18 mm 11.5mm 15 mm 62 mm 128 mm 5

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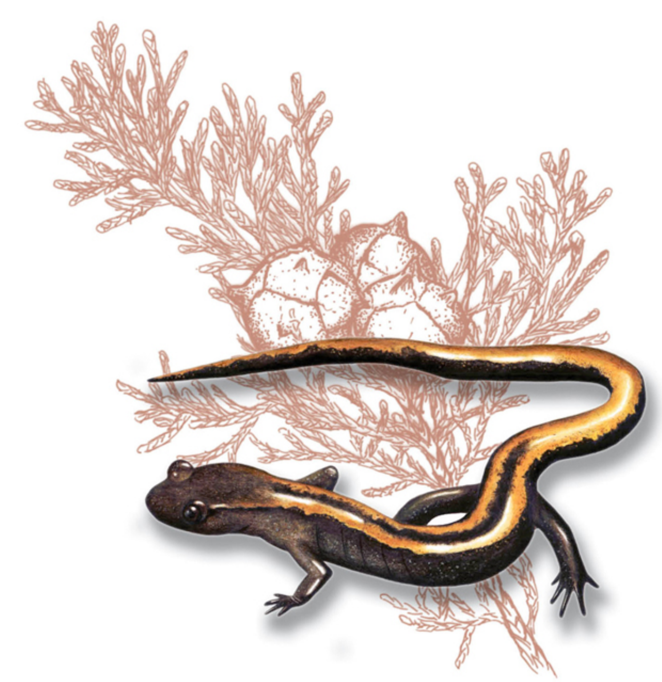
Universidade de Aveiro Departamento de Biologia
2011

Milena Marina Amaral dos Santos Matos

Diversidade de Vertebrados na Serra do Bussaco e áreas envolventes

Vertebrate diversity in the Bussaco Mountain and surrounding areas



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Vertebrate diversity in the Bussaco Mountain and surrounding areas

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do Prof. Doutor Carlos M. M. S. Fonseca, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro e co-orientação do Prof. Doutor Amadeu M. V. M. Soares, Professor Catedrático do Departamento de Biologia da Universidade de Aveiro.

Apoio financeiro da FCT e do FSE no âmbito do III Quadro Comunitário de Apoio (Bolsa de Doutoramento SFRH/BD/31146/2006).

À memória do meu Affonso...

Ao Bussaco, meu amor...

o júri

presidente

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agradecimentos

No man is an island. John Donne

Esta viagem começou num registo solitário mas felizmente avançou no sentido da partilha que a tornou concretizável.
Agradeço aos meus orientadores, Prof. Doutor Carlos Fonseca e Prof. Doutor Amadeu Soares, a oportunidade e a confiança depositada, que me permitiram levar a cabo um projecto tão ambicioso e organizá-lo de forma autónoma.
À FCT pelo suporte financeiro.
À AFN, nas pessoas do Eng.º Rui Rosmaninho e do Eng.º Álvaro Santos, pelo apoio no alojamento e em tudo que lhes foi solicitado.
À minha família, por quem decidi ficar por terras lusitanas. Não há dúvidas que foi uma decisão feliz! Mãe, obrigada pelo afecto e mimos, inesgotáveis mesmo nas minhas crises de mau feitio! Carla, minha ubelhinha linda, és tantas vezes a luz em momentos de noite cerrada… Nelson, agradeço o apoio, o diálogo, as opiniões, a constante aprendizagem. Agradeço por toda a paciência que tiveram e por sempre terem acreditado em mim. Aos meus avós Manuel "Cego" Amaral e Ana do Carmo Costa, sempre presentes, na esperança de que se sintam orgulhosos. *Só o amor…*
Aos meus amigos, sem os quais a senda teria sido bem mais penosa. Ana, com quem tanto cresci e aprendi. Nuno, porque sei que é sincero e por todos os momentos *Senhora do Monte*. Pedro, por tudo, que é tanto. Uma palavra especial e insuficiente à Joana e ao Toni, pela capacidade científica, compreensão, disponibilidade, amizade, incentivo e apoio pessoal e profissional. Devo-vos muito mais que o concretizar de um ansejo impossível. Aos "meus meninos" da música, Rui Pedro, Miguel, Joel e Jorge, pela compreensão, carinho e por todos os momentos numa realidade tão diferente. Ao Pascoal, pela enorme ajuda no trabalho de campo e por me ter tratado do *rafeiro* sempre que necessário. Ao Manelito, pela paciência e apoio numa fase que foi tão difícil. Ao Daniel Afinador, pelas larachas humorísticas. Ao Emanuel, Anabela, Eduardo, Nuno Negrões, Celso Massa, Zizinho, Nelson Puto, Alex, Inês, D. Manuela e Sr. Júlio, Zé António, Abílio, Rosinha, Lísia e Sandra Martins, pelo carinho e incentivo.
Ao Mário Snufi, pelos ratinxus, pinheiros trágicos e por me ter acordado.
À *lata*, por nunca ter falhado! Aos residentes da área de estudo, por me terem permitido aceder aos seus terrenos sem concretizar iniciais maus augúrios.
Deixo um sincero e humilde agradecimento a todas as pessoas que de algum modo me ajudaram ao longo destes anos, tornando um pouco mais alegre ou mais fácil esta longa jornada.
Ao José Saramago e ao Jorge Palma, pelos seus legados, pela companhia.
Agradeço ao meu pai por me ter mostrado o caminho. Ter seguido o oposto fez de mim tudo o que sou.

palavras-chave

Vertebrados, Bussaco, diversidade, uso de *habitat*, conservação

resumo

A biodiversidade é fundamental para o funcionamento dos ecossistemas e, além do seu valor intrínseco, fornece bens e serviços essenciais ao Homem. É consensual que as reservas naturais, por si só, não conseguirão preservar a biodiversidade de modo a que seja travada a perda de espécies que vem acontecendo a ritmos sem precedente. Assim, compreender os padrões de distribuição das espécies à escala regional ou sub-regional, ainda que em territórios não classificados, é crucial para o estabelecimento de políticas de gestão que visem a conservação da biodiversidade. O principal objectivo deste trabalho centrou-se na descrição e compreensão dos padrões de riqueza específica, distribuição e abundância de Vertebrados face aos diversos *habitats* que constituem a área de estudo. Constituíram, assim, objecto de estudo os anfíbios, aves, morcegos, micromamíferos e mamíferos de médio porte.

A Serra do Bussaco e áreas envolventes encontram-se dominadas por vastas extensões de monocultura de *Pinus pinaster* e *Eucalyptus globulus* e por terrenos agrícolas. A Mata Nacional do Bussaco, bosque extremamente diverso, é outro importante elemento de paisagem. Pretendeu-se então analisar o efeito das práticas silvícolas actuais e da intensificação da agricultura sobre a biodiversidade, averiguando a importância de cada tipo de *habitat* para os Vertebrados em geral, e para algumas classes em particular. De entre os terrenos agrícolas, é bastante claro que a agricultura tradicional, com a sua típica complexidade e disponibilidade de água, constitui um *habitat* muito importante para a maioria dos Vertebrados, tendo também apresentado o maior valor conservacionista. No que respeita aos *habitats* florestais, o bosque misto apresentou consistentemente maior riqueza específica e diversidade, afirmando-se como o *habitat* preferido para a maioria das espécies e aquele com maior valor conservacionista. Do ponto de vista da conservação, as monoculturas, especialmente as da uma espécie exótica, revelaram-se *habitats* relativamente pobres. No entanto, estas conclusões referem-se às tendências gerais, sendo que *taxa* particulares respondem de forma diferente, atendendo aos seus requisitos específicos. A informação recolhida fornece bases essenciais para a construção de linhas de orientação que visem a integração das actividades humanas com a manutenção da biodiversidade e respectivos serviços, presumivelmente com aplicação a outras áreas geográficas.

keywords

Vertebrates, Bussaco, diversity, habitat use, conservation

abstract

Biodiversity is fundamental to ecosystem functioning and, in addition to its intrinsic value, assures essential goods and services to mankind. It is generally accepted that reserves alone will not be able to effectively preserve biodiversity in order to halt the species loss that has occurring, at unprecedented rates. Thus, understanding distributional patterns of species occurrence and richness at regional or landscape scale, even in unreserved territories, is essential to design effective management policies for biodiversity conservation. The main objective of this thesis was to describe and understand patterns of vertebrate species richness, distribution and abundance among the differently human-altered habitats that constitute the study area. Thus, amphibians, birds, bats, small and medium-sized mammals were sampled.

The Bussaco Mountain and its surrounding areas are dominated by large extensions of monocultures of *Pinus pinaster* and *Eucalyptus globulus* and agricultural lands. Bussaco National Forest, extremely diverse woodland, also integrates the landscape. It was intended to investigate the effect of current forestry practices and of agriculture intensification on biodiversity, by assessing the importance of each habitat type to Vertebrates in general and to some groups in particular. Among agricultural lands, it is clear that traditional agriculture, with available water sites and its typical complexity, is of great importance to most of the vertebrate fauna, having presented the highest conservationist value. With respect to forest habitats, the mixed forest consistently presented higher species richness and diversity, proving to be the preferred habitat for the majority of species and the woodland with greatest conservationist interest. From a conservationist point of view, monocultures, especially of exotic species, revealed to be habitats of relatively poor value. Notwithstanding, these general conclusions report to main trends, being that particular *taxa* may present different individual responses, according to specific requirements and life-history traits. The gathered knowledge provides the essential foundation on which to draw conservation guidelines, focusing on the integration of human activities and the maintenance of biodiversity and respective services.

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Adorai, montanhas,
o Deus das alturas,
também das verduras.

Adorai, desertos
e serras floridas,
o Deus dos secretos,
o Senhor das vidas.
Ribeiras crescidas,
louvai nas alturas
Deus das criaturas.

Louvai, arvoredos
de fruto prezado,
digam os penedos:
Deus seja louvado!
E louve meu gado,
nestas verduras,
o Deus das alturas.

Gil Vicente

Chapter 1

General introduction

1. GENERAL INTRODUCTION

Biodiversity, defined by the Convention on Biological Diversity as *the variability among living organisms from all sources including,* inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems* (Secretariat of the Convention on Biological Diversity, 2005), is fundamental to ecosystem functioning and, in addition to its inherent value, assures essential goods and services to mankind. 'Goods' include food, material for industry, pharmaceutical products, tourism and recreation, and wild genes for domestic animal and plant species. Provisioning of food and fresh water, soil conservation, pests and diseases control, nutrient cycling, climate stability and general well-being constitute a few examples of 'services' that maintain the conditions for life on Earth. Thus, in a nutshell, the loss of biological diversity threatens the very existence of life as it is currently understood.

Furthermore, there are additional important reasons to mind about the loss of biodiversity, apart from nature's immediate usefulness to humankind. As a species sharing space and natural resources with others, man should not forget that every living being has an intrinsic right to exist, and deserves protection. The right of future generations to inherit, as we have, a planet thriving with life, and that continues to provide opportunities to garner the environmental, economic, cultural and spiritual benefits of nature must also be recognized (Secretariat of the Convention on Biological Diversity, 2006).

However, in spite of constituting the living foundation for sustainable development and our "moral obligation" towards nature preservation, biodiversity is being lost at an unprecedented rate, mainly as a consequence of human activities (e.g. Sala et al., 2000; Western and Pearl, 1989; Wilson, 1988). Hence, the halt of biodiversity loss reasonably constitutes a major environmental issue worldwide and one of the greatest challenges of the modern era.

The growth of human global population has led to the increasing necessity of resources such as food, water, land, medicines, fuel and timber, ultimately resulting in overexploitation, and causing direct effect on biodiversity. But besides this fact, the escalating resource demands of humans and the development of the respective settlements and industrial activities inevitably conduce to land transformation and natural habitat deterioration. As human activities have expanded, patches of natural habitat were lost by conversion or became smaller and more fragmented. For instance, about 80% of the deforestation happening worldwide is due to the conversion of forests to agricultural lands (Pimentel et al., 1986). In the last three centuries, global forest area has been reduced in about 40%. Although forest cover in Europe and North America is currently augmenting, following drastic reductions in the past (Millenium Ecosystem Assessment, 2005), deforestation of natural areas, mainly in the tropics, continues at an alarmingly high rate – some 13 million hectares per year (FAO, 2005). The growth of human population results in the continued need of huge amounts of new agricultural fields, with the parallel effects of the increasing construction of industrial and transportation infrastructures, artificial irrigation systems, use of chemical pesticides and fertilizers, eutrophication of ecosystems, among others (Tilman et al., 2001). Human activities' expansion is such that it is estimated that approximately 40% of Earth's terrestrial area is devoted to agriculture (Foley et al., 2005) and only about 36% of total forest area is classified as primary forest, i.e. forest of native species where ecological processes are not significantly disturbed (FAO, 2005). Western and Pearl (1989) estimated that only 5% of global land remains unmanaged or uninhabited, since that even extensive deserts have a few people with domesticated animals and tropical rainforests also have people inhabitating them.

As a result of the aforementioned matters, anthropogenic pressures such as land-use change and habitat loss or fragmentation are globally amongst the most important drivers of biodiversity loss (e.g. Chapin III et al., 2000; Debinski and Holt, 2000; Fischer and Lindenmayer, 2007; Groom et al., 2006; Groombridge, 1992; Hunter and Gibbs, 2007; van Vuuren et al., 2006; Wilcove et al., 2000).

In the recent past, the global rising of environmental conscience and awareness has triggered undeniable efforts to protect nature and curb the loss of biodiversity. Examples of these actions are the wide-reaching progress of environmental education, research enhancement, the global promotion of protected areas and improvement of their management effectiveness (Secretariat of the Convention on Biological Diversity, 2010) and the implementation of environmental laws, strategies and action plans at different scales: local (e.g. Local Agenda 21), national (e.g. Endangered Species Act – United States of America; *Estratégia Nacional de Desenvolvimento Sustentável* (ENDS) – Portugal; National Biodiversity Conservation Strategy – many countries across the world); international (e.g. Natura 21 network) and global (e.g. The 2010 Biodiversity Target – Parties to the Convention on Biological Diversity). It has also been stated that the achievement of important biodiversity conservation targets is not necessarily inconsistent with societies' progress, productivity or economical developments (e.g. Carlén et al., 1999; Earthwatch, 2002; Edwards and Abivardi, 1998; Polasky et al., 2008). Still, all the endeavors to stop biodiversity loss have not kept pace with the growing encroachment of human activities (Secretariat of the Convention on Biological Diversity, 2010; Pimentel et al., 1992; Verboom et al., 2007) and further action must be taken.

To date, the prime focus of biological conservation has been on a system of protected areas, which in theory would adequately protect biodiversity (Margules and Pressey, 2000; Sarkar et al., 2006) by providing quality habitat for all species, in a sort of modern day Noah's Ark. Protected areas have been expanded in number and extent (Secretariat of the Convention on Biological Diversity, 2010), but even so, only about 12% of all terrestrial land is covered with protected areas, and less than half of these are explicitly designated for the protection of biodiversity (Hoekstra et al., 2005), including ecosystems, biological assemblages, species and populations. Although protected areas constitute a fundamental part of any pertinent conservation strategy (Margules and Pressey, 2000) it is becoming patent that natural reserves alone will not be able to effectively protect biodiversity (Araújo et al., 2011; Fischer et al., 2006; Franklin, 1993; Lindenmayer et al., 2006). Reserves are too insufficient, too isolated, too static, and often are not able to protect biodiversity from the processes that threaten their existence in the wild, such as overexploitation, jeopardizing the long-term survival and viability of the species and other elements of biodiversity they should preserve. Moreover, natural reserves not always represent the full variety of regional biodiversity, at all organizational levels (Araújo et al., 2007; Bengtsson et al., 2003; Margules and Pressey, 2000; Rodrigues et al., 2004).

Some reserves have been established on wild and aesthetically pleasing landscapes (Franklin, 1993), on their historical value or opportunistically because the land has not been in high demand for human use, rather than for its biological significance (Pressey, 1994; Scott et al., 2001). Similarly, some conservation programmes or funding efforts have focused on charismatic species, such as colorful butterflies or magnificent large mammals. It is important to understand that anthropocentric notions of aesthetics or value should not dictate strategies for biodiversity conservation. Again, most of conservation campaigns only target rare or endangered species, which is incontestably relevant, provided the importance of all other species is not overlooked. All organisms, even the smallest or commonest, contribute to ecosystems' functioning and stability (Pimentel et al., 1992), sometimes in ways that are scarcely understood (Wilson, 1987). In fact, some authors have argued that widespread, abundant species may be the most ecologically and economically important, not only because of their ecological impact, but also because of the research opportunities they may present (e.g. Bevill and Louda, 1999; Pierson, 1998).

Successful conservation requires taking biodiversity into account in its vast conceptual extent. It implies an integrated strategy that complements the conservation within protected areas and of threatened species by conservation outside protected areas (Daily, 2001; Lindenmayer and Franklin, 2002; Pienkowski et al., 1996). Thus, comprehensive conservation efforts must be expanded to the "unreserved matrix" of ecosystems, which includes commodity production landscapes, like agriculture and commercial forests.

Nowadays, production industries such as agriculture and forestry represent the dominant human land uses (Morris, 1995). As previously stated, these industries have been the leading promoters of wide-reaching landscape modifications (Millenium Ecosystem Assessment, 2005) and depend on a range of vital ecosystem services, such as nutrient cycling, healthy soils, fresh water, waste decomposition, seed dispersal, pest control, pollination, among others. These services are provided by biodiversity, from genes to ecological processes, therefore, maintaining or promoting a diversity of functionally equivalent species in production ecosystems brings an array of pivotal aspects, besides conservation *per se*. For instance, in case of disturbance, such as a drought or a disease, ecological equivalence allows functional compensation by members of the community that where less affected. Though, diversity enhances the resilience of ecosystem (Walker, 1995), contributing to the desirable ecosystem states after change (Elmqvist et al., 2003). Resistance and resilience lead to more stable ecosystems (Bengtsson et al., 2000). Also, complementary patterns of species resource use, only possible with diversity, result in ecosystem higher productivity (Kanowski et al., 2005; Sala, 2001). Further, the response diversity of functionally equivalent species to human perturbation, insures the system against management mistakes, allowing managers to learn and adapt their managing policies (Elmqvist et al., 2003). Summarizing, maintaining biodiversity in production landscapes may provide an economically profitable synergy between conservation and production (Polasky et al., 2008; Ricketts et al., 2004).

Conservation programmes based on ecological principles may, then, help agriculture and forestry to be more sustainable, while at the same time maintaining biodiversity. However, they must be based on research and reasonable knowledge and be part of an integrated strategy to be applied consciously. Understanding the multifaceted relationship between biodiversity and land-use is a key to conservation policy.

In the Iberian Peninsula, as in Europe, a long history of human land-use changes has deeply modified natural vegetation (Amo et al., 2007). For instance, the landscape of Central Portugal was once covered with vast extensions of mixed woodland, dominated by oak species *Quercus* spp. (Bingre and Damasceno, 2007; Ramil-Rego et al., 1998). With human occupancy, 7-8 thousand years ago, native forest was being eroded and a vast majority of the landscape was converted to agriculture (Paiva, 1998). The remaining forests were gradually replaced by faster growing and economically profitable species (Vieira et al., 2000). Currently, the greater part of forested areas (more than 78%) is composed of maritime pine *Pinus pinaster* Ait. and *Eucalyptus globulus* Labill. (CNIG, 1995; DGRF, 2007).

The maritime pine is an autochthonous species (Figueiral, 1995) with great tradition in Portuguese timber industry. During the beginning of the 20th century, it was intensively planted and consequently experienced a great expansion in all the country. However, its area of occurrence is diminishing since the 1980's mainly due to forest fires (Mendes, 2007). At present, *Pinus pinaster* is facing another severe threat that has triggered massive harvesting actions in several parts of the country: contamination with the *Bursaphelenchus xylophilus* nematode (Mota et al., 1999).

Eucalyptus globulus is an Australian species that was introduced in Portugal in the 1850's decade. Though, a great expansion happened since the middle of the 20th century (Radich, 2007) and nowadays it can be found in the entire country (DGRF, 2007). This species is mainly planted in vast monocultural even-aged stands that are mostly exploited for paper industry. In general, harvesting happens each eight or ten years, through clear-cutting procedures (Valente et al., 1997).

Plantation forests are widely connoted as causing negative effects on a wide range of taxa (e.g. Carnus et al., 2006; Faria et al., 2007; Hartley, 2002; Hobbs et al., 2002; Lindenmayer et al., 2003; Norris et al., 2010; Stephens and Wagner, 2007), especially in the case of even-aged exotic monocultures such as eucalyptus in Portugal (CESIE, 1989; Proença et al., 2010; Silva et al., 2007; Zahn et al., 2009). In relation to natural forests, commercial monocultures reduce habitat structural complexity, floristic variety and, therefore, niche diversity and resource availability (Díaz, 2006; Lindenmayer et al., 2003), reducing overall biodiversity. Vast extensions of monocultural stands also preclude landscape heterogeneity, which is acknowledged to boost species diversity (Atauri and de Lucio, 2001; MacArthur and MacArthur, 1961; Moreno-Rueda and Pizarro, 2007; Tews et al., 2004). Nonetheless, as reviewed by and Carnus et al. (2006) and Stephens and Wagner (2007) a few studies found that biodiversity was marginally different or even higher in forest plantations, in comparison with natural or native forest. Furthermore, caution must be taken when generalizing the negative impact of plantation forests, as that when compared with other intensive industrial land uses such as annual crop agriculture or human developments (Moore and Allen, 1999) or with degraded or cleared fields, the former can even be favorable, in terms of biodiversity (Borsboom et al., 2002; Klomp and Grabham, 2002; Stephens and Wagner, 2007). The role of plantation forests in biodiversity, at a regional level, also depends on its spatial location within the landscape. Some authors argue that plantation forests may benefit landscapes, by, for instance, enlarging forest habitat for some species, when located adjacent to indigenous forest remnants (Carnus et al., 2006), increasing connectivity among forest fragments (Norton, 1998) or facilitating land rehabilitation, promoting early stages of successions (Lugo, 1997). In the face of these arguments, it becomes clear that generalizations of the effect of production forests in ecosystems may be misleading. Thus, management plans and conservation strategies must be structured in a case to case basis.

