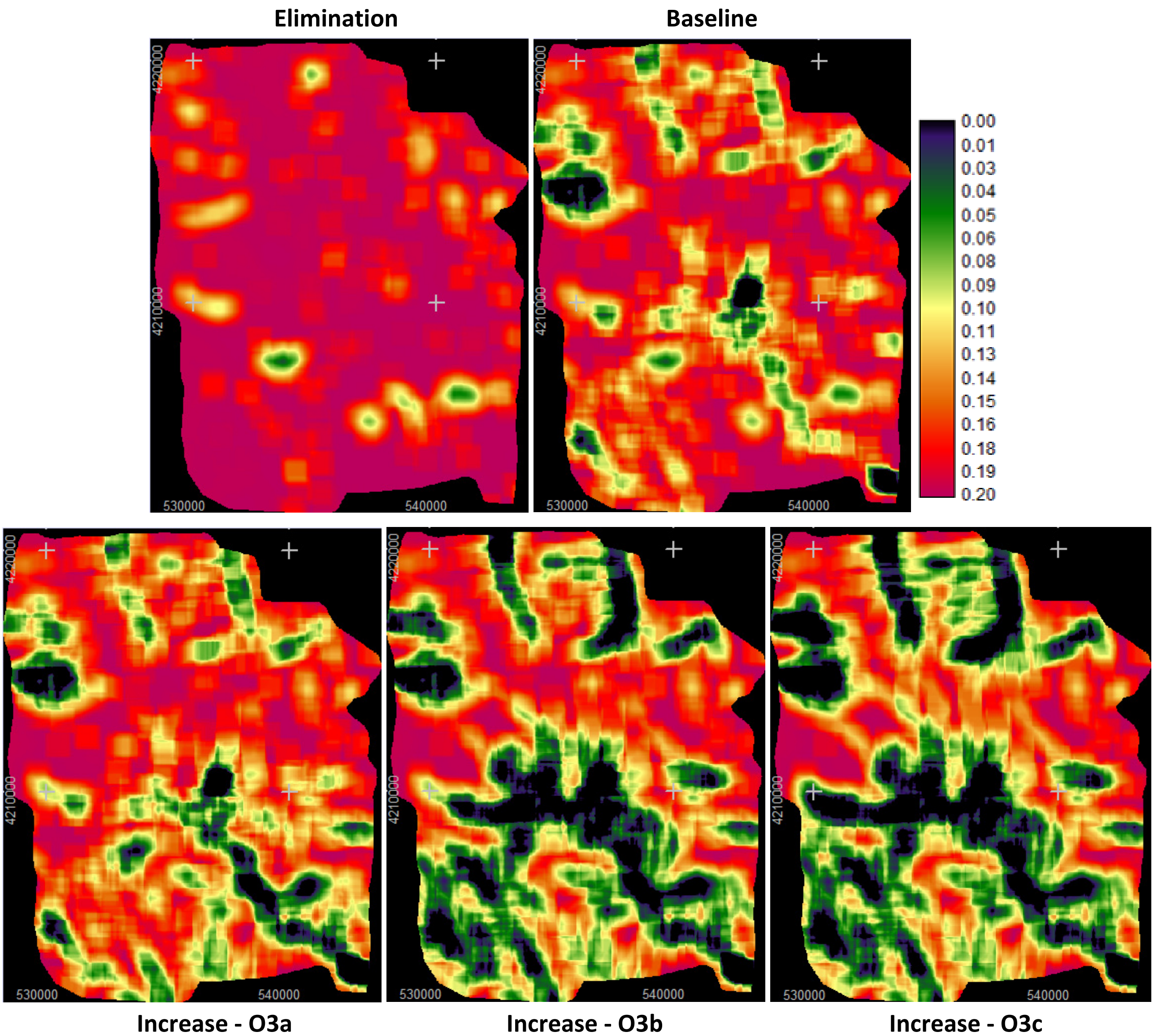


Figure 5.8. Maps of predicted woodlark density (individuals/ha) in Baseline, Elimination and Increase of riparian gallery scenarios. Scenarios "3a, b, c" correspond to a progressive increase of riparian vegetation (respectively +50%, +180% and +215%, in relation to the Baseline scenario).

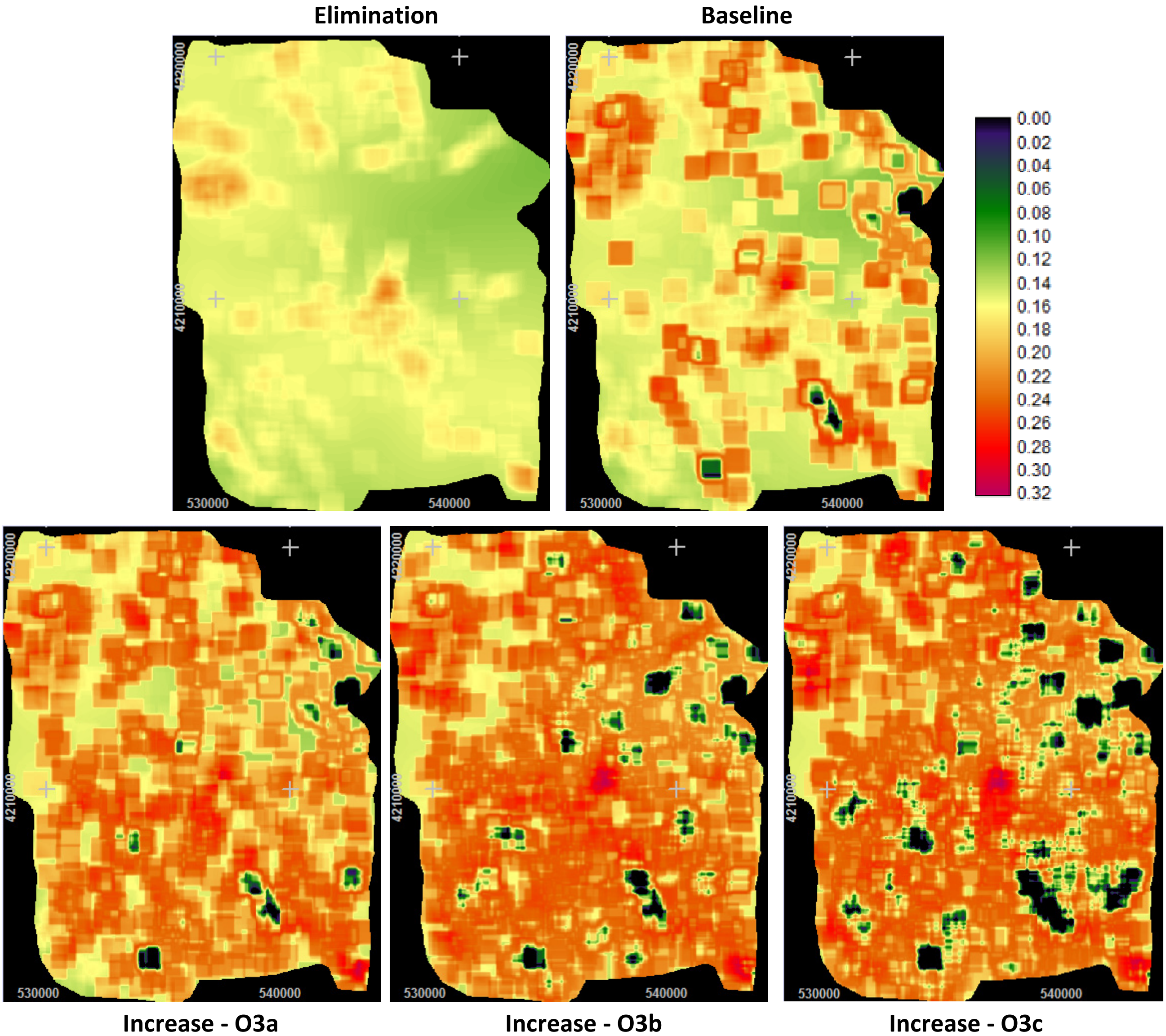


Figure 5.9. Maps of predicted great tit density (individuals/ha) in Baseline, Elimination and Increase of olive grove scenarios. Scenarios “3a, b, c” correspond to a progressive increase of olive groves (respectively twofold, threefold and fourfold, in relation to the Baseline scenario).