With respect to agriculture, it is known that activities such as tillage, drainage, intercropping, planting, rotation, grazing and extensive usage of pesticides and fertilizers have significant implications for wild species of flora and fauna (McLaughlin and Mineau, 1995). Obviously, the effects of such farming activities depend largely on the way and intensity they are carried out. For instance, the traditional, low-intensity agricultural systems of temperate regions have been defined as “High Nature Value farming” (Baldock, 1998; Pienkowski, 1998), since they are generally well integrated with the environment and involve management practices that do not over-exploit the natural carrying capacity of the land. However, the growing demand for high productivity that happened since World War II, has triggered dramatic changes in farmlands of many European countries, as a result of agricultural intensification (Bignal and McCracken, 2000). Farmland management to increase yields has had severe negative effects on the environment, derived from the significant use of chemicals (synthetic fertilizers, biocides), mechanization, monoculture, as well as from the structural changes such as the disappearance of hedgerows, woodland patches, ponds and other landscape features related to traditional farming (e.g. Ewald and Aebischer, 2000; McLaughlin and Mineau, 1995; Robinson and Sutherland, 2002). Thus, arable intensification and subsequent landscape simplification has been associated with the impoverishment of plant and animal communities within farmlands, with the consequent disruption of food chains and declines in many farmland species (Stoate et al., 2001). The impacts of agricultural intensification have received a good deal of attention at both species and community levels (e.g. Bilenca et al., 2007; Burel et al., 2004; Donald et al., 2006; Herzon, 2008; Newton, 1998; Robinson and Sutherland, 2002; Smith et al., 2005; Stoate et al., 2009; Stoate et al., 2001; Wickramasinghe et al., 2004), however, there is still a pressing need for detailed information to justify the importance of preserving traditional farming systems (Bignal and McCracken, 2000).

In Central Portugal, vast areas remain eminently rural and agriculture plays an important role in regional economy (Direcção-Geral da Agricultura, 2003). Primary sector activities, where agriculture is included, employ about 23% of the region's workforce (INE, 2010a). However, the number of people working on agriculture is diminishing, as a result of the main trends that are happening in both Portugal and Europe: agriculture's modernization and land abandonment. On the one hand, the farming that persists is becoming more mechanical and the mean area per farmland is increasing, on the other hand, traditional tillage is being abandoned, arable lands are diminishing and consequently, the proportion of fallow land and pastures is expanding (INE, 2010b; Russo, 2007).

In order to design effective conservation strategies, the effects of current land uses on biodiversity must be correctly understood. The knowledge of biodiversity patterns at regional or landscape scale provides the essential foundation on which to build more refined assessments of ecological processes, what highlights the importance of monitoring at a landscape or ecosystem level. But, of course, as the term "biodiversity" refers to the entire range of life expressions, it is theoretically and practically impossible to assess it as a whole with a simple indicator (Lawton et al., 1998), even at a small scale. There is no perfect surrogate for biodiversity, because organisms respond differently to environmental features or changes depending on their taxonomic group (e.g. Atauri and de Lucio, 2001; Burel et al., 1998; Moreno-Rueda and Pizarro, 2007; Sauvajot et al., 1998; Stephens and Wagner, 2007). Each aspect of biodiversity requires its own indicator (Duelli and Obrist, 2003). For instance, monitoring changes in habitats resulting from human activities requires a wide range of taxa to be studied, entailing species with different ecologies and life histories (Lawton et al., 1998).

Taking all the aforementioned into consideration, this research focused on the relationships between biological diversity and differently human-altered habitats, within a rural and typically fragmented landscape of Central Portugal: the Bussaco Mountain and surrounding areas.

In order to avoid terminology and conceptual confusion, it is important to clarify that in this dissertation, the term "habitat" is used in its structural sense (Gaillard et al., 2010). Following Hutto (1985), a habitat will be defined as *a spatially contiguous vegetation type that appears more or less homogeneous throughout and is physiognomically distinctive from other such types*.

Biodiversity was assessed through a multi-taxa approach, which, in relation to a single species or taxon study, can provide a more comprehensive appraisal of the ecosystem’s reality and the opportunity to examine concordance in patterns of response among taxa. Given that the study area locates at the limit of the Mediterranean Basin, which constitutes one of the world’s biodiversity hotspots (Myers et al., 2000) and presents considerable landcover heterogeneity, which also contributes to plant and animal diversity (e.g. Atauri and de Lucio, 2001), it was intended to investigate the ecosystem as a whole, at the Vertebrates level. Accordingly, several terrestrial Vertebrate groups were evaluated: amphibians, birds, bats, small mammals and carnivores. All these assemblages present specific ecological features and conservation value that justify their study both *per se* or in the community context.

Iberian herpetological communities encompass species with very different natural histories and evolutionary pathways (Loureiro et al., 2010), being considerably rich in both diversity and conservationist value. Among the amphibians that are listed in Portugal, several endemic and protected species occur. Amphibians play a pivotal role in ecosystem, namely as secondary consumers and as preys in many food chains, as pest controllers or as intervenients in nutrient cycling. Due to their ecological importance, decline or extinction of their populations have significant impact on other organisms along with them. Since amphibians are, in general, sensible organisms, they are regarded as good ecological indicators (e.g. Welsh Jr and Ollivier, 1998), responding even to slight changes in the environment.

Bird conservation represents a cornerstone for biodiversity conservation in general, as birds constitute valuable indicators of ecosystem’s health (e.g. Gregory et al., 2003; Robledano et al., 2010). Their ecological importance is stated by their ability to spread seeds, pollinate plants, control insect or rodent plagues, indicate land use or climate alterations, etc. Migrating birds allow several geographical and ecological studies and also, the attractiveness that birds present to the general public permits to foment environmental education and fundraising. Due to the geographical location of mainland Portugal, among several migratory routes, to the climatic conditions and to the landscape diversity held by the country, the occurring bird communities are very diverse and encompass birds with very different life histories and conservation statutes.

Mammals include a vast diversity of organisms, with markedly different habits, morphologies, biological functioning and habitat preferences. Thus, mammals may occupy very different positions in food chains, explore extremely diversified ecological niches and very differently contribute to ecosystems’ functioning. As a result, different groups of mammals also respond in different ways to environmental change or perturbation. In Portugal, the occurring terrestrial mammals include wild species belonging to six orders (Insectivora, Chiroptera, Rodentia, Carnivora, Lagomorpha and Artiodactila), each presenting particular ecological features and conservation requirements.

1.1. Objectives

The main objective of this thesis was to describe and understand patterns of vertebrate species richness, distribution and abundance among the differently human-altered habitats comprised in the study area and with the obtained data determine the conservation value of each habitat type. This basic knowledge of biodiversity patterns provides the essential foundation on which to draw conservation guidelines, focusing on the integration of human activities and the maintenance of biodiversity and respective services.

The Bussaco Mountain and its surrounding areas constitute a profoundly human-altered heterogeneous landscape. It was intended to investigate the importance of each habitat type to vertebrates in general, and to some particular groups. More specifically, we aimed to assess the effects of current forestry practices and agriculture intensification on the following taxa: amphibians, birds, bats, small mammals and carnivores.

Thus, it was meant to compare vertebrate's habitat use, species richness and diversity between three forest types (exotic monoculture of *Eucalyptus globulus*, native monoculture of *Pinus pinaster* and an old-growth mixed forest) and two types of farmlands (large agricultural fields with intensification tendency and small patches of traditional agriculture).

We aimed to analyze the responses of the various sampled groups to different land use, in order to better understand the whole ecological dynamics of local biodiversity and more comprehensively establish conservation priorities.

Besides, whereas some vertebrate groups are generally well studied, others, such as bats and amphibians, remain with considerable lack of knowledge. Hence, this study may contribute, at least at regional extent, to somehow fulfill that gap.

With this research it was also projected to elucidate the importance of Bussaco National Forest, as a case study of generally unprotected areas, for biodiversity conservation.

Based on all the gathered knowledge, it is intended to infer about the role of habitat fragmentation and the adequacy of current main land uses in biodiversity conservation. Further, discuss and propose some land-use management measures and conservation actions that should improve or protect vertebrate fauna, conceivably with application in other geographical areas.

1.2. Thesis structure

This thesis is organized in seven main chapters. The first chapter presents a general introduction about the theme and aims of the thesis. The second chapter describes several aspects of the study area. Research questions are presented in the four following chapters (Chapters 3 to 6) in the format of scientific articles. These papers are intended to be independent and mutually exclusive, thus some repetition may occur. The main findings of the research are summarized and generally discussed in the final chapter.

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Escuta o salpicado riso dos pássaros.
A vida denunciada em chilreios descompassados.

Bussaco, murmúrio surdo, um cântico ao ócio.
E eu estou contigo, voz silenciosa, voz serena.
Sou uma pequena folha na felicidade do ar.
Dormes desperto, deslumbre que não se insinua.
É aqui, e é aqui, neste jardim, que se renova a luz...

Suzanna Matos

Chapter 2

Study area

2. STUDY AREA

2.1. Location

The study area encompasses 25 000ha and locates in “Beira Litoral”, a province in Central Portugal, between latitudes 40°17’ and 40°27’N and longitudinally between 8°17’ and 8°27’W (Fig. 2.1). It comprises territories of three districts (Aveiro, Viseu and Mealhada) and five municipalities (Anadia, Mealhada, Mortágua, Penacova and Coimbra). The largest locality in the study area is the city of Mealhada, with around 4000 inhabitants (Soares, 2004). At the centre of the area locates Bussaco National Forest.

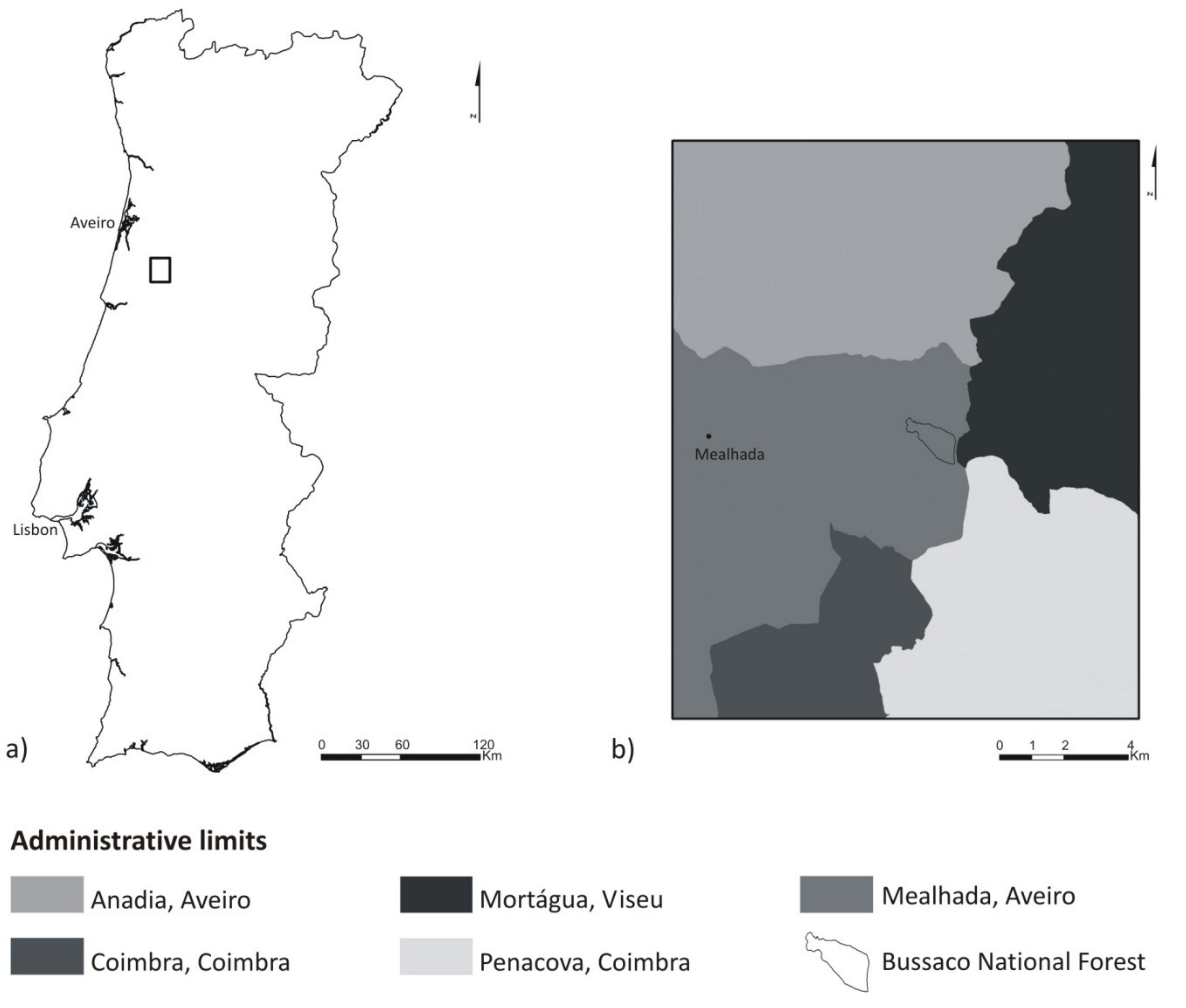

Fig. 2.1. a) Location of the study area in mainland Portugal. b) Limits of municipalities in the study area. Adapted from “Atlas do Ambiente Digital” (Instituto do Ambiente, 2007).

2.2. Land cover

In the past, this region was covered with mixed forests dominated by oak species (*Quercus* spp.) (Bingre and Damasceno, 2007; Ramil-Rego et al., 1998). A long history of human occupation profoundly altered the landscape and, nowadays, it is mainly composed of cultivated lands and monoculture plantations (Table 2.1). In Central Portugal, the former occupy approximately 27% of the total area and the latter constitute more than 78% of the forested areas (CNIG, 1995; DGRF, 2007). In the study area, agriculture occupies roughly 29% of the area and monoculture plantations around 62% (eucalyptus 40% and *Pinus pinaster* 22%, approximately).

Table 2.1. Area and percentage of each land cover class in the study area and in Central Portugal.

	Study area		Central Portugal
Land cover class	**Area (ha)**	**Percentage**	**Percentage**
Agriculture	7406.12	28.68%	27.16%
Eucalyptus	10423.38	40.36%	12.26%
Deciduous trees	275.77	1.07%	4.42%
Shrub	651.10	2.52%	31.74%
Resinous trees	5602.67	21.70%	19.70%
Urban	1359.89	5.27%	4.73%
Bussaco Forest	104.06	0.40%	
TOTAL	25822.98	100.00%	100.00%

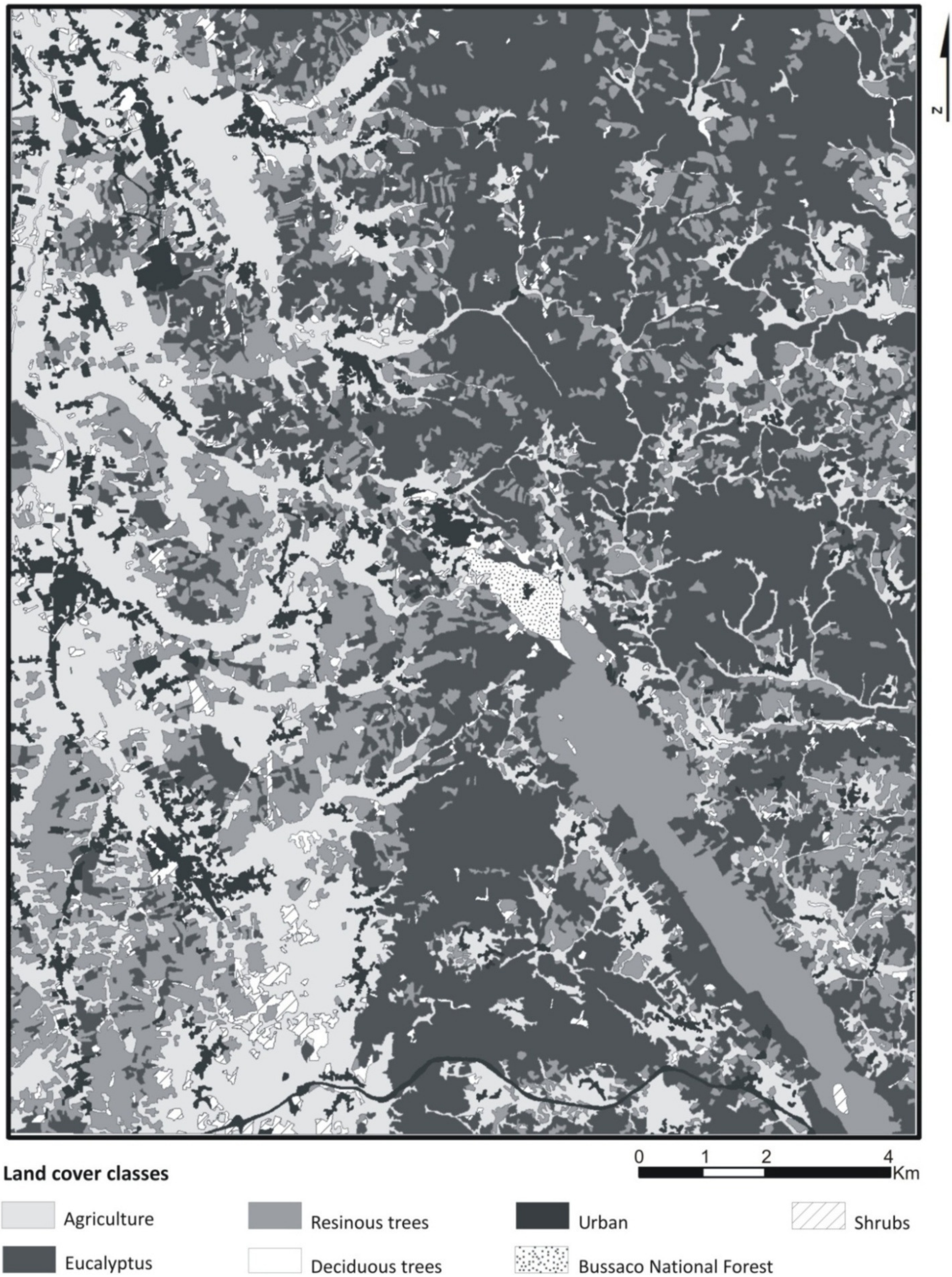

Fig. 2.2. Land cover in the study area. Adapted from "COS'90" (CNIG, 1995).

The study area includes “Serra do Bussaco”, a mountain with a general NW-SE orientation, which constitutes the most relevant relief element of the landscape. The highest point situates at “Cruz Alta” (547 m.a.s.l., 40°22’13’’N, 8°21’59’’W), at the northwestern far side of the mountain and at the centre of the study area. Serra do Bussaco includes Bussaco National Forest (see respective section) and presents a large extension of *Pinus pinaster* mostly planted in the first half of the 20th century (Morais, 2002). The remaining middle and low-raised relief terrains in the study area are, in general, covered with *Eucalyptus globulus* plantations, mostly planted since the second half of the last century (Radich, 2007). These lands belong to private owners that plant even-aged eucalyptus stands for the paper production industry, clear-cutting them totally when the desired size is achieved (approximately 8 years).

The lower lands, which in general locate in the western part of the study area, comprise the major part of urbanized and agricultural territories. Urban areas occupy about 5.3% of the study area.

Two types of agriculture can be considered in this region: one, traditional, hand-ploughed, cultivated in small patches of produce gardens for domestic consumption; and a second, more intensive, machine-labored, producing for commercial purposes. In both cases, the main cultivated items are corn *Zea mays* L., bean, such as *Phaseolus* spp., grape *Vitis vinifera* L., mostly for wine production, olive *Olea europea* L., potato *Solanum tuberosum* L., fruits (apple *Malus* spp. and *Citrus* spp., for example) and several vegetables such as cabbage *Brassica oleracea* L., lettuce *Lactuca sativa* L. and tomato *Lycopersicum esculentum* Mill..

Agricultural fields are usually located near water streams, which in the area are small or medium-sized (maximum about 4m wide).

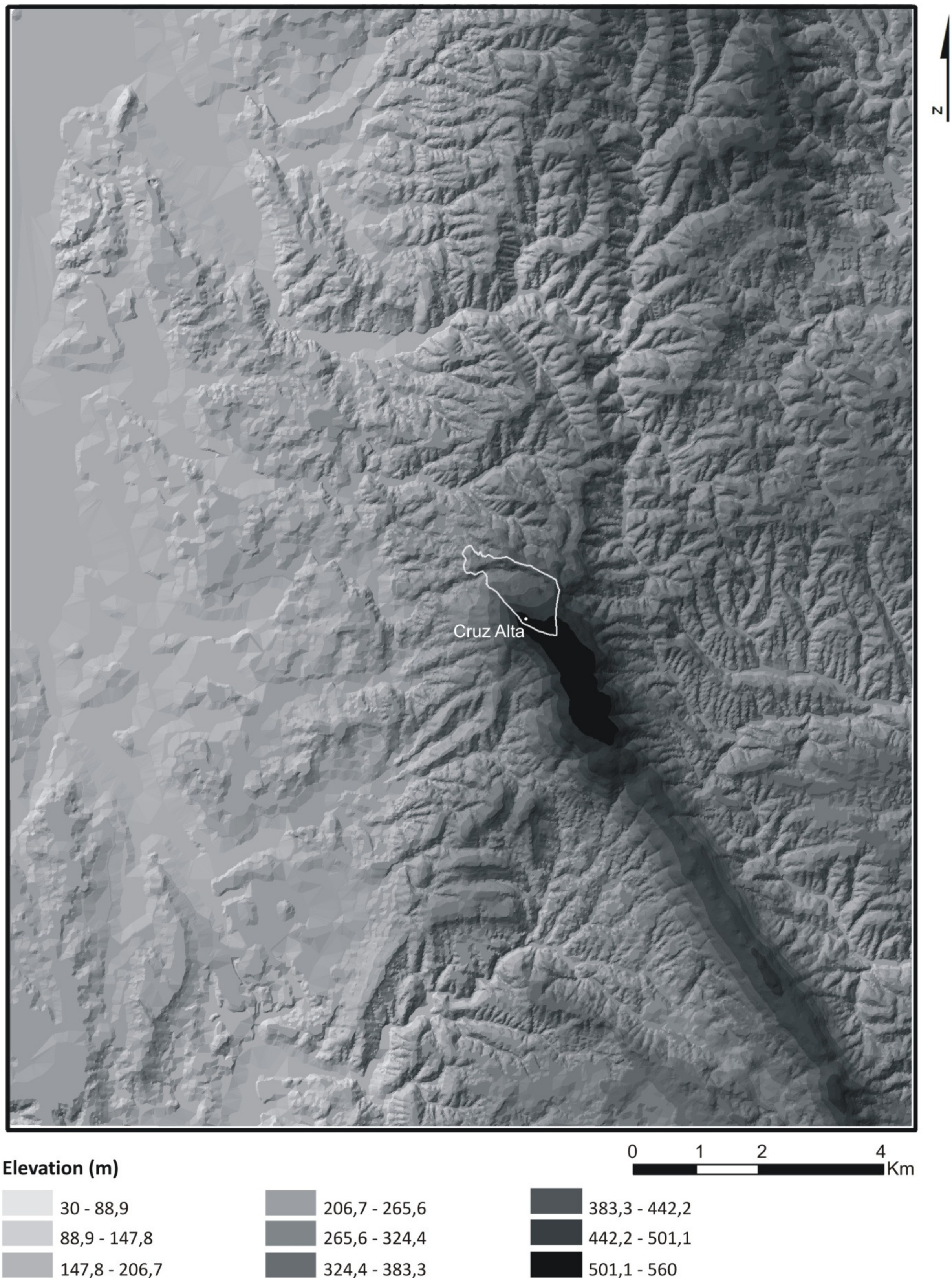

Fig. 2.3. Relief map of the study area. Adapted from "Atlas do Ambiente Digital" (Instituto do Ambiente, 2007).