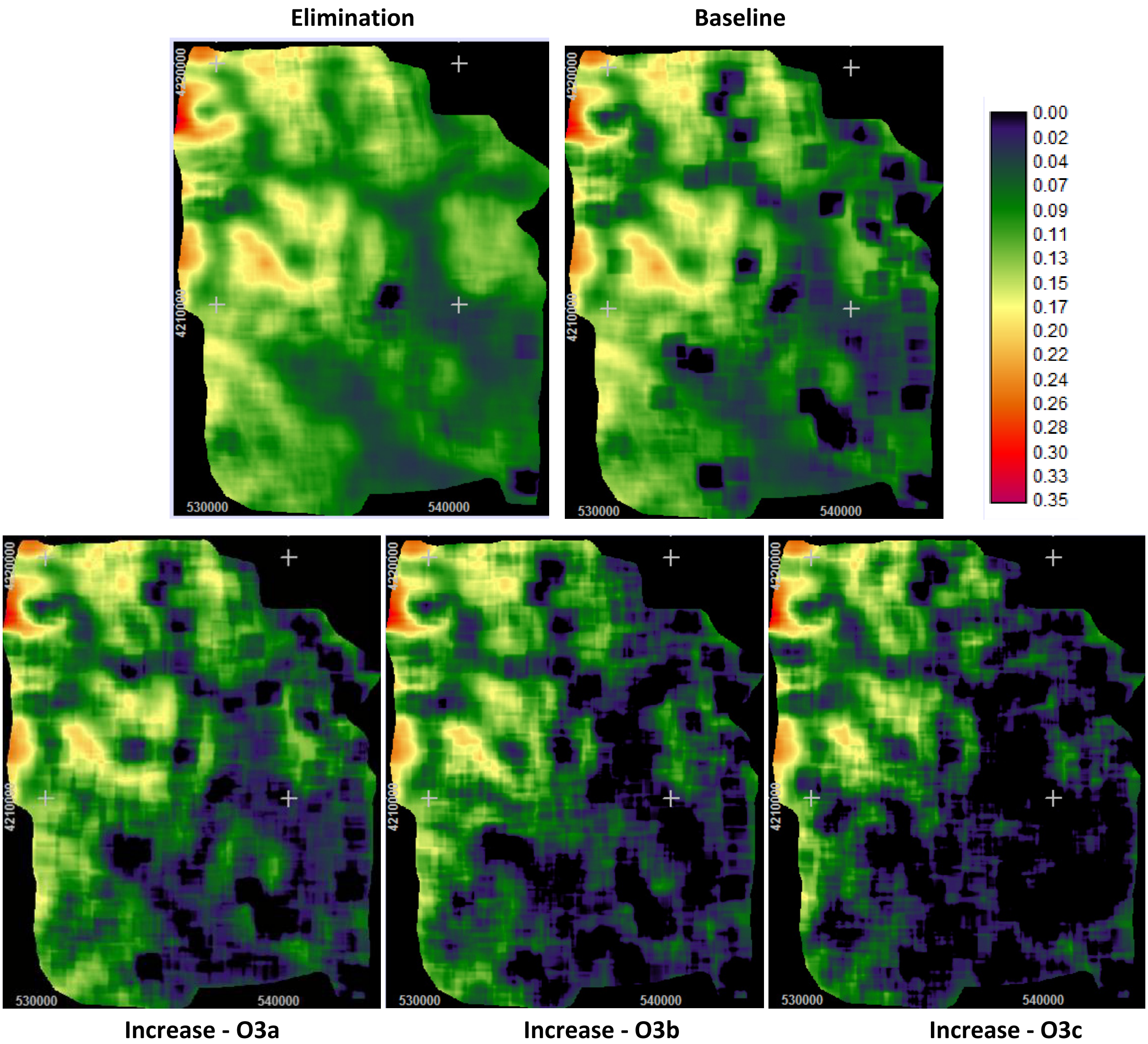


Figure 5.10. Maps of predicted common redstart density (individuals/ha) in Baseline, Elimination (O2) and Increase of olive grove scenarios. Scenarios "3a, b, c" correspond to a progressive increase of olive groves (respectively twofold, threefold and fourfold, in relation to the Baseline scenario).

5.5. Discussion

Methodological considerations

The application of spatially-explicit models of species' habitat selection over simulated landscape scenarios has proved to be very useful in studies to predict the response of species to management alternatives (e.g. Baker *et al.* 2004; Gehrt & Chelsvig 2004; Swetnam *et al.* 2005; Bar Massada *et al.* 2009; Rainho & Palmeirim 2011), or even to climate change (Pearman *et al.* 2011). In our study, this process involved two separate modeling procedures. In the first we evaluated how the selected landscape descriptors influenced the spatial distribution and abundance of each bird species. Defining these species-habitat relationships is fundamental to understand how each species would respond to simulated changes in the habitat. In the second, we modeled the suitability of the full study area for the two habitats – olive groves and riparian galleries – to simulate ecologically-sound scenarios. This was necessary because the construction of future scenarios required the identification of areas most suitable for the expansion or contraction of the two habitats to be manipulated.

Two main alternatives existed to build models to identify these most suitable areas throughout the study area: predictive modelling trained with locations with and without habitat, or predictive modelling using expert knowledge. The first approach was tried, but it yielded poor models, with low predictive power. A close examination of the results showed that the reason for this failure is that in many cases the modelled habitats are not present in the most suitable locations, but rather where the land use managers allowed them to strive (in the case of riparian vegetation) or promoted them (in the case of olive groves). For example, riparian vegetation is absent from some highly suitable areas because they have productive soils, valuable for farming. Such false absences created much noise in the modelling process. To overcome this difficulty we resorted to the second alternative – expert knowledge. This was done taking into consideration not only the general knowledge on the conditions most suitable for the two habitats, but also the observation of the environmental conditions at the sites within the study area where they were present. The overall results were very coherent with our expectations and knowledge of the terrain.

The spatially-explicit modelling of the bird response to the habitat management scenarios resulted in spatial variations in species' abundance, as exemplified in Figures 7 to 10. The predictions arising from the models assume that abundance of birds is determined by habitat availability in the breeding season (Boatman *et al.* 2010). In general, these changes in abundance were coherent with our expectations based on the known ecological requirements of the studied species, as discussed in the next sections.

Restoring riparian vegetation would be highly beneficial for most birds in montados landscapes

Univariate statistical analyses revealed that among the nine environmental variables considered, the area of riparian vegetation was the best descriptor for the density and distribution of the largest number of bird species. Many of these would become nearly extinct in the scenario of elimination of riparian gallery, but become far more abundant in the scenarios where it was simulated an increase in riparian vegetation.

In fact, the ordination analysis separated a group of seven species that followed this pattern. In all these cases species are known to be associated to riparian galleries or dense shrubs, which in the study area are usually more abundant along drainage lines. The overall density of the group of species most strictly associated with riparian habitats more than doubled in the scenario with the maximum increase in this type of vegetation. This is the case of the nightingale, melodious warbler, Iberian chiffchaff, blackcap and wren (Equipa Atlas 2008; Catry *et al.* 2010; Leal *et al.* 2011b).

A second group also benefits from the increase in riparian vegetation, but not as much as the previous species. The black bird is part of this group, because although it is quite abundant in riparian galleries, it is also relatively common in *montados*, wherever there is sufficient shrub cover (Rabaça 1990). Another species in the group, the serin, is also regularly found in *montados* matrix (Almeida 1992; Leal *et al.* 2011b), but it probably takes advantage from the availability of high trees in the riparian gallery that it uses as song-perches in territory defence (Cramp & Perrins 1998).

The group of species that are predicted to react negatively to an increase in riparian vegetation includes just the woodlark and spotless starling. In fact, the woodlark has been found to avoid areas of *montados* near riparian galleries, possibly to avoid the increased risk of predation near habitat edges, particularly while nesting (Leal *et al.* 2011b). The decline in the spotless starling may be a consequence of the replacement of open areas, which it strongly favors (Equipa Atlas 2008; Catry *et al.* 2010), by more closed habitats. This means that the decline of the spotless starling is the only that seems to result from a reduction in the area of *montados*. In fact, the restoration of riparian habitats, even in the most extreme scenario, would cause a reduction of just 2% in the area of *montados*. This probably explains why so few birds typical of *montados* are affected by the increase in riparian vegetation.