2.3. Bussaco National Forest

At the center of the study area lays Bussaco National Forest, at the northwestern far side of Serra do Bussaco (approximately between 40° 22’ 15’’N, 40° 23’ 01’’N and 8° 21’ 26’’W, 8° 22’ 30’’W). The altitude ranges between 190m at “Porta das Ameias” and 547m at “Cruz Alta".

Bussaco is a wall fenced old-growth forest with roughly 105 ha and constitutes an exclusive natural heritage, representing one of the best dendrological collections in Europe (Paiva, 2004). It started being planted with exotic species mostly in the 17th century, by friars of the Discalced Carmelites order, who owned the land at the time. The friars introduced several exotic species, such as the Mexican cypress *Cupressus lusitanica* Miller, which is nowadays the most abundant tree in Bussaco. Another substantial amount of exotic tree species, from the entire globe, was planted after 1856, under state administration (Paiva, 1992). Pinho et al. (2009) have recently been studying Bussaco’s flora and vegetation and pointed out the great botanical diversity of this forest, totalizing 257 tree and shrub species, organized in four major botanical ensembles:

- The arboretum, which occupies around 80% of the Forest area, presenting exceptional tree diversity and dozens of “remarkable specimens”, which classification was based on their size, age, national rarity or singularity. *Cupressus lusitanica* Mill., *Quercus robur* L., *Q. pyrenaica* Willd., *Q. suber* L., *Laurus nobilis* L., *Phillyrea latifolia* L., *Prunus laurocerasus* L., *Abies alba* Mill., *Acer pseudoplatanus* L., *Fraxinus americana* L., *Pinus radiata* D. Don, *Cedrus atlantica* (Endl.) G. Manetti ex Carrière, *Pseudotsuga menziesii* (Mirbel) Franco, *Araucaria bidwillii* Hook., *Ulmus minor* Mill., *Castanea sativa* Mill., *Sequoia sempervirens* (D.Don) Endl. or *Eucalyptus regnans* F.Muell are only a few examples of trees present in Bussaco.

- Climax vegetation of Cruz Alta, locating at the highest part of the Forest (and of the study area), representing a remnant of local native vegetation from before human occupancy (Santos, 1993). The most common species are *Phillyrea latifolia* L., *Arbutus unedo* L., *Laurus nobilis* L., *Ilex aquifolium* L., *Viburnum tinus* L. and several *Quercus* spp, such as *Q. robur* L. and *Q. pyrenaica* Willd. This vegetation covers around 17,5ha.

- “Pinhal do Marquês”, occupying about 13ha. The dominant species is the maritime pine *Pinus pinaster* Aiton.

- The Gardens, “Vale dos Fetos” and “Vale dos Abetos”, occupying 6,4ha. The Gardens encircle a luxurious 19th century hotel and present several ornamental species, such as *Ginkgo biloba* L., *Magnolia grandiflora* L., *Staphylea colchica* Steven and *Spiraea cantoniensis* Lour. In Vale dos Fetos, many tree ferns *Dicksonia antarctica* Labill. can be found.

This mixed forest is a markedly different and biologically rich landscape element in the study area, which, as previously described, is mainly covered by agriculture fields and monoculture plantations. Despite its reduced area, in this geographical context, Bussaco’s diversity and structural complexity provides potential ecological value and importance. Therefore, it constitutes an independent land cover class in this study.

2.4. Biogeography

Biogeographically, the study area locates at the confluence zone of two major biogeographic regions from the Holarctic kingdom: Euro-Siberian Region and Mediterranean Region. More specifically, at the junction zone of the Province Cantabro-Atlântica, subsector Miniense and the Province Gaditano-Onubo-Algarviense, subsector Beirense Litoral (Fig. 2.4).

The association of this location with the respective confluence of two different macrobioclimates (Temperate and Mediterranean) results in a particular microclimate (see Climate section) that favors the occurrence of high floristic diversity. Hence, spontaneous vegetation of Serra do Bussaco presents deciduous vegetation, characteristic from temperate climate on the North-facing slopes, and evergreen vegetation, typically Mediterranean, on the South-facing slopes (Costa et al., 1998).

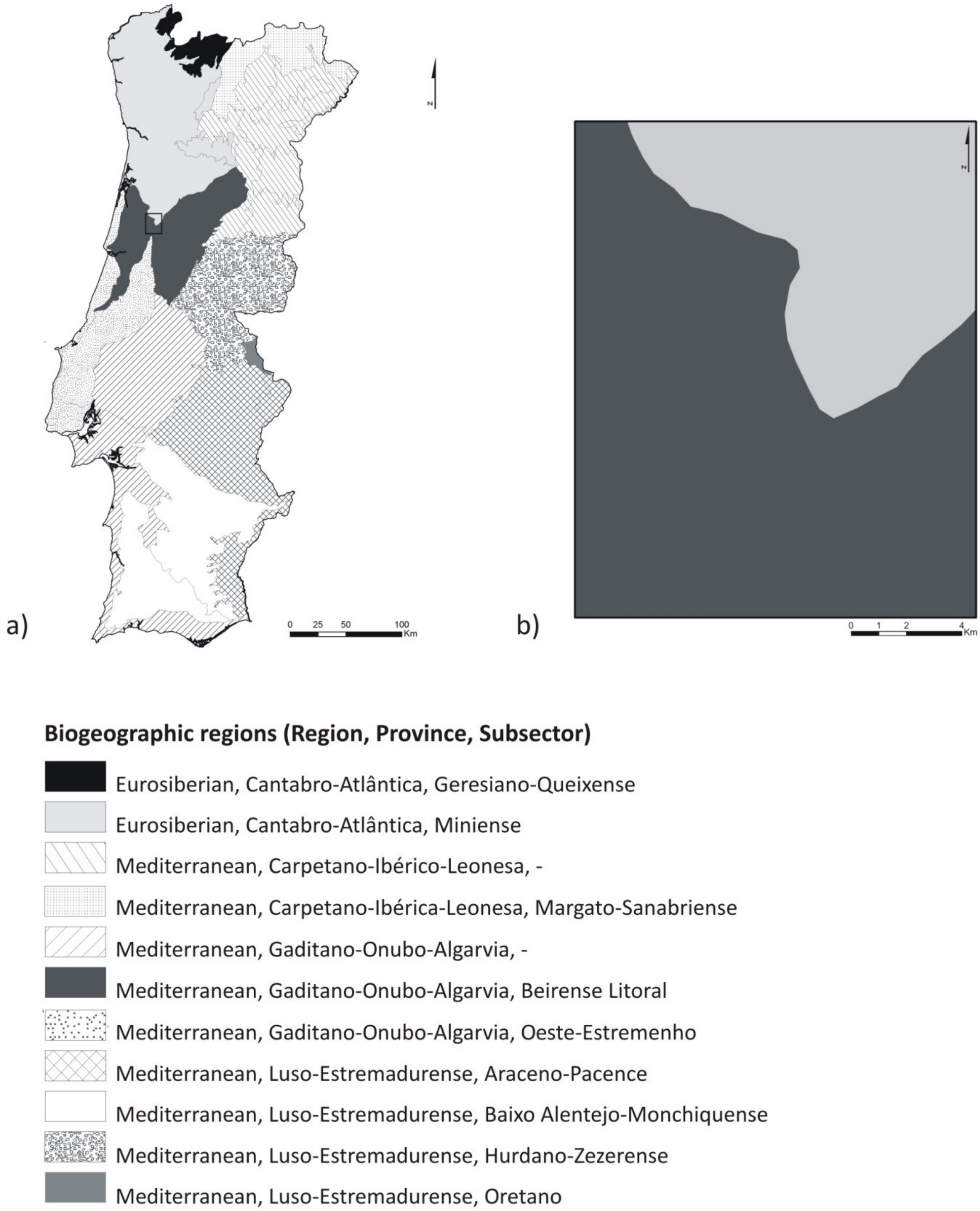

Fig. 2.4. a) Biogeographic regions in mainland Portugal. b) Biogeographic regions in the study area. Adapted from Costa et al., 1998.

2.5. Climate

The study area situates in a transition zone of two major macrobioclimate types: Temperate and Mediterranean, receiving influences from both. As shown in Figure 2.5, the bioclimates present in the study area are Temperate Oceanic and Mediterranean Pluviseaonal Oceanic.

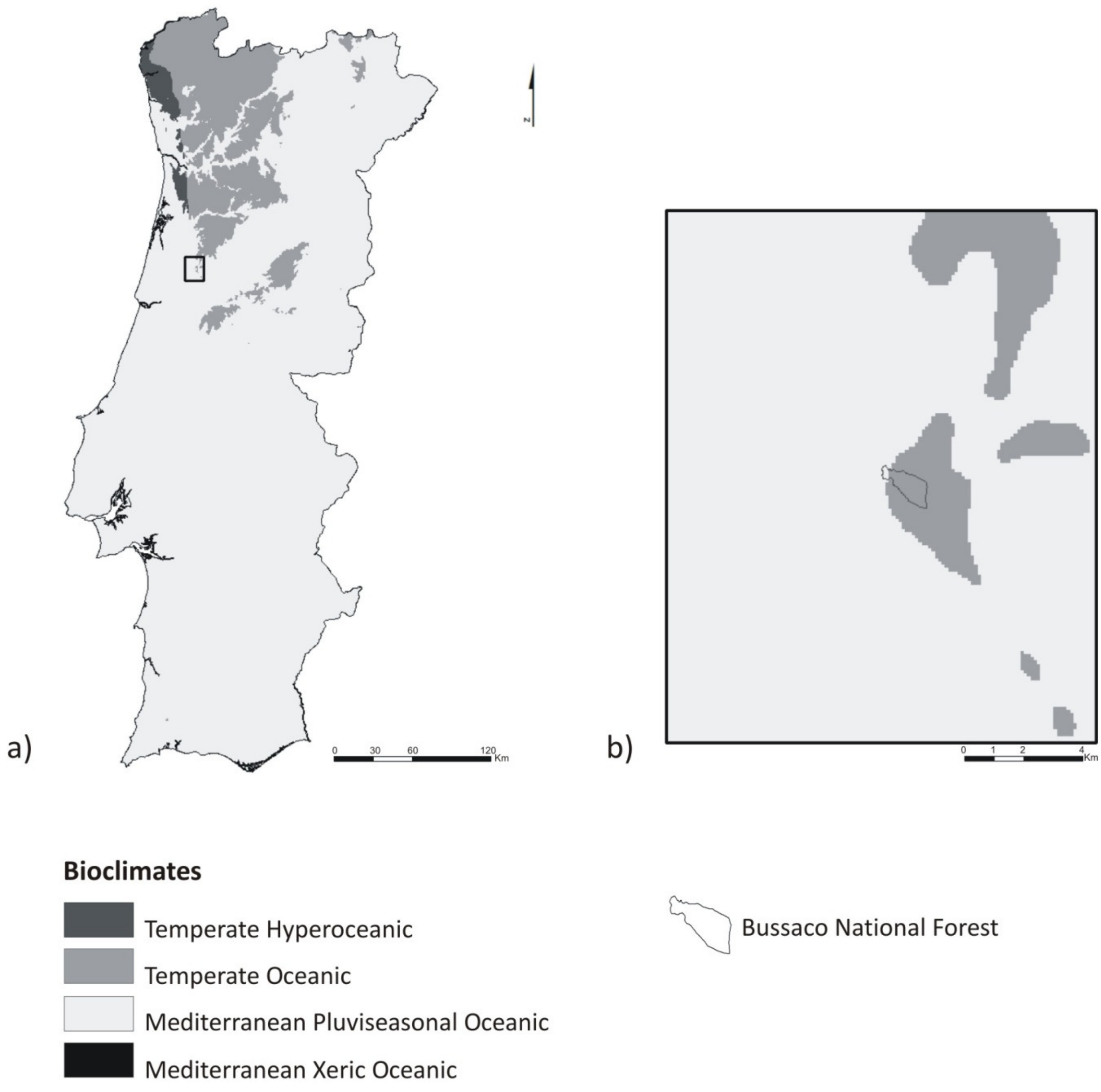

Fig. 2.5. Bioclimates map. a) Mainland Portugal. b) Study area. Adapted from Monteiro-Henriques, 2010.

According to national meteorological reports (Instituto de Meteorologia, 2007), the year of 2007 presented very low precipitation values, being categorized as extremely dry. In terms of air temperature, 2007 presented a slightly higher annual mean temperature than the 1961-90 mean value. 2008 was sorted as a dry to very dry year (with a rainy Spring, though), with temperatures vaguely lower than the mean values (Instituto de Meteorologia, 2008). In terms of precipitation, 2009 was labeled as dry to normal. In Central Portugal, there was a drought situation between March and November, but December was very rainy (precipitation 60% higher than mean values). Mean annual temperature of 2009 was 0,5°C higher than 1971-2000 mean values (Instituto de Meteorologia, 2009).

During the study period (2007, 2008 and 2009), the climate in the region presented the parameters shown in Table 2.2 and Figure 2.6 (©2010 Weather Underground, Inc.; ©Serviço Nacional de Informação de Recursos Hídricos 1995-2010).

Table 2.2. Climate parameters in the study area (2007, 2008 and 2009).

	Parameter	Occurrence	Value
Temperature	**Annual mean temperature**	-	15.4°C
	Hottest month (average)	August	21.1°C
	Coldest month (average)	December	9.8°C
	Absolute maximum temperature	30 July 2007	39°C
	Absolute minimum temperature	9 January 2009 and 20 December 2009	-1°C
Precipitation	**Mean annual rainfall**	-	804.3mm
	Rainiest month (average)	December	120.9mm
	Driest month (average)	August	11.03mm
	Rainiest month in the interval	January 2009	209.9mm
	Driest month in the interval	August 2009	6.0mm
Relative humidity	**Mean annual relative humidity**	-	65.0%
	Moistest month (average)	January	74.1%
	Driest month (average)	March	58.8%

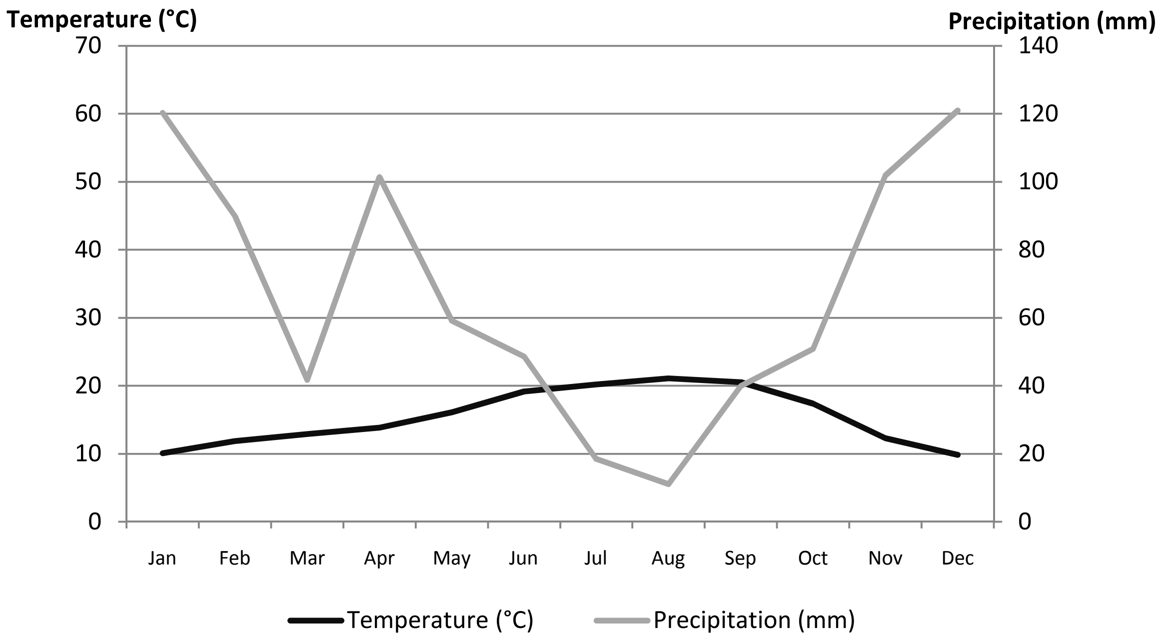

Fig. 2.6. Climate chart of the study area (2007, 2008 and 2009).

It must be highlighted that Bussaco National Forest, due to its particular location and *sui generis* vegetation presents a microclimate quite different from the rest of the study area. In relation to the general study area, Bussaco presents a fresher and rainier climate, with larger amplitude of temperature. A meteorological station of the *Instituto Nacional de Meteorologia e Geofísica* was functioning in the Forest, at an altitude of 381m between 1926 and 1942 (Santos, 1993), yet the gathered data still constitute a good approximation to current conditions. A summary of local's climate parameters is presented on Table 2.3 and Figure 2.7.

Table 2.3. Climate parameters in Bussaco National Forest (1926 - 1942).

	Parameter	Occurrence	Value
Temperature	**Annual mean temperature**	-	13.9°C
	Hottest month (average)	August	21.4°C
	Coldest month (average)	January	7.6°C
	Absolute maximum temperature	August	40.4°C
	Absolute minimum temperature	February	-3.1 °C
Precipitation	**Mean annual rainfall**	-	1525mm
	Rainiest month (average)	December	225.2mm
	Driest month (average)	August	20.4
Relative humidity	**Mean annual relative humidity**	-	80.2%
	Moistest month (average)	November	88.4%
	Driest month (average)	August	71.0%

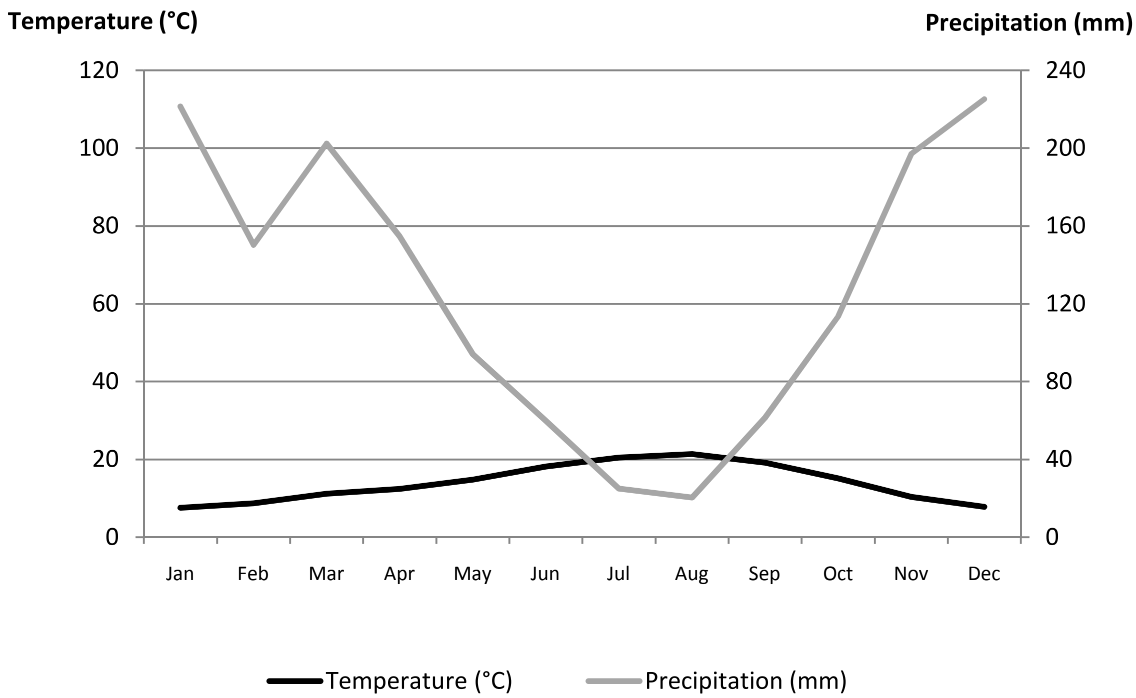

Fig. 2.7. Climate chart of Bussaco National Forest (1926 - 1942).

2.6. Lithology

The lithology of the study area, namely of Serra do Bussaco, has been well studied and cartographed by several researchers, since 1853. Further and more complete descriptions can be consulted, for example, on Costa (1950), Young (1988), Sequeira and Medina (2004) and Flores (2010).

In a general way, the study area comprises terrains of the Meso-Cenozoic margin on the western half and of the "Maciço Marginal" (geomorphological unit of the Iberian massif) on the eastern half. The Meso-Cenozoic margin is constituted by post-Paleozoic terrains, with less than 248 millions of years. The Iberian massif includes the oldest terrains, from Paleozoic and Precambrian, very deformed, with some depressions filled with more recent deposits (Sequeira and Medina, 2004).