Changes in olive grove fragments would not have major consequences for breeding birds

The univariate analysis revealed that changes in the area of olive groves are expected to have a much weaker effect on bird community than changes in the extent of riparian vegetation. In fact, the ordination analysis identified just two species expected to become more abundant as a result of an increase in the number of olive groves: great tit and goldfinch. However, even on these species the effect is quite minimal, because they are both known to be abundant in the matrix of *montados* (Almeida & Granadeiro 2000; Leal *et al.* 2011b).

A group of four species – treecreeper, crested tit, stonechat, and common redstart - are expected to decline in scenarios of increased number of olive groves. These declines range from 18%, in the case of treecreeper, to 45% for common redstart. The last species is particularly affected because it is known to be strongly associated to *montados* (Catry *et al.* 2010). The remaining three species are less affected because, as described in the literature (Catry *et al.* 2010; Leal *et al.* 2011b), they also use olive groves, although to a lesser extent than *montados*.

Conservation implications

Landscape heterogeneity has been largely indicated as having a positive influence on species richness and abundance of farmland birds (Benton *et al.* 2003). In fact, the development of management solutions that recreate the heterogeneity that has been lost, mainly as a consequence of agricultural intensification, is considered a key for restoring and sustaining biodiversity in temperate agricultural systems (Benton *et al.* 2003). Traditional land use in the Mediterranean region resulted in complex landscape structures characterized by high ecological diversity (Franz *et al.* 2011). Cork oak woodlands are one of the most significant components of these landscapes, especially in the western Mediterranean, and combine a wealth in biodiversity with a substantial economic value. This makes them a priority target for conservation.

These habitats are semi-natural, and thus maintained by management, which in the past has been exclusively determined by the need to maximize economic income. However, with the recognition of the role that these semi-natural habitats play in the conservation of biodiversity, it is becoming increasingly relevant to take into consideration conservation interest in management. The two types of management manipulations modeled in this study had a good potential for improving the value of *montados* landscapes for the conservation of birds. Our results indicate that restoring the riparian vegetation along the major streams and drainage lines would be highly beneficial for birds in *montados* landscapes. In fact, it would increase the abundance of many species, and cause a minimal decline in just two. The near absence of negative effects is probably partly due to the fact that the growth in riparian coverage would affect a very small proportion of cork oak area. In addition, the number of species that are likely to respond negatively to the presence of forested edges is small, probably because although *montados* often have substantial grasslands, the presence of trees is a constant, so there is some structural similarity between those habitats. A larger effect would be expected in more open landscapes, as observed for large grasslands that often occur in the same regions as cork oak woodlands (e.g. Reino *et al.* 2009). It is worth noting that the species that increased the most with the simulated recovery of riparian vegetation are among the least abundant in the region. Moreover, some of them, like the nightingale, melodious warbler and serin, are known to have declined in Europe over the last decades (PECBMS 2011). In summary, the simple measure of stopping the aggressive practices in riparian habitats, allowing the restoration of the vegetation could result in high increases in some bird species densities, with null or small negative consequences to the great majority of *montados* species. A proactive management of riparian vegetation, made by conservation managers in collaboration with stakeholders, could accelerate its natural recovery.

Managing olive groves would have weaker conservation implications for birds in *montados* than riparian habitats. However, some bird species are known to benefit from the presence of these traditional groves particularly in winter when they act as complementary feeding habitats to species as chaffinches, blue tits, blackcaps and robins (e.g. Rey 1993; Leal *et al.* 2011b). Traditional olive groves seem to somehow compensate the scarcity of fruit-bearing shrubs in *montados,* caused mainly by regular shrub removal that reduces the suitability of this habitat for some of the passerines that winter in the Mediterranean region (Tellería 2001). Given the existing information about the importance of both olive groves and riparian vegetation for some bird species during winter it would be interesting to obtain data for this season. In the view of our results, the compromise solution of maintaining the already existing traditional olive groves patches seems to be the most adequate alternative for the conservation of bird populations in *montados* landscapes. This would involve the maintenance of the low-input management of the olive groves patches that are still exploited, and an investment in the restoration of others to avoid a replacement by other habitats due to a lack of economic returns.

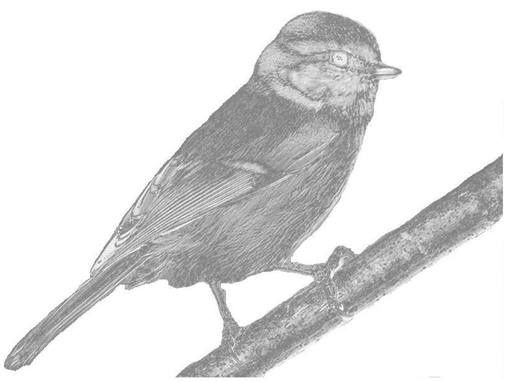
Because most of the income of *montados* dominated landscapes comes from the exploitation of cork, management measures that result in a decrease of the area covered by cork oaks are unlikely to be accepted by landowners. However, the only proposed measure that would result in a reduction of the valuable area of cork oak is the expansion of riparian vegetation, but even in this case the reduction would be minimal (1 or 2% of the cork oak area). In conclusion, the results of our simulated future scenarios indicate that simple management measures, like restoring riparian habitats and protecting the existing traditional olive groves, may have substantial positive effects on the bird community of *montados*, without compromising the economic rentability of the system.

Appendix 5.1. List of the 21 studied species with the indication of the variables (and the direction of the relation: +/-) that were included in the models of bird abundance: Altitude, Slope, Soil capability (Soil C), Cork oak area (Cork area), Olive groves area (Olive area), Riparian galleries area (Gal area) and Distance to urban areas (Urbdist).

Species	**Altitude**	**Slope**	**Slope^2**	**Soil C**	**Cork area**	**Olive area**	**Oli area^2**	**Gal area**	**Gal area^2**	**Urbdist**
Black bird (*Turdus merula*)		+				+		+		
Blackcap (*Sylvia atricapilla*)		+		+		+		+		
Blue tit (*Parus caeruleus*)					+	+		+		-
Chaffinch (*Fringilla coelebs*)				-	+	-		+		
Common redstart (*Phoenicurus phoenicurus*)		+		+		-		-	-	
Corn bunting (*Miliaria calandra*)		+	-	+		+		-		
Crested tit (*Parus cristatus*)	+					-		+		+
Goldfinch (*Carduelis carduelis*)				-		+	-	+		-
Great tit (*Parus major*)						+	-	+		-
Iberian chiffchaff (*Phylloscopus ibericus*)		+		-	+	-		+	-	
Melodious warbler (*Hippolais polyglota*)		+			-	-		+	-	
Nightingale (*Luscinia megarhynchos*)				+	-	+		+		
Nuthatch (*Sitta europaea*)		-		+		-		+		
Rock sparrow (*Petronia petronia*)		-			+	-		-		
Serin (*Serinus serinus*)		-				+		+		
Spotless starling (*Sturnus unicolor*)		-		-		-		-		
Stonechat (*Saxicola torquata*)		+				-		-	+	
Treecreeper (*Certhia brachydactyla*)					+	-		-		
Woodchat shrike (*Lanius senator*)		-				+	-	-		-
Woodlark (*Lullula arborea*)		-			+	-		-		
Wren (*Troglodytes troglodytes*)		+		+		-		+	-	

CHAPTER 6

General Discussion



6. General Discussion

The primary objective of this thesis was to investigate the effects of well-established management practices in cork oak woodlands on bird populations. This economically-relevant issue was addressed at different spatial scales, by looking at impacts at the tree level, but also by examining landscape effects. Previous chapters analysed several specific questions directly linked with the main subject of the thesis, and major conclusions were discussed in each. This section presents a synthesis of the implications of the major findings for the conservation of the cork oak woodlands system, offering recommendations of management alternatives and suggestions for future research in this field.

6.1. Consequences of management practices on bird populations in cork oak woodlands: from trees to landscapes

Montados are managed habitats in which interventions range from practices that are applied directly to the tree, to measures that have repercussions at a landscape level. These are among the semi-natural habitats that offer greatest biodiversity values in Europe. Consequently, understanding the ecological consequences of management practices at several spatial scales is of great importance to the conservation of this ecosystem. However, thorough knowledge of the impacts of even routine exploitation activities (like debarking and pruning, among others) remains lacking and is often insufficient to support management decisions. In this thesis, certain management practices were considered based upon their potential to produce measurable impacts on the bird communities of *montados*. In doing so, we aimed to contribute to the creation of a sound scientific basis and generate advice for improving existing management practices, striving towards better conciliation of exploitation with wildlife conservation.

Birds have often been used as indicator of environmental quality. The large numbers of species that can be found in *montados,* and the diversity of niches that they occupy, makes them a very good study model, and enable investigations of the ecological response of different functional groups according to the main resource explored (see Chapters 2 and 3). These groups include, for example, species that forage mainly on the tree (like blue tit and treecreeper), as well as species that mostly feed on the ground (like chaffinch and woodlark). The existence of different functional groups raises a relevant question: are all the birds equally affected by small-scale management practices? Results from the study of impacts of cork extraction provide strong evidence that the species that commonly forage on bark (e.g., treecreeper, nuthatch, blue tit and great tit) are the only ones affected by this practice (Chapter 2). Moreover, the magnitude of the effect on each species seems to be proportional to its dependence on bark for foraging, since bark-foraging species were clearly more affected than bark-foliage ones. Similar conclusions were obtained during our analysis of the effects of pruning, since only species that forage mainly in the canopy of the tree were influenced by this activity (like blue tit, great tit and chiffchaff) (Chapter 3).

The influence of such small-scale management practices on birds starts with the individual choice of a tree. Species that forage on the bark, for example, exhibited a preference to forage on trees with older cork, mainly because well-developed cork had the highest densities of arthropods both in spring and winter (Chapter 2). This is most likely due to differences in the structure of the bark, which is more homogeneous in young than in older cork (Natividade 1950; Pereira 2007). Further research is needed to determine the consequences of pruning on prey availability in cork oak trees, particularly to estimate the number of arthropods that are lost in pruned branches, which would help to quantify pruning effects both at smaller and broader scales. Cork oak trees are known to be vulnerable to a wide number of insect-attacks that affect acorns and seedlings, but also adult trees (through defoliation and even bark and wood-boring) (Branco & Ramos 2009), a more detailed study of the diet of insectivorous birds in *montados* could allow for studying their role and importance as biological pest controllers.

The effect of both cork extraction and pruning is noticeable not only in the way birds select individual trees but also at larger scales (Chapters 2 and 3). Indeed, bird census revealed that bark gleaners are more abundant in fields with older cork than in those more recently debarked (Chapter 2). This negative effect of cork extraction on species that forage on bark also was recently demonstrated by other investigators who analyzed the influence of various forest and management variables on the distribution of *montados* bird species (Godinho & Rabaça 2011). Although bark gleaners and bark-foliage gleaners seem to be affected by cork extraction or pruning, both practices did not have important effects on the species composition of bird assemblages. Moreover, impacts on the abundance of specific functional groups at the landscape level were not nearly as substantial as those observed at the field level.