Figure 2.8 shows a very simplified schematic diagram of the foremost geological formations present on the study area.

The oldest formations are sedimentary and metamorphic rocks, from Cambrian to Precambrian (including *Schist-Greywacke Complex). Serra do Bussaco encompasses terrains with different ages that belong to a formation called "Bussaco syncline". This structure extends from Bussaco National Forest for 40km, until "penedos de Góis", in Serra da Lousã and includes* sedimentary and metamorphic rocks such as *metasandstones, carbonated rocks, metapelites and conglomerates. The most recent outcrops of Serra do Bussaco (silicified sandstones) date from the Cretacic period and compose the "grés do Bussaco".*

The western part of the study area includes several sedimentary formations (such as alluvial deposits, sands, conglomerates, limestone, clay deposits) dated from between the Jurassic period and the Holocene epoch.

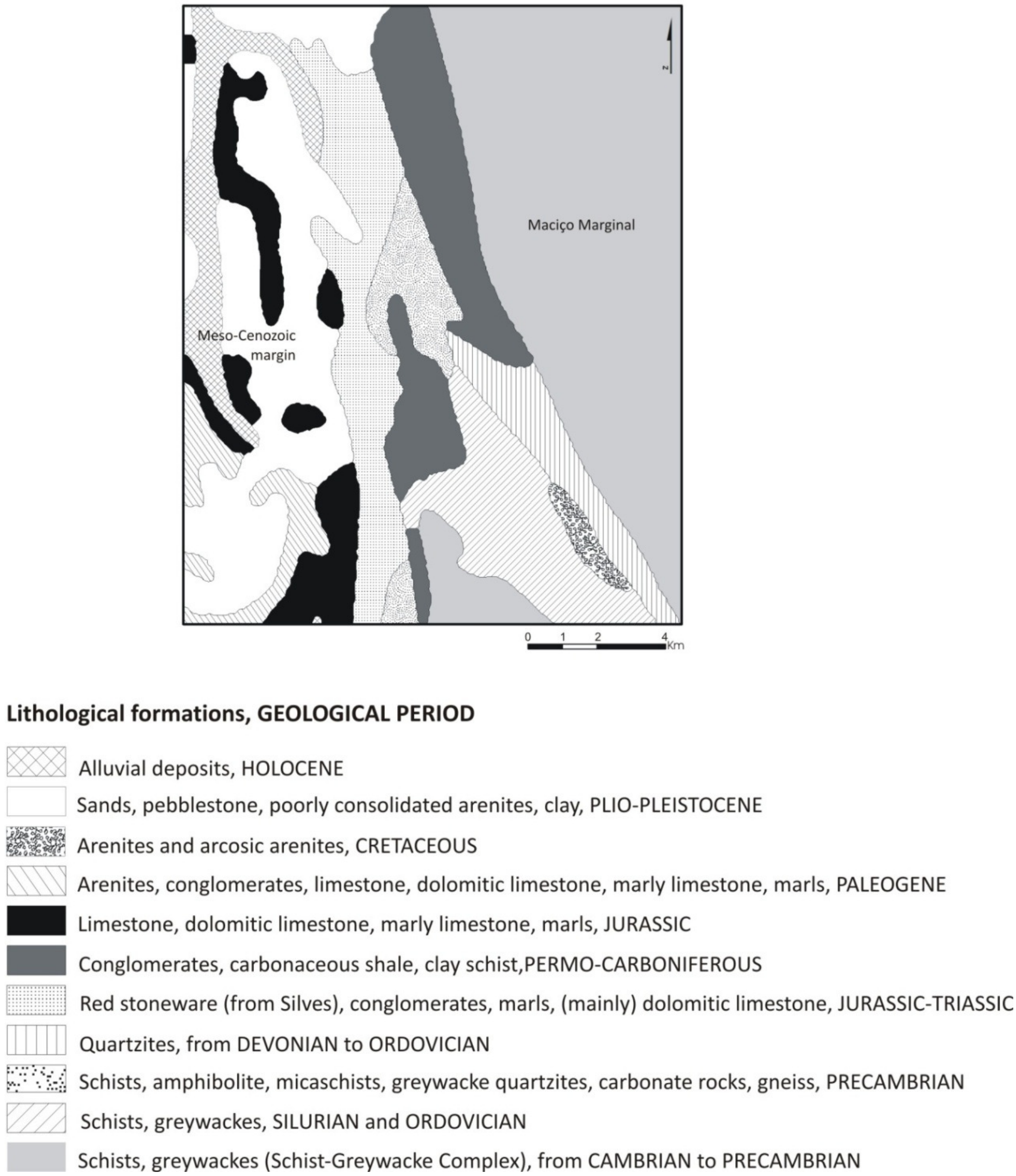

Fig. 2.8. Lithological formations in the study area. Adapted from “Atlas do Ambiente Digital” (Instituto do Ambiente, 2007).

2.7. Soil

The study area includes three major types of soil: Cambisols, Podzols and Litosoils. As can be observed in Figure 2.9, the greater part of the study area is covered with Humic Cambisol developed over schist or schist and quartzite. Adjacent to these territories, Chromic Cambisols can be found and in the western part of the study area locate Ortic Podzols associated with Calcaric Cambisols.

In the southern part of the study area and in less significant extents situate Eutric Cambisols (post-Paleozoic sedimentary rocks), Calcic Cambisols and Eutric Litosoil associated with Luvisoil.

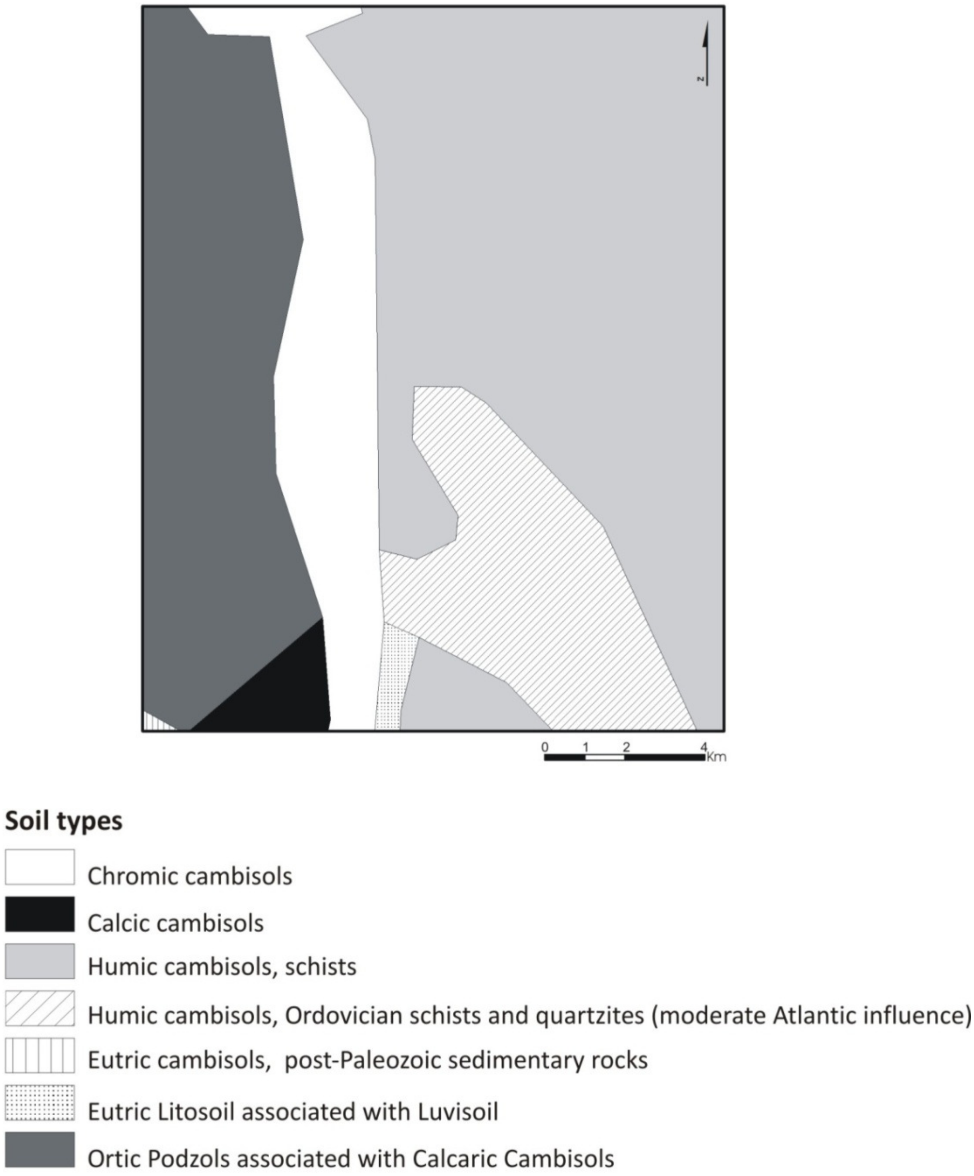

Fig. 2.9. Soil types in the study area. Adapted from "Atlas do Ambiente Digital" (Instituto do Ambiente, 2007).

2.8. Hydrography

The study area comprises watercourses from two hydrographic basins: those of Vouga and Mondego rivers, as shown in Figure 2.10. In the northwestern part of the study area, all thalwegs drain to Cértima river, which is a left tributary of Vouga river. In the south-eastern part of the study area, thalwegs drain to Mondego's affluents or bayous.

Not all watercourses in the study area are permanent. A great part of small creeks only carry water during the rainiest season of the year.

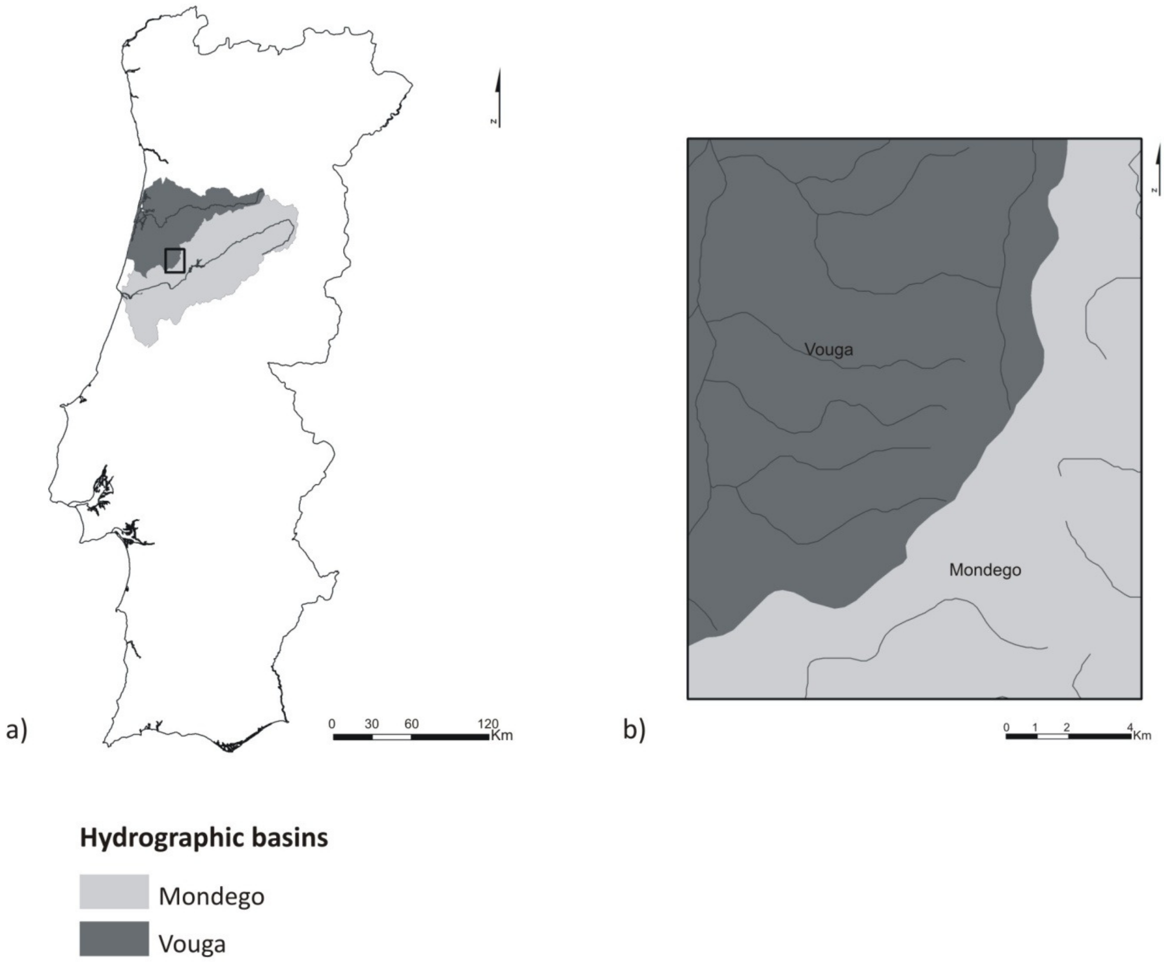

Fig. 2.10. a) Location of Vouga and Mondego's hydrographic basins in mainland Portugal. b) Main watercourses present in the study area. Adapted from "Atlas do Ambiente Digital" (Instituto do Ambiente, 2007).

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Ensombram a ribeira
e o verde da seara
e passam pela eira
em que o sol se pousara
nas gotas do orvalho
luarento e vacilante
refrescam o cansaço
e dormem um instante

Pássaros do Sul
bando de asas soltas
trazem melodias
p'ra cantar às moças
em noites de romaria

Mafalda Veiga

Chapter 3

Diversity of bird assemblages on human-altered habitats in a heterogeneous landscape

3. DIVERSITY OF BIRD ASSEMBLAGES ON HUMAN-ALTERED HABITATS IN A HETEROGENEOUS LANDSCAPE

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Submitted to *Acta Ornithologica*

3.1. Abstract

Bird conservation constitutes an important keystone for biodiversity conservation in general. Central Portugal's natural landscape has been profoundly modified, and is currently dominated by agricultural fields and monoculture production forests of *Pinus pinaster* and *Eucalyptus globulus*. Patterns of bird species richness, diversity and evenness were assessed in these habitats and in an old-growth mixed forest, in order to understand bird responses to different anthropogenic land-uses. Conservation value of each habitat was also calculated. In total, 49 bird species were identified in the study. Farmlands presented the greatest species richness and conservation value, with traditional agriculture patches exhibiting more diverse and even communities than the more intensively cultivated fields. Among forest habitats, the mixed forest presented the greatest species richness, diversity and conservation value. As expected, the exotic eucalyptus stands held the lowest bird diversity, abundance and conservation importance. The results indicate that preservation of traditional agriculture, promotion of diverse woodland areas and alternative management strategies for plantation forest should be taken into account on land-planning policies, integrating human activities with biodiversity conservation.

3.2. Introduction

Biodiversity loss constitutes a major environmental issue worldwide, as species are declining at unnaturally rapid rates as a consequence of human activities (Sala et al., 2000; Western and Pearl, 1989). Anthropogenic pressures such as land-use change and habitat fragmentation or loss are amongst the most threatening disturbance factors (e.g. Fischer and Lindenmayer, 2007; Groombridge, 1992; Wilson, 1988), thus representing a key theme for conservation research.

Production industries like agriculture and forestry represent the dominant human land uses (Morris, 1995) which have been the leading promoters of wide-reaching landscape modifications (Millenium Ecosystem Assessment, 2005). In Iberia, as in Europe, natural vegetation has been deeply modified (Amo et al., 2007). For instance, Central Portugal's landscape was once covered with mixed woodland dominated by oak species (*Quercus* spp.) (Bingre and Damasceno, 2007; Ramil-Rego et al., 1998). A vast majority of the landscape was converted to agriculture and the remaining native forest was gradually replaced by faster growing and economically profitable species (Paiva, 1998; Vieira et al., 2000). Nowadays, most of the forested areas (more than 78%) are composed of maritime pine *Pinus pinaster* and *Eucalyptus globulus* (CNIG, 1995; DGRF, 2007) intensively planted since the beginning and the middle of the 20th century, respectively (Mendes, 2007; Radich, 2007).

Plantation forests are widely viewed as adverse to biodiversity conservation, negatively affecting a wide range of *taxa* (e.g. Faria et al., 2007; Hartley, 2002; Lindenmayer et al., 2003a; Saitoh and Nakatsu, 1997; Tellería and Galarza, 1990), as they reduce habitat complexity and, thus, niche diversity and resource availability (Díaz, 2006; Lindenmayer et al., 2003a). This is even more noticeable in the case of even-aged exotic monocultures such as the eucalyptus in Portugal (CESIE, 1989; Proença et al., 2010; Silva et al., 2007; Zahn et al., 2009). However, such conclusions cannot be generalized. As reviewed by Carnus et al. (2006) and Stephens and Wagner (2007), in some cases the wildlife communities in plantation forests may be as diverse as in natural forests. Moreover, when compared with other intensive industrial land uses such as annual crop agriculture or urban settlements (Moore and Allen, 1999) or with degraded or cleared fields, plantations can even be favorable, in terms of biodiversity (Borsboom et al., 2002; Klomp and Grabham, 2002; Stephens and Wagner, 2007).

This paper compares breeding birds' species richness and community composition in the two aforementioned monocultures with that occurring in different types of land use, an old-growth mixed forest and two types of agricultural fields, within a typically fragmented landscape of Central Portugal. Although bird *taxa* should not be considered absolute surrogates for biodiversity trends (e.g. Gregory et al., 2003; Lawton et al., 1998; Lindenmayer et al., 2002), they constitute an important keystone for biodiversity conservation in general (Pain and Dixon, 1997), as they present many ecological features that justify their use as indicators of ecosystem's health (e.g. Everard, 2008; Garson et al., 2002; Gregory et al., 2005; Moser et al., 1995; Robledano et al., 2010). Thus, we aimed to assess the relative importance of different habitat types for avian conservation, understand the implications that current land management in Central Portugal may have on birds and discuss some conservation measures to be considered on land planning policies.

3.3. Methods

Study area

The study was conducted in a 25 000 ha area, located in Central Portugal and centered at Bussaco National Forest (maximum elevation of 547 m a.s.l. at Cruz Alta 40º22’13’’N, 8º21’59’’W). Bussaco is a wall fenced old-growth woodland with approximately 105 ha which constitutes an exclusive natural heritage, representing one of the best dendrological collections in Europe, where tree species from the entire globe can be found. This forest started being planted during the 17th century and some of the most representative species of trees are *Cupressus lusitanica* Mill., *Quercus robur* L., *Q. pyrenaica* Willd., *Castanea sativa* Mill., *Acer pseudoplatanus* L., *Fraxinus americana* L., *Ulmus minor* Mill., *Sequoia sempervirens* (D.Don) Endl., *Pseudotsuga menziesii* (Mirbel) Franco and *Cedrus atlantica* (Endl.) G. Manetti ex Carrière. Bussaco keeps also a patch of the primitive Mediterranean forest (Paiva, 2004; Santos, 1993), with native shrub and tree species such as *Laurus nobilis* L., *Arbutus unedo* L., *Viburnum tinus* L., *Ilex aquifolium* L, *Ruscus aculeatus* L., *Phillyrea latifolia* L. and several *Quercus* species.

We performed habitat stratification of the study area by means of photo-interpretation and field validation, and came out with 5 dominating habitats within the fragmented landscape: Bussaco Forest, monocultural stands of *Pinus pinaster* and *Eucalyptus globulus*; large agricultural fields (machine-laboured mosaic of fields) and small patches of traditional agriculture (mainly produce gardens, hand-laboured, for domestic consumption), surrounded by large areas of eucalyptus plantations. These small patches located near little rural villages had always a water body, a small river or a pond in the environs.

Being a Mediterranean area with some Atlantic influence, in the study area summers are hot (maximum 39°C) and winters mild (minimum -1°C). Annual average precipitation is of 804 mm, mostly concentrated on autumn and winter. However, Bussaco presents a fresher and rainier microclimate, with a mean annual precipitation of 1525 mm.

Bird counts

We selected 30 sampling sites, corresponding to 6 replicates of each habitat type. Bird counts were carried out by means of 50m fixed-radius point counts, with 10 min duration, which is a standard and widely used method (Bibby et al., 2000; Gibbons, 1996; Gregory et al., 2004; Rabaça, 1995; Ralph et al., 1993). As we intended to survey in open (agricultural land) and forested habitats, counts were limited to 50m radius plots in order to reduce biases associated with differences in vegetation structure or birds detectability, relatively to unlimited-distance counts (Gibbons, 1996; Petit et al., 1994). Furthermore, in comparison with transects, point counts are more time efficient and more appropriate for woodland surveys, allowing the observer to concentrate on birds without the noise and distraction of avoiding obstacles while walking (Bibby et al., 2000).

To ensure spatial independence and avoid double counting, sampling points were separated by a minimum of 1 km in all habitats, except in Bussaco forest, where the minimum distance was of 250m (Ralph et al., 1993) due to spatial limitations.

Censuses began at sunrise and lasted four hours, and were made only on days with favorable weather conditions (i.e. no strong wind, rain or mist) and always by the same trained observer (MM), which recorded all visual or auditory contacts. Birds flying over the sampling plot ("fly-overs") were not counted, in order to eliminate temporal visitors passing through the study site. Attention was paid not to recount individual birds. Data were collected during 2008 and 2009. Two sampling rounds were undertaken per breeding season (April and May).

Data analysis

Cumulative bird species richness and total abundance from the four sampling rounds at each sampling site were used to perform all analysis. We analyzed the sample size and the species richness through species accumulation curves for each habitat type. To examine diversity, we evaluated the species richness (S=number of species) and the Rényi diversity ($H_\alpha = \frac{\ln(\sum_{i=1}^{S} pi^\alpha)}{1-\alpha}$) and evenness ($lnE_{\alpha,0} = H_\alpha - H_0$) profiles (Renyi, 1970; Ricotta, 2003; Ricotta and Avena, 2002). The results are expressed as mean ($\bar{x}$) ± standard error (SE) and respective 95% confidence intervals (CI).

A canonical correspondence analysis (CCA) was applied to elucidate the relationships between the species compositions and the habitat types.