Chapters 4 and 5 used complementary approaches to investigate the extent to which habitat heterogeneity and fragmentation influence bird communities of a given cork oak matrix. The presence of patches of different habitats (such as traditional olive groves and riparian galleries) contributes not only to habitat heterogeneity, which is commonly considered important for the high diversity of cork oak dominated landscapes, but also to the presence of edge habitats. The study of the influence of fragments on the species assemblages of the matrix represents a rather original approach in fragmentation studies (Chapter 4), which usually adopt the reverse approach (i.e., analyzing the effects of the matrix on fragments).

Most of the studied species did not respond significantly to the presence of edge habitats. However, in some situations, the presence of olive groves and riparian galleries increased the diversity of birds in the adjacent matrix, both in spring and winter. The spatial extent of the edge effects on the matrix was relatively low and quite similar to that reported for other artificially-maintained habitat edges (e.g. Tubelis *et al.* 2004; Reino *et al.* 2009).

Resource availability is known to shape species distribution (e.g. Tellería & Pérez-Tris 2007; Butler *et al.* 2010), and the positive response of species like chaffinches, blue tits and robins to the vicinity of olive groves, and of the great tit to riparian galleries, is probably explained by the fact that these habitats provide important supplementary feeding resources, mainly in winter (Chapter 4). In fact, managed *montados* can be relatively poor in pulpy fruit resources (Tellería 2001), especially because the understory often is removed to avoid the development of a shrub layer (to facilitate cork extraction and maintain adequate grass cover for cattle grazing). In this circumstances, many species that are common in *montados* were observed frequently in riparian galleries eating blackberries, and in olive groves feeding on fallen olives (unpublished data), which are known to be an important resource for birds wintering in Mediterranean regions (e.g. Jordano 1987; Rey *et al.* 1997).

Since olive groves and riparian galleries seem to play a significant ecological role for *montado* biodiversity (Rosalino *et al.* 2009; Chapter 4), and their management seems to be compatible with maintaining of the economic value of this system, scenarios offering different management options in these two habitats were designed (Chapter 5). The use of spatially-explicit models allowed for the selection of the most suitable areas for habitat management (both for restoration of riparian galleries and for expansion of small olive groves), and for quantifying the population response of birds to different management measures. This combination enabled the study of the effect of changing landscape features on population dynamics (Dunning *et al.* 1995), which has proven to be very useful to model the response of plants and animals to alternative management strategies (e.g. Baker *et al.* 2004; Gehrt & Chelsvig 2004; Swetnam *et al.* 2005; Bar Massada *et al.* 2009), or even to climate-change scenarios (Pearman *et al.* 2011).

The results of the simulated future scenarios indicated that seven species would clearly benefit from extending the riparian galleries: nightingales, melodious warblers, Iberian chiffchaffs, blackcaps, wrens, blackbirds and serins. In all cases, this is in agreement with the known ecological requirements of these species (Equipa Atlas 2008; Catry *et al.* 2010; Chapter 5). In fact, they all are frequently associated with riparian galleries or dense shrubs, which are usually more abundant along drainage lines, as observed in the study area. Two species are expected to react negatively to an increase in riparian vegetation in the study area: woodlarks and spotless starlings. Avoiding an increase in predation risk near the edges of riparian galleries (e.g. Flaspohler *et al.* 2001) is a possible explanation for the observed negative response of woodlarks to riparian habitats, which was evident both at a finer (Chapter 4) and landscape scale (Chapter 5). Reduction in the density of spotless starlings under a scenario of increased riparian vegetation could be due to the consequential increase in the relative importance of closed habitats, since this species is known to prefer open habitats and even avoid areas with dense shrubs (Equipa Atlas 2008; Catry *et al.* 2010).

Finally, results from univariate analyses and scenario simulations showed that changes in the number of small olive groves would be expected to have less effect than changes in riparian habitats on bird densities. Only great tits and goldfinches seem to benefit, and just slightly, if olive grove numbers increase. However, these results can be potentially undervaluing the importance of traditional olive groves since they refer only to spring, and previous studies have proved that those fragments are of particular importance in winter for many bird species in cork oak woodlands (Rey 2011; Chapter 4).

6.2. Management measures that can enhance bird populations: suggestions and major conservation implications

There is increasing evidence that the preservation of biodiversity depends not only on the maintenance of networks of protected sites, but also on the condition of the habitats present in the matrix, usually economically exploited (e.g. Lindenmayer & Franklin 2002; Cox & Underwood 2011). In fact, biodiversity-rich farmland and forestry habitats, like *montados*, can be critical to maintain interconnections between protected areas, and may harbour important populations of many species of conservation concern (e.g. Tucker 1997; Child *et al.* 2009). Consequently, it is very important to promote management practices that are simultaneously economically-valuable and biodiversity-friendly.

This study proved that cork extraction is compatible with maintaining a rich bird community in *montados*), despite the cyclic disturbance of densities in species that forage on the bark (Chapter 2. In order to enhance habitat quality for those species, to as great an extent as possible, land managers should promote temporal de-synchronization of cork extraction among neighbouring parcels, to provide a varied mosaic of alternative good-quality areas at reasonable distances for birds. In fact, it was demonstrated that, at a regional scale, the habitat quality for bark gleaners remained relatively stable over time in the study area, because the landscape is a mosaic of parcels with non-synchronized exploitation cycles (Chapter 2). In actuality, in most cases it should be in the interest of cork producers to have parcels that are being exploited in non-synchronized cycles, since it allows them to avoid years without economic income from cork exploitation (e.g. Borges *et al.* 1997), and years with production above their selling capacity; consequently, extensive areas with synchronized cork ages are rare. In many areas, managers keep trees with different cork ages in the same parcel (Pereira & Tomé 2004), instead of arranging the parcel based on the year of cork extraction. We found that, such areas where trees with different cork age are mixed, harbour high densities of bark and bark-foliage gleaning species (although usually not quite as high as those areas with just old cork) and can then be considered favourable to the species in these guilds.

Pruning is another important management practice that is applied to cork oak trees, whose impacts were still poorly documented (Torras & Saura 2008). Pruning has long been a controversial practice, even from a silvicultural perspective (Cañellas *et al.* 2007). Light pruning is considered by some authors as beneficial for the health of the trees, as it rids them of weak branches and increases acorn yield (González & Cayon 1990; Cañellas *et al.* 2007), but severe pruning can cause serious damage to the tree (Natividade 1950; Pinto-Correia & Mascarenhas 1999). In fact, the international code of cork oak silvicultural practices (Proyecto Subernova - Interreg III A 2005) advises against maintenance pruning. We found that pruning is compatible with a diverse and abundant bird community, since it has no significant impact on overall bird assemblage composition (Chapter 3). However, it does cause a substantial reduction in the density of foliage-gleaning bird species, like blue tits and great tits that feed mainly in tree canopies. As a consequence, it is advisable to avoid high-intensity pruning to minimize these potentially-harmful effects. Another negative consequence of pruning for birds in cork oak woodlands is related to the eventual destruction of nests of early breeders, such as some resident species, given that pruning in Portugal is legally allowed until the end of March. Therefore, we propose that, whenever possible, pruning should be carried out before the onset of the breeding season of all species (which corresponds to the end of February in southern Iberia).

In this context, it also would be relevant to evaluate the consequences of the loss of leaf biomass due to pruning, in light of the known generalized increase in crown defoliation that is occurring in southern European forests, including cork oak woodlands (Carnicer *et al.* 2011). First, the consequences of pruning can mimic those of the defoliation caused by the response of trees to increased water-stress, so it can help to predict the consequences of future changes in water availability on biodiversity; secondly, the consequences of pruning, both to the tree and bird communities, can be enhanced when it occurs simultaneously with climate change-related droughts.

Changes in land use in the Mediterranean are resulting in an increase in fragmented cork oak woodlands. Understanding the role of the different components of those landscapes, of either natural or anthropogenic origin, is extremely important for management compatible with conserving biodiversity. Results described in Chapters 4 and 5, reveal that the presence of both traditional olive grove and riparian gallery fragments exerts an overall positive effect on bird assemblages in cork oak woodlands, both in the vicinity of fragments, and at a landscape scale. Fruit availability in riparian galleries and olive groves seems to compensate for the reduced availability of fruit in *montados* (Tellería 2001). Recovery of the fruit-producing shrub layer in patches within the cork oak matrix can be an alternative management practice that could help to minimize this constraint.

Although fragments of olive groves seem to play an important role, in terms of the complementary provision of food resources, especially in winter, simulations of a possible increase in their density in the study area revealed that it could yield negative consequences for some bird species (Chapter 5). Therefore, the most balanced alternative seems to be to maintain the existing small fragments of traditional olive groves, avoiding their abandonment by farmers (Duarte *et al.* 2008). Conversely, simulations of management alternatives for riparian galleries showed that their recovery should have large positive effects on some species of birds in the breeding season. Consequently, the restoration of riparian vegetation along streams and drainage lines would be a welcome management measure. This could be obtained simply by stopping aggressive management practices like the elimination of riparian vegetation (Aguiar *et al.* 2000; Corbacho *et al.* 2003), or through the plantation of autochthonous riparian species. The establishment and recovery of riparian vegetation would provide important ecological services for birds and other organisms in *montados* (Matos *et al.* 2009) and in similar habitats of Mediterranean landscapes. It is also important to highlight that such recovery would claim a very small proportion of cork oak area, but would result in a substantial increase in the population of several bird species, some of which are presently among the least abundant in the region.

6.3. Major threats and conservation challenges

Cork oak woodlands face an uncertain future all over their range. They are subject not only to land use changes, driven by local conditions in North Africa and Europe and by European Union agricultural policies, but also to global climatic changes and market trends (Aronson *et al.* 2009).

Globally, the health and resilience of cork oak woodlands have decreased, and cork oak populations are aging because of the deficient natural regeneration, which affects many cork oak populations throughout the western Mediterranean (Acácio *et al.* 2007; Pausas *et al.* 2009a). It is therefore essential to understand and promote natural regeneration processes as part of an efficient conservation plan; however, very little detailed information is available on the regeneration cycles of the cork oak (Pons & Pausas 2006). Moreover, the susceptibility of cork oak to pests and diseases appears to have increased in recent decades, perhaps furthered by the effects of drought (Desprez-Loustau *et al.* 2006). Unfortunately, in many areas, restoration has not been sufficient to compensate for the ongoing loss of mature cork oak stands through disease, senescence and lack of regeneration (Branco & Ramos 2009; Pausas *et al.* 2009a).