In order to assess the conservation value of each habitat type, conservation value indexes were calculated. This sort of indexes has been developed to allow comparison of bird assemblages attending not only to their diversity but also to the species conservation status (Nuttle et al., 2003; Pons et al., 2003). In this study, two conservation value indexes were calculated, based on a simple equation adapted from Pons et al. (2003), which considers both the abundance and the status of the species observed in each habitat type, as follows:

Conservation value index = $\sum_{i=1}^{k}$ $[\log(A_i + 1).status\ score_i]$

where k is the total number of species occurring and A_i the abundance of species i in the considered habitat. The status score of species i is related to the chosen status assessment system. The first status system used in this study was the “Species of European Conservation Concern” or SPEC (BirdLife International, 2004), which evaluates bird status at the European scale. A status score (SPEC value) was assigned to each species, in geometric progression of increasing conservation concern (SPEC value$_i$: Non-SPEC = 1, SPEC 4 = 2, SPEC 3 = 4, SPEC 2 = 8, SPEC 1 = 16). The second status assessment system, developed at a national scale meeting the IUCN Red List Criteria (IUCN, 2001, 2003), was the Red Book of Portuguese Vertebrates (Cabral et al., 2005). A status score (Red List value) was attributed to each species, with the following geometric progression of conservation concern: Least concern or introduced species = 1, Data deficient = 2, Near threatened = 4, Vulnerable = 8, Endangered or Critically endangered = 16. We acknowledge the relative subjectivity of this categorization, and any other choice would have been subjective as well.

3.4. Results

A total of 49 species (2607 individuals) were seen or heard during the study. 18 species were only detected on agricultural habitats, which had the greatest species richness (Fig 3.1). On average, large farmlands presented higher number of species (12.71±0.66) and bird abundance (45.21±4.24 individuals) per point count than the small patches of traditional agriculture (12.08±0.89 and 26.21±2.93, respectively). However, the former presented less diverse assemblages (Fig 3.2), strongly dominated by a few species (Fig 3.3), namely *Parus domesticus* and

Serinus serinus. In the small patches with traditional agriculture the most abundant species were *Serinus serinus*, *Fringilla coelebs* and *Troglodytes troglodytes*.

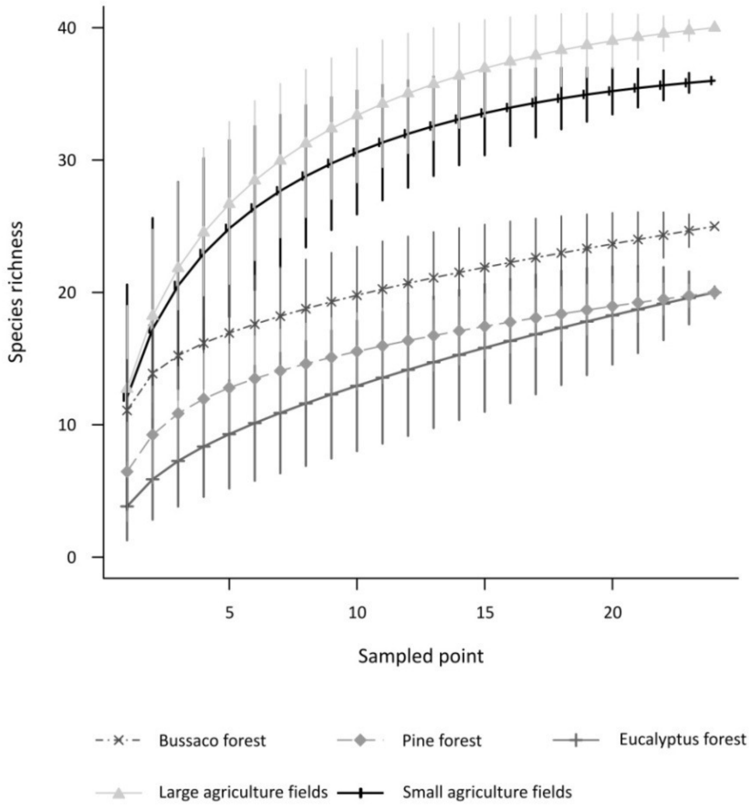

Fig. 3.1. Species accumulation curves for the five habitat types.

In relation to forest habitats, Bussaco's mixed forest presented the highest values of species richness (Fig 3.1) and diversity (Fig 3.2). By opposition, eucalyptus plantations exhibited the lowest values. Bird abundance (number of individuals) followed the same pattern, with the mixed forest presenting the highest (21.17±1.42), pine stands the intermediate (10.46±1.06) and eucalyptus the lowest value (5.58±0.45). The three assemblages were similarly even, though Bussaco's data were more consistent throughout the samplings (Fig 3.2) whereas in eucalyptus the identified assemblages differed between counts. The most common species in Bussaco were *Cyanistes caeruleus*, *Regulus ignicapilla, Erithacus rubecula* and *Sylvia atricapilla*. *Periparus ater*, *Troglodytes troglodytes* and *Erithacus rubecula* were the most abundant species in pine plantations and in eucalyptus stands, the commonest species were *Troglodytes troglodytes, Periparus ater* and *Fringilla coelebs*.

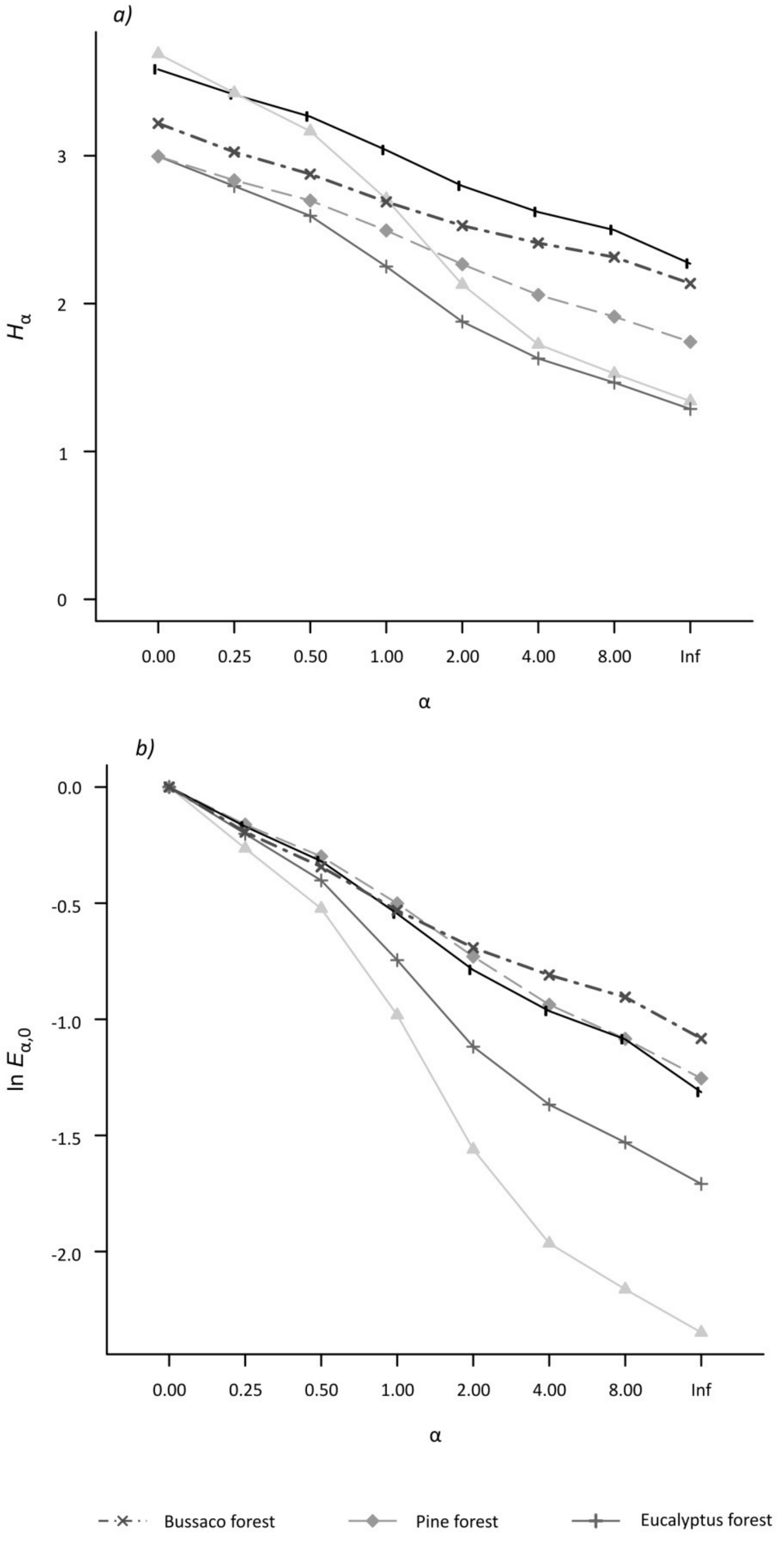

Fig. 3.2. Rényi profiles for the five habitats. a) diversity profiles; b) evenness profiles.

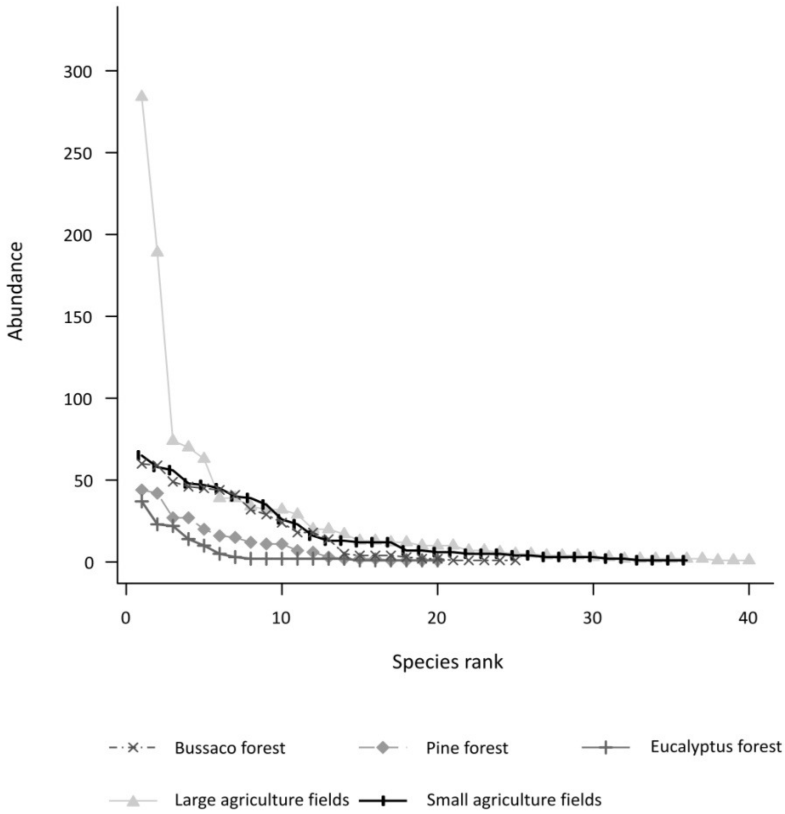

Fig. 3.3. Rank-abundance curves for the five habitats of the study area.

The canonical correspondence analysis (Fig 3.4) divided the assemblage by two gradients. The gradient associated to the first axis is related to the habitats' openness, clearly separating open habitats from cluttered habitats, that is, agriculture fields from woodlands. Small patches of traditional agriculture were placed in the middle of this gradient, which was expected because they were located mostly near the edge of eucalyptus stands and comprised species occurring in those forests too. The second axis shows, to a certain degree, the complexity of the habitat. In the case of forests, they are arranged from Bussaco to the homogeneous exotic eucalyptus monoculture. The position of large farmland was strongly influenced by the numerous flocks occurring there and became less clear.

The CCA plot visibly shows that composition of the assemblages is different among habitats and also demonstrates a certain association between some species and specific habitats. These relations are clearer for the large farmlands, with which, for instance, *Cisticola juncidis*, *Saxicola torquatus* and *Passer domesticus* were associated. Concurring with previous results, no particular species were associated to eucalyptus plantations.

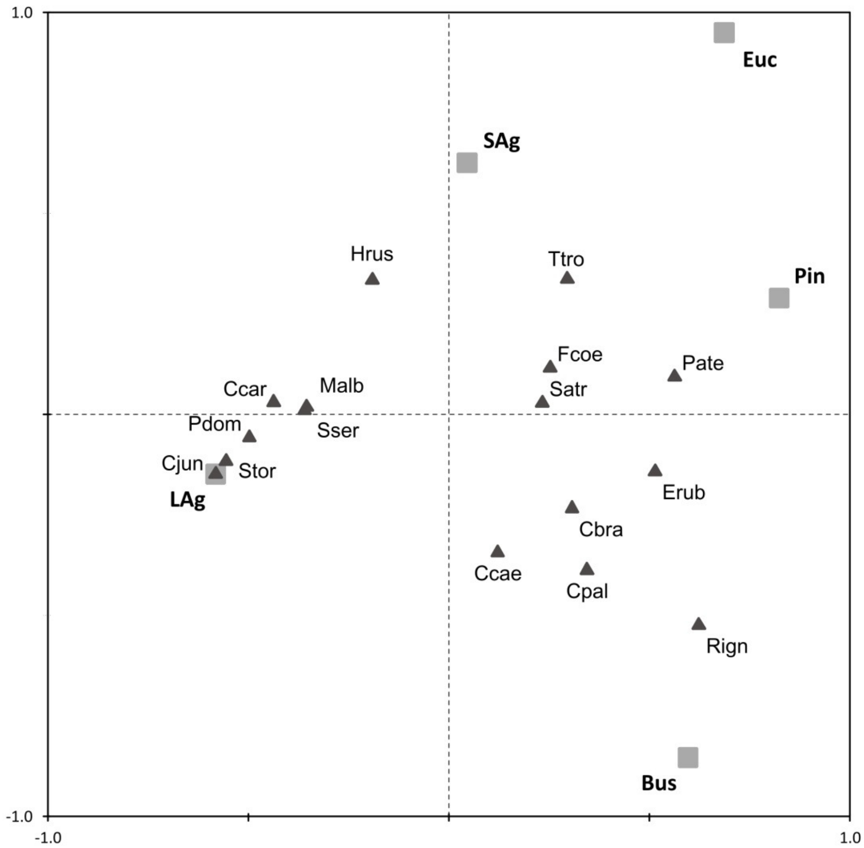

Fig. 3.4. CCA biplot of species and habitats present, where black triangles (Cbra – *Certhia brachydactyla*, Ccar – *Carduelis carduelis*, Cjun – *Cisticola juncidis*, Cpal – *Columba palumbus*, Erub – *Erithacus rubecula*, Fcoe – *Fringilla coelebs*, Hrus – *Hirundo rustica*, Malb – *Motacilla alba*, Pate – *Periparus ater*, Ccae – *Cyanistes caeruleus*, Pdom – *Parus domesticus*, Rign – *Regulus ignicapilla*, Satr – *Sylvia atricapilla*, Sser – *Serinus serinus*, Stor – *Saxicola torquatus*, Ttro – *Troglodytes*) represent species data and grey squares (Bus – Bussaco forest, Pin – Pine forest, Euc – Eucalyptus forest, LAg – Large agricultural fields, SAg – Small agricultural fields) represent the habitat types.

The conservation value indexes calculated per habitat type are presented in Table 3.1. Results of the two indexes are congruent, both attending to European or national contexts, and indicate large farmlands as the most valuable habitat, in terms of conservation value, followed by the small agricultural patches. Among woodlands, Bussaco was the most valuable habitat and eucalyptus plantations the habitat with least conservation importance. As two different systems of status evaluation were used, the numeric value of the obtained indexes cannot be directly compared across systems.

Table 3.1. Conservation value indexes calculated for each habitat, based on SPEC values and Portuguese Red Book status assessment. See text for explanation.

	SAg	LAg	Euc	Bus	Pin
SPEC	61.12	74.67	22.05	36.73	31.20
Red List	40.84	42.35	13.07	25.94	18.20

3.5. Discussion

An overview of the obtained results indicates that agricultural fields lodge more species and higher numbers of breeding birds than forest habitats. This is in agreement with previous findings, stating that in Mediterranean regions, open and cultivated areas are generally more attractive for birds than woodlands (Farina, 1989), as they increase habitat heterogeneity by concentrating resources and providing a wealth of niche opportunities. These statements are valid for mosaic-like, policultural systems, such as those of the study area, where elements as trees, ponds, hedgerows and other boundaries raise habitat complexity (Russo, 2007). Nevertheless, we compared two types of agricultural fields. The larger and more intensively cultivated fields presented higher numbers of species and birds, though the small agricultural patches held a more diverse community. This was due to the dominance of some granivorous species, occurring at high densities in the former. These large fields were mainly cultivated with cereals and also present some temporarily fallow terrains, where herbaceous vegetation grows, thus providing abundant seed and cereal food during spring (Wilson et al., 1999). During field work, numerous flocks of *Passer domesticus* and *Serinus serinus* were observed feeding on these food resources. The large open agriculture areas were important for some species that are characteristic of open areas, such as *Cisticola juncidis* and *Saxicola torquatus*, as long as some traditional features, such as scattered trees and shrubby edges are maintained, providing invertebrates for feeding and shelter for nesting (Wilson et al., 1999).

The small agricultural patches also presented an expressive species richness, yet with much more even and diverse communities. This fact is comprehensible, as these sites allocate a considerable variety of niche opportunities and cumulative edge effects, due to their location near water sites, housing, fruit trees, shrubs, eucalyptus stands, besides the diversity of cultivated items, allowing the occurrence of several ecologically different guilds (e.g. granivorous, insectivorous, 'open space', 'cluttered habitat' species, etc.).

The results obtained for forest habitats are in agreement with other studies that compared communities of mixed/natural forests with those of forest plantations (Atauri et al., 2004; Kwok and Corlett, 2000; Lindenmayer et al., 2003b; Proença et al., 2010; Santos and Alvarez, 1990; Sweeney et al., 2010; Tellería and Galarza, 1990; Zurita et al., 2006). Although Bussaco is mainly a planted woodland, autochthonous arboreal species such as *Quercus* spp. and *Castanea sativa* are abundant in the arboretum. There is also a 17.5 ha patch of climax vegetation, constituting a rare remnant of local native vegetation. Thus, in the study area, Bussaco forest is the closest to natural forest. The differences in species richness and bird abundance indicate that the carrying capacity of Bussaco is greater than that of the monocultures for most bird species, suggesting Bussaco actually constitutes a habitat of improved quality for those species.

Bird species richness is associated with vegetation structure (Cherkaoui et al., 2009; Nikolov, 2009) and plantation forests generally present less diverse assemblages largely because of their structural simplicity (Hobbs et al., 2002). Monoculture stands are usually managed in order to attain commercial targets, failing to provide adequate conditions for birds' subsistence or establishment, such as understory vegetation, nesting sites or food (Carrascal and Tellería, 1990; Crow et al., 2002; Endels et al., 2004; Fraterrigo et al., 2006; Lindenmayer et al., 2003a). These limitations seem to be even more critical in exotic, even-aged and short rotational stands, as the case of eucalyptus, which presented the lowest abundance and diversity values. For example, these stands are totally harvested sometimes with no more than 10 years (Valente et al., 1997), presenting no snags or large-diameter trees (Tellería and Galarza, 1990; Torras and Saura, 2008), features requested by some forest species. Having been recently introduced in the country, eucalyptus have also poorer fauna (Zahn et al., 2009) and understory associated, in comparison to maritime pine, an autochthonous species (Figueiral, 1995). Moreover, the eucalyptus' phenology is not synchronized with the demands of native avifauna (Proença et al., 2010) because *Eucalyptus globulus* flowers during winter and, consequently fails to provide food resources during the birds' breeding season. Besides, native bird species are not adapted to exploit their nectar or seeds (Tellería and Galarza, 1990). By opposite, maritime pine provides several food sources for native birds, namely arthropods present in the needles or in the soil (Carrascal and Tellería, 1990). All these factors may explain the differences of bird abundance and diversity found between pine and eucalyptus plantations. Bussaco forest deeply contrasts with both monocultures, being a forest with great structural complexity and vast vegetation diversity, at all levels, presenting countless feeding, nesting and refuge opportunities for birds.

In relation to eucalyptus, pine and mixed woodlands both presented more consistent bird assemblages, meaning that throughout the samplings, the exotic stands presented differently composed ornithocenoses. Taking all the factors that may explain eucalyptus' reduced bird diversity and the large extensions that they occupy into account, this may suggest that eucalyptus stands are functioning like a transition habitat. If birds move between habitats, through the landscape, at some moment they will stop on eucalyptus, not necessarily nesting or residing there. This would explain the presence of several occasional species, such as *Picus viridis* or *Sturnus unicolor*.

Conservation value indexes are in agreement with the previous results, reinforcing the importance of farmlands and Bussaco mixed woodland, considering both European and national conservation contexts. The presence of large flocks, though of common species, in large cultivated fields boosted the respective conservation value of this habitat, so these indexes must be carefully interpreted. For instance, the house sparrow is common and abundant in Portugal (Classification of Least Concern in the Red Book), but detains a certain degree of European concern (SPEC 3). In large farmlands, due to food availability, sevenfold more sparrows were counted than in traditional fields, which had an influence on their conservation value. With respect to forest monocultures, the poorer conservation value of eucalyptus stands compared with pine plantations was confirmed.

In terms of land cover, the study area is very similar to a great extension of Central Portugal, thus some conservation measures can be outlined from this study. In this region, natural forests are scarce and eucalyptus continues to be planted, sometimes in areas of previous traditional agriculture. This type of agriculture, proved to be of high value for conservation, is also being abandoned all over the country. Mixed or natural woodlands and traditional agriculture constitute key habitats for breeding birds, so they must be encouraged and preserved. It must be reinforced that the sampled traditionally cultivated fields locate in valleys among large extensions of eucalyptus plantations, so the presence of these small patches is fundamental for bird conservation in this landscape. As previously stated (Russo, 2007; Tscharntke et al., 2005) agriculture can contribute to the conservation of high-diversity systems. Also, production forests can contribute to bird conservation if some measures, promoting landscape heterogeneity and enhancing stand structural complexity, are applied (Fischer et al., 2006; Lindenmayer et al., 2003a; Moreira et al., 2001; Sayer et al., 2004). Such actions may involve the plantation of native trees within stands or in contiguous patches or the adoption of different harvesting systems (Lindenmayer et al., 2006; Lindenmayer et al., 2010).

Portuguese pine stands are currently facing a serious infection of the nematode *Bursaphelenchus xylophilus* (Mota et al., 1999) and it is expected that large extensions will be harvested, as a control measure. It is important that conservation recommendations are taken into account, to avoid reforestation with detrimental species for birds and overall biodiversity.

Acknowledgements

The authors are grateful to Dr. Jaime Ramos, for helpful comments on an earlier draft of this manuscript. Milena Matos was supported by a PhD grant from Fundação para a Ciência e a Tecnologia (SFRH/BD/31146 / 2006).

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No céu cinzento sob o astro mudo
Batendo as asas pela noite calada
Vêm em bandos com pés de veludo…

José Afonso

Chapter 4

Foraging bats in a heterogeneous landscape: diversity and habitat use

4. FORAGING BATS IN A HETEROGENEOUS LANDSCAPE: DIVERSITY AND HABITAT USE

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Submitted to *Acta Chiropterologica*

4.1. Abstract

Bat conservation requires knowledge about foraging behavior and habitat use. This study aimed to determine habitat use by foraging bats in five habitat types in a region of Central Portugal. During the main activity periods of 2008 and 2009, bat activity was monitored by line transects using an ultrasound detector. Species were identified through the analysis of recorded echolocation calls. The most common species belonged to the *Pipistrellus* genera. *Barbastella barbastellus* was the only species using all habitats indiscriminately. *Tadarida teniotis* significantly selected a mixed forest. In general, mixed woodland and small patches of traditional agriculture with water sites, presented the highest total numbers of both bat passes and feeding buzzes. Exotic *Eucalyptus* stands were the less used habitats. Our results seem to support that the major land-uses in Central Portugal, monospecific plantations and intensive agriculture, constitute poor foraging habitats for bats. The preservation of traditional agriculture and the associated water sites as well as the promotion of diverse woodland areas should be strongly considered on land-planning and bat conservation plans.

4.2. Introduction

Bats constitute a very diverse group and the second largest order of mammals, with more than 1100 described species (Simmons, 2005). Their unique biological characteristics allow them to exploit many different ecological niches world-wide and provide enormous ecological and economical importance (e.g. as seed dispersers, pollinators, insect number controllers (Heithaus et al., 1975; Hutson, 2001; Jones et al., 2009; Sazima and Sazima, 1978; Williams-Guillen et al., 2008)). Insectivorous bats (Microchiroptera) present ecological aspects such as low fecundity, high longevity and relatively high survivorship that make their communities limited by environment resources (Findley, 1993; Ma et al., 2008; Stebbings, 1988), mainly by insects and suitable foraging habitats. These features paired with their sensitivity to prevail climatic conditions and vulnerability to land transformations make these bats valuable indicators of the "health" of ecosystems (Bat Conservation Trust, 2008; Davidson-Watts et al., 2006; Jones et al., 2009; Ma et al., 2008).

There is growing evidence that many bat species are declining world-wide, primarily due to human-induced environmental stressors such as global climate change, habitat loss or fragmentation, pollution, agricultural intensification and pesticide use, deforestation, roost loss or disturbance and persecution (e.g. Duchamp and Swihart, 2008; Hutson, 2001; Jones et al., 2009; Mickleburgh et al., 2002; Rebelo et al., 2010; Stebbings, 1988; Wickramasinghe et al., 2004).

Bat conservation requires further research on foraging behavior and habitat use, being the gathered knowledge of crucial importance to establish urgent conservation practices (Hutson, 2001; Stebbings, 1988). In Mediterranean countries, only a few studies on bat communities have been carried out (Carmel and Safriel, 1998; Rainho, 2007; Rebelo and Rainho, 2009; Russo and Jones, 2003), despite the high bat diversity found there (Hutson, 2001). In mainland Portugal, 25 species occur, the majority of them threatened or insufficiently known (Cabral et al., 2005; Hutson, 2001). Currently, these species are being taxonomically reviewed.

Central Portugal's landscape is dominated by forest, bush coverage and agricultural land. Most of the forested areas (more than 78%) are composed by maritime pine *Pinus pinaster* and *Eucalyptus globulus* (CNIG, 1995; DGRF, 2007) planted mostly since the beginning and the middle of the 20th century, respectively (Mendes, 2007; Radich, 2007). There is a common belief that plantation forests have a negative effect on a wide range of *taxa* (e.g. Carnus et al., 2006; Hartley, 2002; Hobbs et al., 2002; Lindenmayer et al., 2003; Saitoh and Nakatsu, 1997; Stephens and Wagner, 2007; Tellería and Galarza, 1990), particularly in the case of even-aged exotic monocultures such as the eucalyptus in Portugal (CESIE, 1989; Proença et al., 2010; Silva et al., 2007; Zahn et al., 2009), by reducing habitat complexity and, thus, niche diversity and resource availability (Díaz, 2006; Lindenmayer et al., 2003). Nevertheless, a few studies (reviews in Carnus et al., 2006 and ; Stephens and Wagner, 2007) have found that biodiversity was marginally different or even higher in forest plantations, in comparison with natural or native forest. Furthermore, caution must be taken when generalizing the negative impact of plantation forests, when compared with other intensive industrial land uses such as annual crop agriculture or human developments (Moore and Allen, 1999) or with degraded or cleared fields, the former can even be favorable, in terms of biodiversity (Borsboom et al., 2002; Klomp and Grabham, 2002; Stephens and Wagner, 2007). In this scope, one of the goals of this study was to compare bats' habitat use in the aforementioned monocultures with the one taking place in different types of land use, namely, an old-growth mixed forest and two types of agricultural fields, within a fragmented landscape, thus determining which habitats enclose greater bat species richness, diversity and activity. We aimed to describe the occurring bat community in terms of habitat preference, to understand the implications that current land management in Central Portugal may have on bats and to discuss some conservation measures to be considered on land planning and management policies.

4.3. Methods

Study area

The study was conducted in a 25 000 ha area, located in Central Portugal and centered at Bussaco National Forest (maximum elevation of 547 m a.s.l. at Cruz Alta 40º22’13’’N, 8º21’59’’W). Bussaco is a wall fenced old-growth woodland with approximately 105 ha which constitutes an exclusive natural heritage, representing one of the best dendrological collections in Europe, where tree species from the entire globe can be found. This forest started being planted during the 17th century and some of the most representative species of trees are *Cupressus lusitanica* Mill., *Quercus robur* L., *Q. pyrenaica* Willd., *Castanea sativa* Mill., *Acer pseudoplatanus* L., *Fraxinus americana* L., *Ulmus minor* Mill., *Sequoia sempervirens* (D.Don) Endl., *Pseudotsuga menziesii* (Mirbel) Franco and *Cedrus atlantica* (Endl.) G. Manetti ex Carrière. Bussaco also has a patch of the primitive Mediterranean forest (Paiva, 2004; Santos, 1993), with native shrub and tree species such as *Laurus nobilis* L., *Arbutus unedo* L., *Viburnum tinus* L., *Ilex aquifolium* L, *Ruscus aculeatus* L., *Phillyrea latifolia* L. and several *Quercus* species.

We performed habitat stratification of the study area by means of photo-interpretation and field validation, and came out with five dominating habitats within the fragmented landscape: Bussaco Forest, monocultural stands of *Pinus pinaster* and *Eucalyptus globulus*; large agricultural fields (machine-laboured mosaic of fields) and small patches of traditional agriculture, mainly produce gardens, hand-laboured, for domestic consumption, surrounded by large areas of eucalyptus plantations. These small patches locate near little rural villages and always have a water course, a small river or a water pond in the environs.

Being a Mediterranean area with some Atlantic influence, in the study area summers are hot (maximum 39°C) and winters mild (minimum -1°C). Annual average precipitation is of 804 mm, mostly concentrated on autumn and winter. However, Bussaco presents a fresher and rainier microclimate, with a mean annual precipitation of 1525 mm.

Sampling design and echolocation recording

We selected 30 sampling sites corresponding to 6 replicates in each habitat type. Each sample consisted on a 500 m line transect, walked at a constant pace for 15 minutes to acoustically survey bat activity using a Pettersson D240X (Pettersson Elektronik AB, Uppsala, Sweden) ultrasound detector. Transects were separated by a minimum of 1 km to increase spatial independence, except in Bussaco Forest, due to spatial constraints.

The bat detector was set to heterodyne mode and the 10-120 kHz range of frequencies was swept through, in order to maximize the chance of detecting different bat species and at a rate ensuring that virtually all individual bats were detected. When a bat pass (sequence of "clicks" heard as a bat flies within range (Fenton, 1970)) was detected, recording was manually triggered and the 10x time-expanded echolocations were digitally recorded (Edirol R-09, Roland, Los Angeles, USA) as Wav files (sampling rate 44.1 kHz and 16 bits/sample) for subsequent analysis.

A total of 7 survey rounds were conducted, between May and October of two consecutive years (3 in 2008 and 4 in 2009). Each sampling night, a maximum of 6 surveys were performed at random order, starting half an hour after civil twilight and ending up to 3 hours later, which is a period of general peak in bat feeding activity (Bartonicka and Rehak, 2004; Hayes, 1997). Surveying was not carried out during adverse weather conditions such as strong wind, mist, rain or temperatures <10ºC. Air temperature and relative humidity and time at survey start were recorded (Geonaute digital weather station).

Sound analysis and species identification

Field recordings were analyzed with the software Bat Sound Pro version 3.31b (Pettersson Elektronik AB, Uppsala, Sweden), which produces spectrograms, oscillograms and frequency spectra. Spectrograms were obtained with a sampling rate of 44.1 kHz, 16 bits/sample and a 512 points fast Fourier transform (FFT) with a Hanning window. Power spectra were generated with a FFT of 1024 points. Call parameters were measured using crosshair screen cursors; temporal variables were measured from oscillograms, while frequencies were taken from power spectra.

A bat call, or call sequence, can be defined as a series of pulses separated by pauses controlled by the bats (de Oliveira, 1998). Despite within and inter species variation in the calls of echolocating bats, associated to many different factors (Bayefsky-Anand et al., 2008; Fenton, 1999; Gillam et al., 2009; Griffin, 1958; Jones et al., 2000; Kalko and Schnitzler, 1993; Kingston et al., 2000; Obrist, 1995; Obrist et al., 2004; Parsons and Jones, 2000; Patriquin et al., 2003; Russo and Jones, 2002; Russo et al., 2001), it is generally accepted that species identification through echolocation analyses is possible, at least to a high level, if the adequate techniques are used (Ahlen and Baagoe, 1999; Jones et al., 2000; MacSwiney et al., 2008; O'Farrell et al., 2000; O'Farrell et al., 1999; O'Farrell and Gannon, 1999; Parsons and Szewczak, 2009). Time-expansion system is excellent for recording analyses (Ahlen and Baagoe, 1999), as it allows temporal and spectral analyses of signals, without any loss of sound resolution (Jones et al., 2000; Parsons et al., 2000; Parsons and Szewczak, 2009).

As in most literature, no identification was made for call sequences with call pulses of low quality or with less than 3 call pulses. For each suitable call, the following parameters were determined: pulse structure, start frequency (SF), end frequency (EF), frequency of maximum energy (FmaxE), bandwith (BW), pulse duration (Dur) and inter-pulse interval (IPI), in order to identify bat species (or groups of species, when identification to species level is not possible) by comparison with available literature (Ahlen and Baagoe, 1999; e.g. Barataud, 2002; Lundy and Montgomery, 2009; Obrist et al., 2004; Parsons and Jones, 2000; Russ, 1999; Russo and Jones, 1999, 2002; Teixeira, 2009; Zbinden and Zingg, 2009) and data bases (Barataud, 1996).

However, this identification method presents limitations in distinguishing species that echolocate pulses with overlapping characteristics. Thus, the following considerations must be presented:

- *Myotis myotis* and *M. blythii*'s echolocations are virtually indistinguishable, so these bats were pooled. Though, *M. blythii* is a very rare species in Central Portugal (Cabral et al., 2005), so it is assumed that these echolocations belong to *M. myotis*.
- *Myotis nattereri, M. emarginatus, M. mystacinus, M. daubentonii* and *M. bechsteinii* are generally difficult to distinguish with certainty, so they were grouped as "*Myotis* spp. small".
- *Pipistrellus pipistrellus* and *P. pygmaeus* cryptic species were not discriminated, being identified as a group, due to overlapping features of echolocation calls (Salgueiro et al., 2002). Some calls with FmaxE higher than 51 kHz, similar to *P. pygmaeus'* could belong to *Miniopterus schreibersii*. Nevertheless, it is an exclusively cave-dwelling species (Rodrigues et al., 2010), which closest known roost (at Verride, Montemor-o-Velho) locates at approximately 40km from the study area. *M. schreibersii* can be relatively abundant but only in the surroundings of important underground roosts (Rebelo and Rainho, 2009), which is not the case of the study area. So, although there was a possibility of occurrence of *M. schreibersii*, we understood that it was a much reduced one and attributed those echolocations to the most common and widespread species, *P. pygmaeus.*
- *Nyctalus lasiopterus* and *N. noctula* emit virtually indistinguishable echolocations, but the latter is an occasional, extremely rare species in Portugal (Cabral et al., 2005; Rainho et al., 1998), so these calls were attributed to the former.
- *Eptesicus serotinus* presents considerable echolocation plasticity and in many cases their calls are similar to those of *Nyctalus leisleri.* Thus, when identification to species was not confident, these species were pooled.
- *Plecotus auritus* and *P. austriacus* are whispering species that present undistinguishable echolocations, so they were grouped.

Recorded social calls or feeding buzzes were also registered. Social calls consist on acoustic signals broadcasted by bats with the exclusive function of communication (Fenton, 1977, 2003; Fenton and Brockett, 1985; Pfalzer and Kusch, 2003), which can assume many different purposes, such as repelling conspecifics (Budenz et al., 2009), courtship and mating (Barlow and Jones, 1997b; Lundberg and Gerell, 1986), food patch defense (Barclay et al., 1979; Barlow and Jones, 1997b), mother-young interaction (Barclay, 1999; Schmidt-French et al., 2006), attract conspecifics and probably to incite other bats to mob predators (Russ et al., 1998), among others. Since these vocalizations carry information to conspecifics, they may provide information to species differentiation (e.g. Barlow and Jones, 1997a; Jones et al., 2000; Russo and Jones, 1999). Feeding buzzes are call sequences produced with high pulse repetition rates that indicate prey capture attempt (Griffin et al., 1960; Schnitzler and Kalko, 2001).

In order to evaluate MM and NP's combined aptitude to correctly identify species through their echolocation calls, a test was performed using 80 call sequences of several species from individuals of known identity. The results are presented in a classification matrix (Appendix 1).

Data analysis

Number of bat passes was taken as a measure of bat activity (Russo and Jones, 2003; Vaughan et al., 1997). Data from the 7 sampling seasons were pooled to perform all analysis. To test for statistical differences among specific bat activity per habitat, analyses of variance were used (ANOVA's). Whenever relevant, the Fisher's least significant difference (LSD) was performed for multiple post-hoc comparisons. Such analyses were conducted for the 8 most abundant species or groups of species.

To analyze diversity, we evaluated the species richness (S =number of species), the Pielou's evenness $J' = H'/\log(N)$, the Shannon diversity index $H^{'} = \sum_{i=1}^{S} Pi\ (\ln Pi)$ and the Hill's diversity ($N_1 = e^{(H^{'})}$) for each habitat type. These indexes were calculated using data from all identified species/groups except those pooled as *E.serotinus*/*N.leisleri*.

Foraging activity and social interactions were assessed through the comparison of the total number of recorded feeding buzzes and social calls per habitat. The correlation between feeding buzzes and bat passes was calculated using a Pearson correlation. In all statistical analysis values of P<0.05 were considered significant. The results are expressed as mean ($\bar{x}$) ± standard error (SE) and respective 95% confidence intervals (CI).

4.4. Results

A total of 2624 bat passes were considered suitable for sound analysis and 13 species/groups of species were identified (Table 4.1).

Due to a high correlation value between bat passes and feeding buzzes (r=0.905; P=0.035), only bat passes were used to analyze the bat foraging activity and habitat use.

Overall, the species most frequently recorded belonged to the *Pipistrellus* genera, followed by *E. serotinus*. We identified 151 bat passes of *E. serotinus*, but notice the categorization of 127 bat passes as *E. serotinus/N.leisleri* (see methodological constraints in methods section).

Table 4.1. List of recorded species/groups of species and conservation status in Portugal (Cabral et al., 2005). Total number and relative percentage of bat passes per species. Number of bat passes identified in each habitat. Bus – Bussaco forest, Pin – Pine forest, Euc – Eucalyptus forest, LAg – Large agricultural fields, SAg – Small agricultural fields.

Species/Group of species	Status	Bat passes (%)	Bus	Pin	Euc	Lag	Sag
Rhinolophus ferrumequinum	VU	1 (0.04)	0	1	0	0	0
Rhinolophus hipposideros	VU	7 (0.27)	1	3	1	2	0
Myotis myotis/blythii	VU/CR	44 (1.68)	19	15	2	4	4
Myotis spp. small	VU/DD/DD/LC/EN	62 (2.36)	28	5	1	5	23
Pipistrellus pipistrellus/pygmaeus	LC/LC	1733 (66.04)	585	232	88	345	483
Pipistrellus kuhlii	LC	284 (10.82)	4	125	50	15	90
Nyctalus leisleri	DD	80 (3.05)	33	13	20	3	11
Nyctalus lasiopterus	DD	22 (0.84)	9	3	8	0	2
Eptesicus serotinus	LC	151 (5.75)	67	44	19	8	13
Eptesicus serotinus/Nyctalus leisleri	LC/DD	127 (4.84)	39	24	19	6	39
Barbastella barbastellus	DD	45 (1.71)	6	11	6	16	6
Plecotus auritus/austriacus	DD/LC	8 (0.3)	1	3	4	0	0
Tadarida teniotis	DD	60 (2.29)	46	6	1	3	4

Eight species/groups can be considered more frequent. Analysis of habitat use for these species (Fig. 4.1) showed that all of them occurred in all habitats, although with different trends. All species presented significant differences in habitat uses, except *B. barbastellus*, which used all habitats indiscriminately ($F_{(4,199)}$=0.649; P=0.623). *T. teniotis* is the only species that showed a clear preference for only one habitat, Bussaco's mixed forest ($F_{(4,199)}$=12.349; P<0.001).

The analysis of overall bat activity in each habitat reveals three preference levels ($F_{(4,199)}$=14.128; P<0.001), (Fig 4.2). The highest bat activity was found in Bussaco's mixed forest (19.95±2.3) and the lowest in eucalyptus monoculture (5.21±0.74). The small agricultural patches presented an overall bat activity almost as high as Bussaco's (18.75±1.71). These results point these two habitats as the most important for foraging bats of the study area.

In terms of diversity, the results showed in Table 2 prove Bussaco's attractiveness for local bats. This mixed woodland presented the highest diversity, followed by the small agricultural fields that also showed elevated diversity values. However, these two habitats also exhibit low evenness, because their bat populations are clearly dominated by *P. pipistrellus/pygmaeus* (Table 4.1). Pine plantations presented no statistical differences in species richness from small agricultural fields, however *Pinus*' bat populations were much more even. Similarly, eucalyptus presented the lowest diversity but exhibited the highest evenness.

Table 4.2. Diversity indexes calculated per habitat. Mean values ($\bar{x}$) and 95% confidence interval (CI) are presented.

		Bussaco	**Pine**	**Eucalyptus**	**Large Agric.**	**Small Agric.**
Species richness	$\bar{x}$	3.33	2.71	1.81	1.88	2.72
	CI	2.89 - 3.77	2.24 - 3.19	1.45 - 2.17	1.52 - 2.25	2.38 - 3.06
Pielou's evenness	$\bar{x}$	0.68	0.82	0.87	0.66	0.63
	CI	0.62 - 0.75	0.77 - 0.87	0.82 - 0.93	0.54 - 0.78	0.56 - 0.70
Shannon diversity	$\bar{x}$	0.75	0.72	0.47	0.34	0.58
	CI	0.62 - 0.89	0.57 - 0.86	0.32 - 0.62	0.21 - 0.47	0.48 - 0.68
Hill's diversity	$\bar{x}$	2.32	2.25	1.79	1.54	1.87
	CI	2.01 - 2.62	1.96 - 2.54	1.51 - 2.06	1.29 - 1.79	1.68 - 2.06

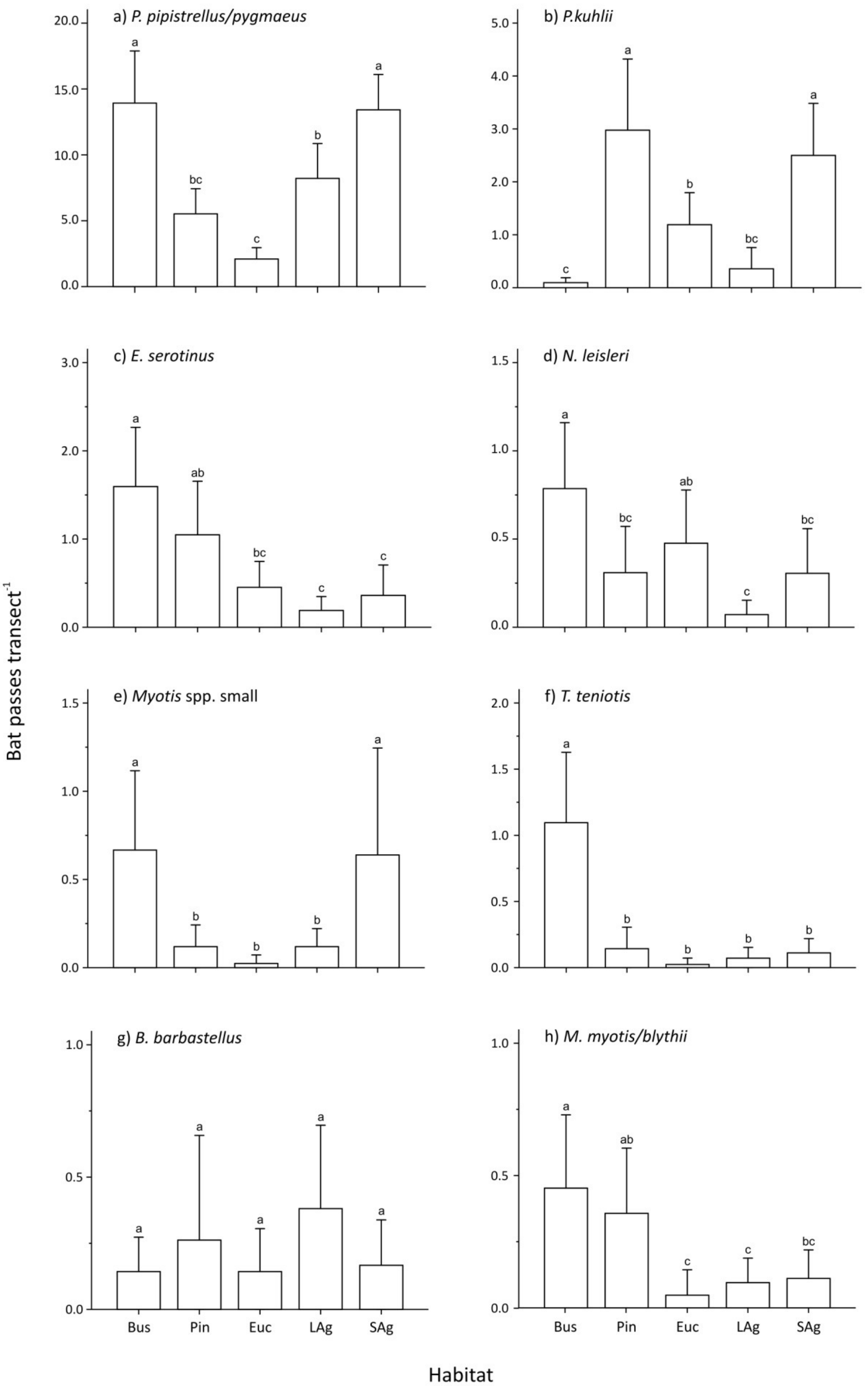

Fig. 4.1. Mean number of bat passes per transect, per species. Vertical lines show the 95% confidence limits. Habitat abbreviations as in Table 1. Notice the differences in scale of the *y*-axis.