Nevertheless, the major threat that cork oak woodlands face nowadays is most probably the decrease in the commercial value of cork. In fact, the economy of most managed cork oak woodlands is based mainly upon cork production, and the declining market share of cork bottle stoppers in the wine industry is an increasingly important issue. More than 70% of cork's market value comes from the production of cork stoppers (Pereira *et al.* 2008), which is under increasingly strong competition from plastic stoppers and screw caps. It is already known that the production of cork stoppers results in less solid waste, greenhouse gases and other forms of pollution than those alternatives (Natural Cork Quality Council 2009; Vallejo *et al.* 2009); but no study had evaluated the impacts of this production on biodiversity. Results from Chapter 2 contribute to understanding the ecological consequences of cork extraction, and prove that it does not significantly affect the rich diversity of birds in *montados*. It is, therefore, a profitable, biodiversity-friendly economic activity. Moreover, unless the commercial value of cork is maintained, there is the risk of conversion of *montados* to other uses (e.g., agriculture, urbanization) which can be much less valuable for biodiversity. The loss of the economic value of cork oak landscapes also can result in land abandonment, which could rapidly spread to vast areas of currently-managed woodlands (mainly in Iberia), increasing their vulnerability to fires (Berrahmouni *et al.* 2009). Abandoning agricultural and silvo-pastoral activities in some areas, and overly intensive use of land in others, could result in a potential disaster for cork oak woodlands (Vallejo *et al.* 2009). It is also important to consider that all these threats could be magnified by climate change, increasing *montados* vulnerability to disease, pests, and catastrophic events. Climate change can, for example, increase fire frequency in these ecosystems which, combined with the increase in shrubs and wood fuel caused by land abandonment, might have major impacts on those woodlands. Study of the potential impacts of climate change on the future of cork oak trees and cork oak biodiversity should be included in future research planning.

In summary, there is an urgent need to integrate sustainable economic development, biodiversity conservation and active restoration in cork oak woodlands. This requires collaboration among governments, the conservation community, land owners and managers, industries, communities and even consumers.

One important measure would be, not only to improve management of *montados* outside protected areas, but also to effectively implement Natura 2000 in areas covered by cork oak woodlands or even expand national protected areas. In Portugal, for example, only approximately 2.5% of the cork oak woodland area is included in national or natural parks (Santos & Thorne 2010) and 20.4% when considering Natura 2000 network (Berrahmouni *et al.* 2009). A more flexible conservation approach is needed integrating protection objectives as part of participatory planning processes and sustainable land uses within large territories (Berrahmouni *et al.* 2009). To establish adequate management proposals, it is important to carry out studies that analyse the consequences of management measures on larger scales that exceed private land boundaries. The simulated scenarios study (Chapter 5) is a contribution in that direction; but further research to generate additional data is needed. This is, for example, the case of studying the large-scale consequences of the control of groundcover (including understory clearing, grazing and cereal crops) for *montados* biodiversity.

Another important measure would be to promote and expand Forest Stewardship Council (FSC) certification for cork oak woodlands and products. The FSC is an international organization that promotes environmentally-appropriate, socially-beneficial, and economically-viable management of the world's forests (Auld *et al.* 2008). FSC certificate allows stakeholders and the general public to invest in sustainable cork oak woodlands and products, and provides financial incentives for the responsible management of *montados*. This can be really enhanced if the cork and wine industries, and the building sector, invest in the promotion of this certification.

Involving the public in the safeguarding of cork oak ecosystems could also be beneficial for their conservation. This may include both the promotion of certain already-popular cork oak commodities, like cork and black pig products (e.g., ham and meat), but also taking advantage of the cultural, recreational and ethical services provided by this landscapes (MA 2005). For example, *montados* have a high recreational value that can be used for sustainable ecotourism that values the biodiversity, local resources and environment in these unique landscapes. The involvement of local populations would also be beneficial in social and economic terms, by stimulating new productive activities while avoiding abandonment in favour of major cities.

Birds can have an important role in these activities since, besides being very abundant in cork oak woodlands, they may have a symbolic value for many audiences, from the public to decision-makers. Moreover, the development of recreational and tourism activities can contribute to the economic sustainability of *montados*, and reduce their dependence on the wine bottle stoppers market, a dependence that is a real threat to their survival. Key to the conservation, not only of *montados* but also of other oak woodlands, is creating a value chain based upon diverse and parallel economic activities that contribute to system's sustainability.

In summary, although cork oak woodlands are biodiversity-and economically-valuable landscapes, knowledge regarding the impacts of management measures to sustain such systems remains incomplete. This thesis has contributed to fill this gap of knowledge, by identifying the impacts of some of the main current practices. It is, therefore, a contribution to the definition of best management practices for the sustainable exploitation of both cork oak trees and woodlands. This can be important for the integrated management of private and public lands, especially in areas of cork oak that are included in Natura 2000 sites. These protected areas are expected to be managed with the ultimate aim of improving their conservation value.

Agro-environmental schemes have proven successful at reversing declines in farmland wildlife populations (Donald & Evans 2006), and may become necessary to implement if *montados* loses a substantial part of its economic value. They have the potential to function as a temporary solution to help maintain and restore the *montados*, providing that they offer incentives for management that are well grounded on scientific research. In doing so they can contribute to the future sustainability of *montados* and encourage people to preserve their lands and maintain this ecologically and socially valuable Mediterranean system.

Sustainable and profitable management measures are fundamental for the survival of this system that is, to a large extent, highly dependent on market changes. Although the management measures proposed here are of particular interest for the large regions of southern Portugal and Spain that are dominated by cork oak *montados*, some may also be applicable to the management of a few other systems with similar structure and management challenges.

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