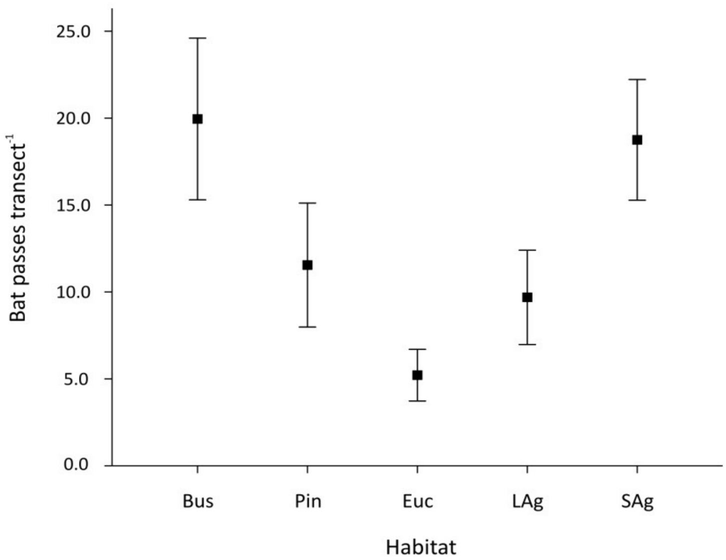

Fig. 4.2. Mean number of bat passes per transect. Vertical lines show the 95% confidence limits. Habitat abbreviations as in Table 1.

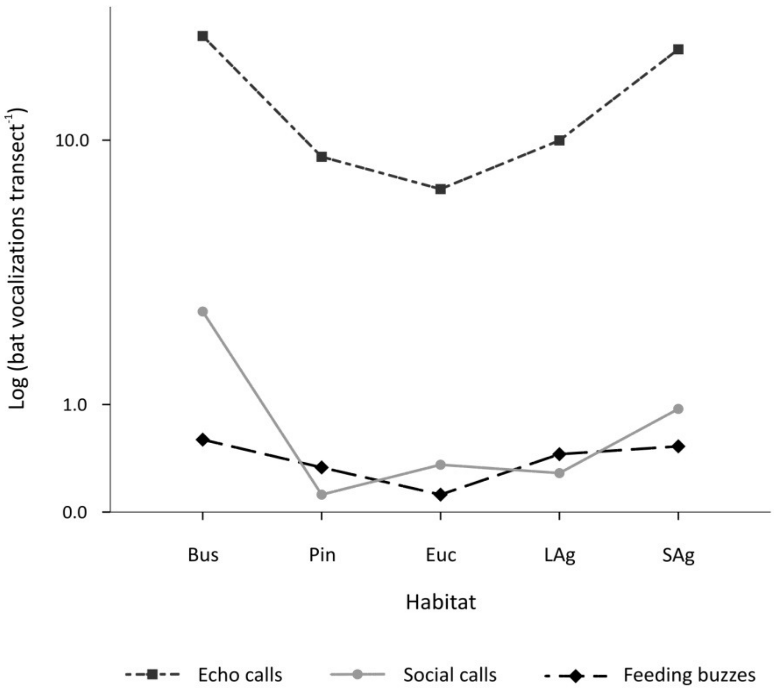

Fig. 4.3. Mean number of bat passes (echolocation calls), feeding buzzes and social calls recorded per transect. Habitat abbreviations as in Table 1.

The majority of social calls were recorded in Bussaco forest, again followed by the small agricultural fields. In pine monocultures, only a few social calls were recorded (Fig. 4.3).

4.5. Discussion

The used method provides a wealth of important data for bat research, assessing several species and habitats in a single study, despite some constraints.

In this study we identified 8 most common species/groups. Amongst the *Myotis* groups, 4 endangered species might occur, although with slight probability (with the exception of *M. myotis*/*blythii)*. Records obtained for rhinolophids (threatened species) and *Plecotus* spp. may be underestimated because their echolocation calls are difficult to detect (Vaughan et al., 1997). In the particular case of *R. hipposideros*, the detected activity level may suggest the existence of a roost in the study area that could be confirmed by the application of complementary sampling methods.

In the study area, as expected, the most common bat species are the Pipistrelles. We were not able to assess *P. pipistrellus* and *P. pygmaeus* habitat use individually, but altogether, they exhibited preference for Bussaco's mixed forest and small agricultural patches. Eucalyptus plantations were the less used habitat. One the other hand, *P. kuhlii* demonstrated an unexpected preference for pine plantations, practically avoiding the mixed woodland. Further studies, namely related with prey availability and diet, are required to explain these preferences. In previous studies (Carmel and Safriel, 1998; Rainho, 2007; Russo and Jones, 2003) *P. kuhlli* preferred, in general, water sites or human settlements. These features are found in our small agricultural patches, which always had a small river or a pond and street lamps.

E. serotinus and *N. leisleri* made use of all habitats ($F_{(4,199)}$=6.493; P<0.001; $F_{(4,199)}$=3.901; P<0.001, respectively), seeming to avoid large farmlands. The majority of bat passes were recorded in Bussaco's forest, what does not corroborate the preferences for water sites and open areas described by Vaughan et al. (1997). For *E. serotinus*, our findings are in agreement with those of Zukal and Rehak (2006), Wickramasinghe (2003) and Rainho (2007), which mention this species' ability to exploit many habitats.

Myotis spp. small could not be distinguished individually, but most of the recorded bat passes should belong to the most common species, *M. daubentonii*. This would explain the observed preference for Bussaco's forest and small agricultural fields, given the foraging habits dependent on aquatic sites (Akasaka et al., 2009). Nevertheless, large farmlands also present water sites, but were not more used then dry pine plantations.

Assuming that *Myotis blythii* is very rare, the most used habitats by *M. myotis* are Bussaco's and pine woodlands. Eucalyptus plantations and both agriculture fields presented low activity and no relevant differences between them. These findings are concomitant with general foraging habits described in literature (Zahn et al., 2007; Zahn et al., 2006)

T. teniotis is considered a typical 'open space' forager that feeds mainly on migrating moths, high above the canopy (Arlettaz, 1995). Notwithstanding, in this study, this molossid selected positively only Bussaco's forest, that is essentially cluttered. A study based on radio-marked *T.teniotis* (Marques et al., 2004) refers that these bats usually fly directly from their roosts to previously identified feeding sites, that can locate quite far from the roost. In the same study this species was highly selective, foraging mostly over stone pine and cork oak woodland. Rainho (2007) obtained a preference for pine woodland and shrubs, Carmel and Safriel (1998) for human settlements and Russo and Jones (2003) reported no significant differences in the use of several habitats. Taking all this to account, as well as the availability of different habitats among the study area, our results suggest that Bussaco's forest constitutes a very profitable foraging area for *T. teniotis*. As even basic knowledge about this species' foraging ranges and trends is still missing (Cabral et al., 2005; Marques et al., 2004), these results can be an important contribute and constitute the basis for further research.

B. barbastellus was the only species using all habitats indiscriminately. These results seem to support Sierro's (1999) assumption, indicating that barbastelle's feeding specialization on moths does not stem from a specialized habitat selection.

Overall bat activity differed significantly between habitat types. Bussaco's forest and small agricultural patches, both habitats with water sites, are of crucial importance for foraging bats in the study area. These results concur with those of Walsh and Harris (1996b), stating that woodlands and water sites are key foraging sites for bats, even when constituting less common habitats in the landscape.

Previous studies of bat communities in different habitats demonstrated the importance of fresh-water sites and streams for bats in many places (e.g. Brooks, 2009; Grindal et al., 1999; Lundy and Montgomery, 2009; Russ and Montgomery, 2002; Vaughan et al., 1997; Walsh and Harris, 1996a, 1996b; Zukal and Rehak, 2006), including Mediterranean regions (Carmel and Safriel, 1998; Rainho, 2007; Rebelo and Rainho, 2009; Russo and Jones, 2003). Riparian areas present a higher diversity and abundance of insects than any other type of habitat (Barclay, 1991) and this prey availability seems to support an elevated richness of foraging bats (Lloyd et al., 2006).

Several studies pointed broadleaved or mixed woodlands amongst bats' preferred foraging areas (Russ and Montgomery, 2002; Russo and Jones, 2003; Walsh and Harris, 1996a, 1996b). Notwithstanding, coniferous woodlands represent a less optimal woodland type for bats, demonstrating low foraging value in the generality of the studies (Rainho, 2007; Russo and Jones, 2003; Walsh and Harris, 1996b). This may be due to the lower insect diversity and abundance present in these forests, in relation to broadleaved ones (Entwistle et al., 1996; Fry and Lonsdale, 1991; Waring, 1988; Winter, 1983).

Pine plantations of the study area presented similar activity to that of large farmlands. Agricultural intensification seems to contribute to bat populations decline (Wickramasinghe et al., 2003), as it causes the homogenization of the habitat and the increased use of pesticides reduces prey availability (Wickramasinghe et al., 2004). There is also growing evidence that the use of these chemicals may directly poison bats (Allinson et al., 2006; Brosset et al., 1988; Geluso et al., 1976). In addition, homogeneous agricultural fields usually lack roosting or shelter sites provided by trees or woodland. All these factors may partially explain why bats tend to avoid intensively managed areas or wide arable lands, as shown in several studies (Carmel and Safriel, 1998; Rainho, 2007; Russo and Jones, 2003; Walsh and Harris, 1996b; Zukal and Rehak, 2006).

The obtained results clearly show that eucalyptus stands are the less used habitat in the study area. The other monoculture plantations considered are from an autochthonous species (Figueiral, 1995), whilst eucalyptus was recently introduced in the country, having poorer fauna (Zahn et al., 2009) and understory flora associated. In terms of land cover, the study area is very similar to a great extension of central Portugal, thus some conservation measures can be outlined from this study. In this region, natural forests are scarce and eucalyptus continues to be planted, sometimes in areas of previous traditional agriculture. This type of agriculture is also being abandoned all over the country. Mixed or natural woodlands, water sites and traditional agriculture constitute key habitats for foraging bats, so they must be encouraged and preserved.

Portuguese pine stands are currently facing a serious infection of the nematode *Bursaphelenchus xylophilus* (Mota et al., 1999) and it is expected that large extensions will be harvested, as a control measure. It is important that conservations recommendations are taken into account, to avoid reforestation with detrimental species for overall biodiversity.

Although temporal analysis did not constitute an objective of this study, the great number of social calls recorded in Bussaco forest took us to look more carefully at this data. Further studies are required, but since the majority of these calls concentrated in late summer and early autumn, it is possible that this forest constitutes a swarming area. Swarming areas are known for their importance for mating and outbreeding (Parsons et al., 2003) thus constituting key habitats and conservation priority sites (Furmankiewicz and Altringham, 2007; Kerth et al., 2003). This possibility reinforces Bussaco's National Forest for bat conservation, in a regional context.

Acknowledgements

The authors are grateful to Dr. Hugo Rebelo, for helpful comments on an earlier draft of this manuscript, and to Pedro Pereira and Luís Pascoal da Silva for assistance in field work. Milena Matos was supported by a PhD grant from Fundação para a Ciência e a Tecnologia (SFRH/BD/31146/2006).

Appendix 1. Classification table of the identification of 80 echolocation sequences of 13 species and 3 species complexes (*M. myotis*/*M.blythii*, *P. auritus*/*P. austriacus*, *P. pipistrellus*/*P.pygmaeus*) that represent the regional bat communities. Values in the diagonal represent the number of sequences correctly identified. Overall, the results show good performance of the identification procedure.

Species	n	Classification																	
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	Myostis spp. small	%
1. *B. barbastellus*	5	5																	100,0
2. *E. serotinus*	13		13																100,0
3. *M. daubentonii*	5			5															100,0
4. *M. emarginatus*	2				1													1	50,0
5. *M. myotis/M. blythii*	6		1			5													83,3
6. *M. mystacinus*	2						2												100,0
7. *M. nattereri*	1																	1	0,0
8. *M. bechsteinii*	1																	1	0,0
9. *N. lasiopterus*	5									5									100,0
10. *N. leisleri*	9		1								8								88,9
11. *P. auritus/P. austriacus*	4											4							100,0
12. *P. kuhlii*	5												5						100,0
13. *P. pipistrellus/P. pygmaeus*	12													12					100,0
14. *R. ferrumequinum*	2														2				100,0
15. *R. hipposideros*	4															4			100,0
16. *T. teniotis*	4																4		100,0
																		Global efficiency	93,8

4.6. References

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O leão riu muito das palavras do ratinho e perguntou:
Como pode um bichinho desse tamanho ajudar-me em alguma coisa?

Fábula de Esopo

Chapter 5

Spatial and temporal patterns of small mammal communities’ structure

5. SPATIAL AND TEMPORAL PATTERNS OF SMALL MAMMAL COMMUNITIES' STRUCTURE

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Submitted to *Acta Oecologica*

5.1. Abstract

Agriculture and forestry have been leading promoters of wide-reaching landscape modifications, often with deep effects on wildlife communities. Small mammals are an important group to consider where the maintenance of ecological values is a concern. This study aimed to compare the diversity and abundance of small terrestrial mammals in five differently human-altered habitats of Central Portugal: fields of traditional agriculture, larger and more intensively cultivated farmlands, monocultures of *Pinus pinaster* and *Eucalyptus globulus* and an old growth mixed forest; and thus assess the influence of land use on these communities. It was also meant to compare temporal and spatial influences on the composition of small mammal assemblages. Spatial attributes, traduced by habitat differences, presented a much greater influence on the composition of small mammal communities than time, related to sampling seasons. Agricultural intensification did not affect species richness but seemed to enhance species abundance, which should probably be due to higher food availability. Forests were mainly dominated by *Apodemus sylvaticus*, a generalist species, thus results did not allow us to conclude about a negative effect of monocultural plantations on small mammal communities.

5.2. Introduction

Small mammals play a major role in ecosystems' structure and functioning. Firstly, they contribute to the complexity of food webs (Korpimäki and Norrdahl, 1991), as they constitute an important food resource for many avian (e.g. Goutner and Alivizatos, 2003) and mammalian (e.g. Rosalino and Santos-Reis, 2002) predatory species, and may directly influence their abundance, distribution and dynamics (e.g. Korpimäki, 1984; Sálek et al., 2010). Furthermore, they represent primary consumers of plants, lichens, fungi and invertebrates (Hörnfeldt et al., 1990) and may be positively involved in plant species long-term survival, for example acting as seed (Herrera, 1995; Jensen and Nielsen, 1986) and mycorrhizal fungi (Maser et al., 1978) dispersers. Small mammals' numerous (Jacob, 2003) and fast growing populations (Wijnhoven, 2007) in association with their feeding and burrowing behavior can also take part in landscape engineering (Andersen and Cooper, 2000; Davidson and Lightfoot, 2008; Mace et al., 1997). Shrew species have also a significant impact on litter decay process (Shvarts et al., 1997). Moreover, small mammals may also serve as indicators of environmental health, biodiversity or ecological change (Flowerdew et al., 2004; Sullivan et al., 2005). However, despite providing such services, small mammals have been frequently regarded only as major pests causing damages to agricultural production and forestry (Batzli and Pitelka, 1971; Myllymäki, 1977; Santini, 1977). The diversity and occurrence of small mammal species that are common at lower trophic levels may be essential to promote biodiversity as a whole (Arlettaz et al., 2010).

This research was carried out at Central Portugal, in a typically fragmented region. The primeval landscape of this region, mainly covered with woodland dominated by oak species (*Quercus* spp.) (Bingre and Damasceno, 2007; Ramil-Rego et al., 1998), has been deeply modified by conversion to agriculture and forestry (Paiva, 1998; Vieira et al., 2000). Present natural vegetation is virtually inexistent in the region, and more than 78% of forested areas are composed of monocultural stands of maritime pine *Pinus pinaster* and *Eucalyptus globulus* (CNIG, 1995; DGRF, 2007), faster growing and economically profitable species mainly exploited for timber and paper production industries.

Worldwide growing awareness for sustainability and biodiversity conservation has produced a considerable amount of studies inspecting impacts of anthropogenic activities such as agriculture (e.g. Bilenca et al., 2007; Burel et al., 2004; de la Peña et al., 2003) or forestry (e.g. Constantine et al., 2004; Schmid-Holmes and Drickamer, 2001; Sullivan et al., 2009) on several *taxa*, including small mammals. Most of the literature reports that intensive agriculture or industrial forestry, to some degree, negatively affect small mammals' diversity, community structure or abundance (Bowman et al., 2001; Brown, 1999; Christian et al., 1998; Macdonald and Tattersall, 2007; Michel et al., 2006; Pedersen et al., 2010; Saitoh and Nakatsu, 1997). Notwithstanding, this main trend cannot be generalized, as many exceptions are presented and attention must be paid to the framework of each research. For example, Burel et al. (1998) found that small mammals were poorly affected by intensification of agriculture, along a gradient of agricultural landscapes in France. Sullivan and Sullivan (2001) reported that abundance, species richness and diversity of small mammals did not vary between various forest harvesting treatments in mixed natural forests of Douglas fir *Pseudotsuga menziesii* and lodgepole pine *Pinus contorta*.

It is important to understand distributional patterns and ecological requirements of small mammals for an adequate understanding of their role in ecosystems. Overall, habitat preferences of Iberian small mammals have been little researched (de Alba et al., 2001; Paradis and Guédon, 1993). Some populations' dynamics and specific aspects of their occurrence have been studied (e.g. de Alba et al., 2001; Pita et al., 2010; Rosalino et al., 2011b; Santos et al., 2011), but much is still to know. To our knowledge, this is the first study to focus on spatial and temporal questions of the whole small mammal communities occurring in monocultural forests and different agricultural systems, in the Iberian Peninsula. We aimed to assess the influence of current main land-uses in Central Portugal on small mammals, by comparing their relative distribution, abundance and diversity among five differently human-altered habitats: monocultural stands of *Pinus pinaster* and *Eucalyptus globulus*, an old-growth mixed forest and two types of agricultural fields. Because complex and heterogeneous ecosystems present higher availability of ecological niches and, therefore, superior carrying capacity for small mammal communities (Carey and Harrington, 2001; Fitzgibbon, 1997; Pearce and Venier, 2005), we expect a higher abundance and diversity of small mammals in habitats with the highest structural heterogeneity. We also aimed to compare temporal and spatial influences on the composition of small mammal communities.

5.3. Methods

Study area

The study was conducted in a 25 000 ha area, located in Central Portugal and centered at Bussaco National Forest (maximum elevation of 547 m a.s.l. at Cruz Alta 40º22'13''N, 8º21'59''W). Bussaco is a wall fenced old-growth woodland with approximately 105 ha which constitutes an exclusive natural heritage, representing one of the best dendrological collections in Europe, where tree species from the entire globe can be found. The exotic species started being planted during the 17th century. Bussaco keeps also a patch of the primitive Mediterranean forest, with native shrub and tree cover (Paiva, 2004).

We performed habitat stratification of the study area by means of photo-interpretation and field validation, and came out with five dominating habitats within the fragmented landscape: Bussaco Forest, monocultures of *Pinus pinaster* and *Eucalyptus globulus*; large agricultural fields (machine-laboured mosaic of fields) and small patches of traditional agriculture (mainly produce gardens, hand-laboured, for domestic consumption), surrounded by vast areas of eucalyptus plantations. These small patches locate near little rural villages and always have a water course, a small river or a water pond in the environs.

Being a Mediterranean area with some Atlantic influence, in the study area summers are hot (maximum 39°C) and winters mild (minimum -1°C). Annual average precipitation is of 804 mm, mostly concentrated in autumn and winter. However, Bussaco presents a fresher and rainier microclimate, with a mean annual precipitation of 1525 mm.

Small mammal surveys

We selected 25 sites (5 replicates for each habitat type) where we sampled small mammals. To increase spatial independence, sites were separated by a minimum of 1 km, except in Bussaco Forest, due to spatial limitation.

Small mammals were surveyed by live-trapping, which is the most used method to study rodents and insectivores (Gurnell and Flowerdew, 2006; Thompson et al., 1998) and has been successfully used to analyze patterns of richness, composition and abundance of these communities. In each sampling site we set a line of 30 aluminum box traps (17.5x6x6 cm) separated 10 m from each other and baited with a mixture of canned sardines and hamster food. Cotton was provided as nesting material. Whenever possible, traps were set under the cover of stones, shrubs or herbs to provide camouflage and some thermal insulation (Torre et al., 2007). Traps were left in the field for three consecutive nights and visited every early morning (Gurnell and Flowerdew, 2006). At each trap check, dry bedding material and new food supply were provided. Captured animals were removed and released alive several km away from sampling sites, after identification, weighing and sex determination. Removal of captured animals avoided bias related with trap-proneness. All animals were captured and handled meeting the terms of the Portuguese law (ICNB licenses nº 106/2008/CAPT and 74/2009/CAPT).

We performed a total of six sampling rounds, one at the end of each season, between September 2008 and November 2009.

Data analysis

Species abundances were expressed as total number of unique individuals captured, without any correction, because the trapping effort was exactly the same for each trapping unit/season. Species abundance data were Hellinger transformed in order to make it suitable for ordination analysis (PCA and RDA) (Legendre and Gallagher, 2001). The use of linear ordinations methods (PCA and RDA) in our analysis was tested using a detrended correspondence analysis, DCA (Hill and Gauch, 1980) to determine the longest gradient length and through the inspection of coenoclines. A coenocline shows the distribution of each species along a gradient that can be an axis obtained by an ordination method (PCA, RDA, CA and CCA) or one of the original explanatory variables. The different coenoclines were constructed by fitting a LOESS smoothing function for each species along 4 specific gradients, the first and the second axis obtained by PCA and the first and the second axis obtained by CA. Since the longest gradient was less than 3 standard deviation units and the coenoclines clearly showed that all the smoothing curves were approximately straight lines, we adopted a linear response model (ter Braak, 1995; ter Braak and Prentice, 1988).

As a way of looking for a general pattern in species composition among habitats and seasons we used the values of the first axis of a principal component analysis (PCA) as a global index of differentiation in community composition. We then plotted the mean values of the first axis of the PCA for each different habitat type across the seasons.

In order to clarify the variation in species composition we performed two separate RDA analyses: one by using sampling habitat types (habitat-RDA) and the other by using seasons (season-RDA) as constrained variables. In order to test the habitat-season interaction, we used a two-way MANOVA-like RDA with interaction. This method uses RDA as a form of multivariate analysis of variance to test the relationship between the species data and two crossed factors (Legendre and Anderson, 1999), in this case habitat and season. To find how much of the variance in species structure can be explained by habitat and by season we performed a variation partitioning following the methodology described by Peres-Neto et al. (2006). As a graphical representation of the results of the variation partitioning analysis we constructed a Venn diagram that shows the percentage of the species composition variance accounted by each fraction. All the analyses were performed using the R statistical language (R 2.12.1, R Development Core Team, 2010).

5.4. Results

A total of 954 individual small mammals were caught in 13500 trap-nights, representing 7.1% of trapping success (Table 5.1). Six species were captured: five rodents (wood mouse *Apodemus sylvaticus*, Algerian mouse *Mus spretus*, house mouse *Mus domesticus*, Lusitanian pine vole *Microtus lusitanicus* and brown rat *Rattus norvegicus*) and one insectivore (white-toothed shrew *Crocidura russula*). *Apodemus sylvaticus* was the most abundant species, clearly dominating among the forest habitats. *Mus spretus* was the most abundant species in farmlands. The only capture of one individual *Rattus norvegicus* is due to the relatively small size of the traps, not designed for capturing this species.

Species composition and abundances varied among habitats and sampling seasons. The first principal component axis accounted for 66% of the total variation of the species composition data. The values of this axis can be used as a global differentiation index. The mean of these values for each habitat type in each season is plotted in Figure 1 where we can recognize a clear separation at the habitat level between agricultural habitats (SAg and LAg) and woodlands (Euc, Bus and Pin). This differentiation is highlighted across all the sampling seasons.

Table 5.1. Number of small mammals of each species captured in each habitat type. Habitats types: SAg, small agricultural field; LAg, large agricultural field; Euc, eucalyptus forest; Pin, pine forest; Bus, Bussaco forest. Species: Aposyl, *Apodemus sylvaticus*; Crorus, *Crocidura russula*; Miclus, *Microtus lusitanicus*; Musdom, *Mus domesticus*; Musspr, *Mus spretus*; Ratnor, *Rattus norvegicus*. The two last columns summarize the total number of captures (Total) and species richness (S) per habitat.

Habitat	Aposyl	Crorus	Miclus	Musdom	Musspr	Ratnor	Total	S
SAg	46	8	2	7	95	0	158	5
LAg	73	7	1	11	188	0	280	5
Euc	141	5	17	0	8	0	171	4
Pin	186	0	1	0	0	0	187	2
Bus	149	5	3	0	0	1	158	4
Total	595	25	24	18	291	1	954	6

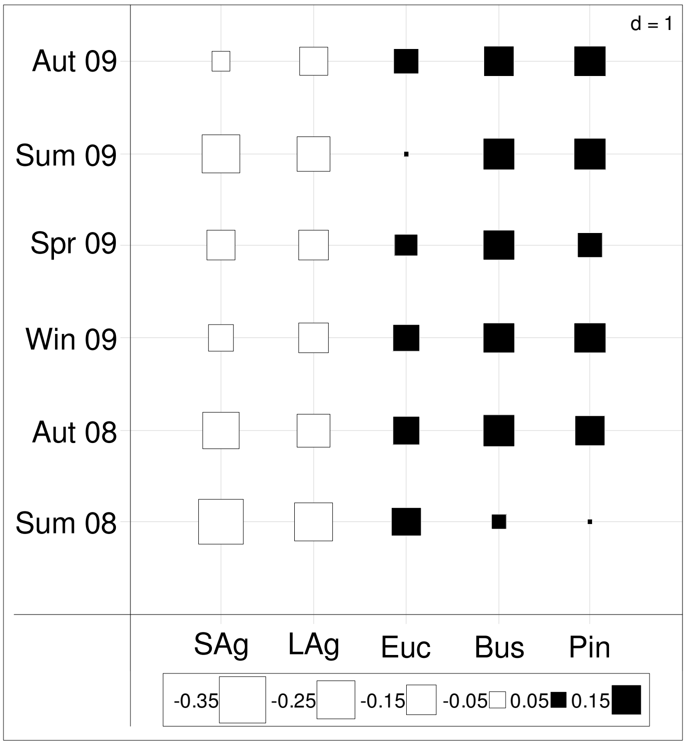

Fig. 5.1. Mean values of the first principal component axis (which account for 66% of the total variation), by habitat and season, of the small mammal species abundance data (Hellinger transformed). The size of the squares is proportional to their values; negative values are in white colour and positive values in black colour. Habitats types: SAg, small agricultural field; LAg, large agricultural field; Euc, eucalyptus forest; Pin, pine forest; Bus, Bussaco forest. Sampling seasons: Sum 08, summer of 2008; Aut 08, autumn of 2008; Win 09, winter of 2009; Spr 09, spring of 2009; Sum 09, summer of 2009.

The habitat-RDA (Fig. 5.2a) explained 45.84% (unadjusted canonical R-square) of the variation in the species assemblage. The test of all canonical axes shows that habitat explained a significant (*Pseudo-F*=30.685, *P*=0.002) amount of the variation of the species data and that the first and second canonical axis represent a significant (axis1: *Pseudo-F*=116.9141, *P*=0.002; axis2: *Pseudo-F*=3.3349, *P*=0.034) part of this variation. The first axis of the habitat-RDA was chiefly related to main habitat types, opposing agricultural fields to forests. *M.spretus* were strongly associated with both types of farmlands, while *Mus domesticus* showed a more reduced affinity with those habitats. *Apodemus sylvaticus* exhibited a clear preference for forests, particularly towards Bussaco and pine plantations. *Microtus lusitanicus* showed affinity with eucalyptus stands and *Rattus norvegicus* and *Crocidura russula* did not reveal association to any of the habitat types.

a) Habitat-RDA

b) Season-RDA

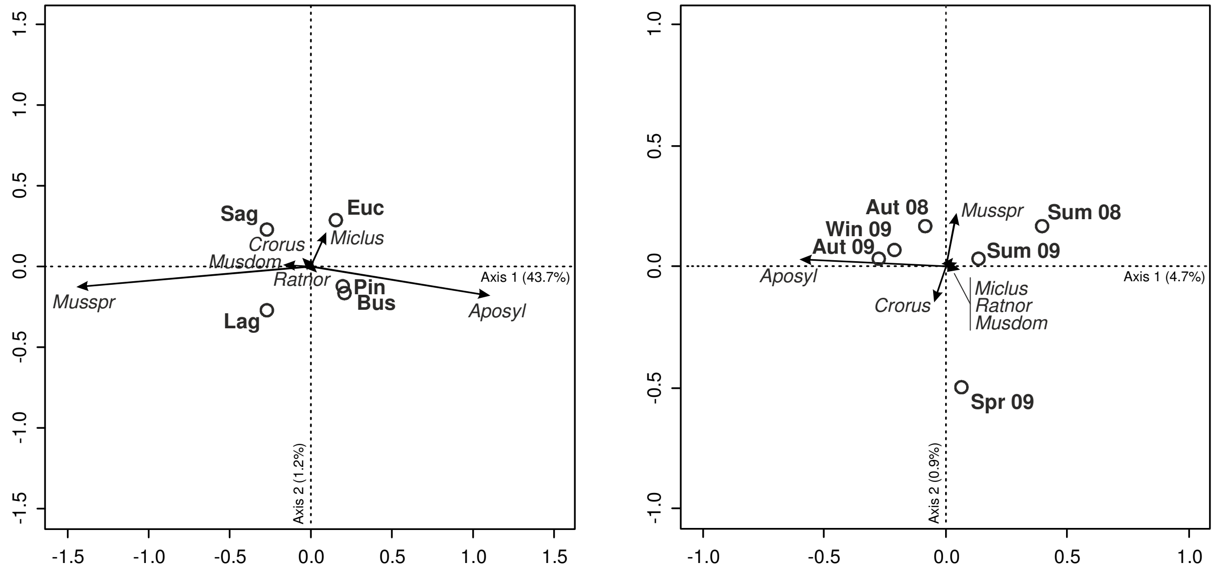

Fig. 5.2. Biplots of the species abundance data constrained by a) habitat and by b) season on the two first canonical axes of the redundancy analysis ordination (RDA). Species are represented by arrows and the explanatory variables (habitat and season) by circles. Species abundance data were Hellinger transformed. Species variables: Aposyl, *Apodemus sylvaticus*; Crorus, *Crocidura russula*; Miclus, *Microtus lusitanicus*; Musdom, *Mus domesticus*; Musspr, *Mus spretus*; Ratnor, *Rattus norvegicus*. Habitat variables: Sag, small agricultural fields; Lag, large agricultural fields; Euc, eucalyptus forest; Pin, pine forest; Bus, Bussaco forest. Season variables: Sum 08, summer of 2008; Aut 08, autumn of 2008; Win 09, winter of 2009; Spr 09, spring of 2009; Sum 09, summer of 2009.

The season-RDA (Fig. 5.2b) shows that the season accounted for 5.98% (unadjusted canonical R-square) of the variation of the species composition data. The test of all canonical axes indicates that season explained a marginally significant part of the variance in species assemblage (*Pseudo-F*=1.8302, *P*=0.048). Although the first canonical axis was highly significant (*Pseudo-F*=7.3058, *P*=0.006), the second canonical axis was not significant (*Pseudo-F*=1.4038, *P*=0.23) and should not be interpreted, since it does not represent a variation more structured than random. The first axis represents a gradient that separated autumn and winter samples from spring and summer samples, indicating that assemblages' composition varied with season. *Apodemus sylvaticus* largely contributed to these results, as they presented accentuated peaks in winter and autumn, namely in autumn of 2009. *Mus spretus* presented smoother fluctuations between warm and cold seasons. This species presented a reduction in abundance during the spring of 2009, which appears well illustrated in the RDA. *Crocidura russula* were identically caught in autumn, winter and spring of 2009, and residually in 2008. *Microtus lusitanicus*, *Mus domesticus* and *Rattus norvegicus* did not show specific temporal trends.

Variation partitioning demonstrated that habitat explains a greater part of the variation (44.3%, adjusted canonical R-square) in the species composition and that season accounts for much less variation (2.7%, adjusted canonical R-square). From the Venn diagram (Fig. 5.3) we see that fraction [b], common to both habitat and season, has a negative value. This simply indicates that together they explain the small mammal community composition better than the sum of their individual effects. The amount of variation explainable only by habitat ([c]=46.0%; Fig. 5.3), such as occurs in general, is greater than the variation explainable only by season ([a]=4.4%; Fig. 5.3). We can than say that the variation of small mammal communities' composition can be better explained by space, i.e. habitats, than by time, i.e. seasons.

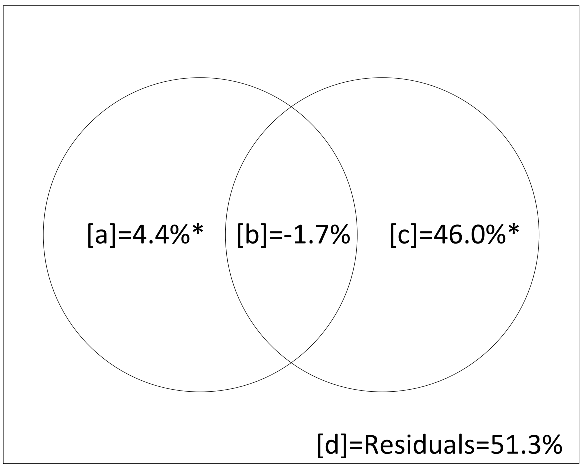

Fig. 5.3. Venn diagram partitioning the variation of the species composition between seasons ([a]+[b]) and habitat ([b]+[c]). The reported values are the percentage of variation corresponding to each fraction based on adjusted canonical R-squares. Fraction [a] and [c] were significant at $P \leq 0.05$ ($P=0.001$, based on reduced model using 999 permutations), fractions [b] and [d] cannot be tested. [a] variation explainable only by season; [b] variation explainable both by season and habitat; [c] variation explainable only by habitat; [d] unexplained variation, residuals.

The season-habitat interaction on small mammal species composition was not significant (P=0.358; Table 5.2), and was excluded from the model in the following analysis. Tests of the main factors season and habitat, showed that species assemblage is significantly related to habitat (P=0.001; Table 5.2) and significantly varied with season (P=0.001; Table 5.2).

Table 5.2. Effects of season, habitat and their interaction on small mammals' community composition. *Values are significant at $P \leq 0.05$. All tests were performed under reduced model using 999 permutations.

	d.f.	Pseudo-*F*	*P*
Interaction included in the model:			
Habitat x season	20	1.0634	0.358
Habitat	4	33.6030	0.001*
Season	5	3.5039	0.001*
Interaction excluded in the model:			
Habitat	4	33.3015	0.001*
Season	5	3.4724	0.001*

5.5. Discussion

Small mammals are an important group to consider where the maintenance of ecological values is a concern. We compared the diversity and abundance of small terrestrial mammals in five habitats and obtained a satisfactory picture of the relative distribution of the species composing regional small mammals' communities, and of its structure as well.

The results show that species have different habitat preferences and conceivably different resource requirements, being landscape heterogeneity a major factor contributing to the diversity of the studied communities (Bobretsov et al., 2005) as it assures the availability of adequate habitat for several different species (Holland and Bennett, 2007). Spatial elements, traduced by habitat types, were proved to be of great importance for communities' structuring.

For each species, the quality of a habitat is strongly influenced by the availability of resources such as food, refuge and breeding sites, and also by the risk of predation (Michel et al., 2007). In theory, individuals occupy more promptly the habitats that favor their survival and reproduction. Therefore, in those habitats population densities should be higher. However, our predictions that habitats with greater structural complexity, such as fields of traditional agriculture and Bussaco National Forest, would present greater species diversity and abundances failed. Large farmlands presented as much species as traditional agriculture, but greater abundances. Among woodlands, eucalyptus and Bussaco mixed forest presented the same species richness and pine plantation the highest densities, though vastly dominated by one single species, *Apodemus sylvaticus*.

The results obtained in farmlands concur with those of Burel et al. (1998), which indicated that the diversity of small mammals was not much affected by the intensification of agriculture and that most species remained present along a gradient from low to high disturbance. The larger farmlands sampled in our study presented some intensification, traduced by some habitat simplification, enlargement of crop patch size and product yield, but keep some traditional features such as creeks, trees, ponds and small hedgerows. Although we did not directly measure those influences, it is likely that those elements contribute to local species diversity and abundance (e.g. Bilenca et al., 2007; Gelling et al., 2007; Michel et al., 2006), providing refuge, nesting and also feeding sites (Rosalino et al., 2011a). Larger farmlands were also the habitat with the highest small mammals' density, which could be due to the large availability of feeding resources such as seeds and cereals resulting from agricultural production intensification. It is also possible that traditional agricultural fields detain greater predatory pressure, as carnivores are favored by these landscape features (Pita et al., 2009). Both types of agricultural fields were dominated by *Mus spretus*. This spatial distribution of *Mus spretus* is consistent with previous descriptions of habitat preferences for this species (Khidas et al., 2002; Palomo, 2002). *Apodemus sylvaticus* were also common in cultivated fields, where it was sympatric with *Mus spretus*. Sympatry between these two species is not extensively documented, however some authors refer some inverse pattern of occurrence (Blanco, 1998; Khidas et al., 2002) and competition for food, presenting *Mus spretus* more specific ecological requirements and thus being more competitive than *Apodemus sylvaticus* (Fons et al., 1988). We consider the study area has potential to promote further studies on this interspecific relationship.

Woodlands, in general, presented fewer species and lower abundances than farmlands, except for *Apodemus sylvaticus*. Monotonous forestry plantations, namely managed for timber production, are greatly simplified habitats for animals and are known to enhance the dominancy of the predominant species (Ota et al., 1976; Saitoh and Nakatsu, 1997). Hence, although we had no data from other studies in the Iberian Peninsula to compare with, the results for both monocultures were not surprising. Nevertheless, as Bussaco is an extremely diverse and complex woodland, with abundant shrubby and herbaceous cover as well as several feeding and nesting resources, a more diverse and even community was expected. As generalist species are able to adapt and thrive even in less favorable environments and only a few non-generalists were captured, results do not allow us to conclude about a negative effect of monocultural plantations over small mammal communities. Further research is needed, attending to micro-scale features, during a longer sampling period and perhaps complementing trapping with other methodologies.

Apodemus sylvaticus is a generalist that may occur in a great variety of habitats (e.g. Díaz et al., 1999; Gorman et al., 1993), though is known to live preferentially in woodlands (e.g. Canova and Fasola, 1991; Kozakiewicz et al., 1999). It is often cited as dominant species of both natural and man-altered landscapes (Robinson and Sutherland, 2002), presenting marked annual fluctuations (Klaa et al., 2005; Wilson et al., 1993). The typical known trend of fluctuation with the peak in autumn and the minimum in spring-summer (Butet et al., 2006; Klaa et al., 2005; Mallorie and Flowerdew, 1994; Wilson et al., 1993) was presented. Though, the abundance of *Apodemus sylvaticus* within the forested habitats presented great differences between the two sampled autumns. These interannual differences in *Apodemus sylvaticus* captures may present several explanations. First, the species' trappability may have differed between the two years although weather and temperature conditions of the same sampling seasons did not differ between sampling years. Second, the maritime pine plantations present some *Acacia dealbata* infestation points where plants have grown from one year to the other, presumably providing more seeds in the second year. As these seeds fall in the ground during the late summer, this augment in food availability could explain *Apodemus sylvaticus* greater abundance in the second autumn in this habitat. For instance, Margaletic et al. (2002) demonstrated an increase in *Apodemus sylvaticus* and other small mammal species abundance resulting from a feeding resource surplus. However, a similar trend in *Apodemus sylvaticus* abundance occurred in eucalyptus forest, were no sizeable resource change happened. Hence, the great boost of *Apodemus sylvaticus* abundance in the second autumn does not seem to be related with the *Acacia* seeds. There are factors other than food supply that affect *Apodemus sylvaticus* populations (Flowerdew, 1972). We did not investigate further explanations for the obtained values, such as predatory pressure (Hanski et al., 1991) or random perturbations (Kaitala et al., 1996), but it is also possible that population densities may actually have differed between years. Pronounced interannual fluctuations of small mammals' abundance are well known and ensue even with non cycling populations (e.g. Bayne and Hobson, 1998; Sullivan et al., 1999). This leads to the question of the time scale of this study. The results of studies conducted at a relatively small temporal scale are likely more susceptible to misinterpretation (Schmid-Holmes and Drickamer, 2001). That is, within a small time interval, in certain years it may be complicated to discern the effects of interannual fluctuations from those of some environmental alteration.

Data obtained for *Mus domesticus*, *Microtus lusitanicus* and *Crocidura russula* did not allow analyzing spatial or temporal patterns in detail, however *Microtus lusitanicus* revealed a certain affinity with eucalyptus plantations. We consider this does not reflect a preference for that specific kind of forest, but should rather be related to micro-habitat features such as soil humidity, compaction and composition and the presence of shrubs (Mira and Mathias, 2002; Santos et al., 2011) in a particular trapping-line, where most of these voles were captured. Spatial distribution and habitat selection of this species in the study area certainly deserves further investigation.

This study reinforces the value of sampling the diversity of available habitats within a landscape in order to get a more comprehensive scenario of regional fauna communities, considering that different species present distinct habitat requirements (Price et al., 2010). Results show that a larger range of species may be preserved if a variety of habitats is maintained. Even habitat types with low expression at the landscape scale may constitute important areas for small mammal communities (Panzacchi et al., 2010). The sampled agricultural fields of traditional agriculture are small patches mostly located at valleys surrounded by large extensions of eucalyptus plantations but showed to provide habitat conditions for an important community of small mammals.

Acknowledgements

The authors are grateful to Dr. Jaime Ramos, for helpful comments on an earlier draft of this manuscript. Thanks to Luís Pascoal da Silva and Pedro Pereira for fieldwork support. Milena Matos was supported by a PhD grant from Fundação para a Ciência e a Tecnologia (SFRH/BD/31146 / 2006).

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You think you own whatever land you land on
The Earth is just a dead thing you can claim…

Have you ever heard the wolf cry to the blue corn moon?
Or asked the grinning bobcat why he grinned?
Can you sing with all the voices of the mountains?
Can you paint with all the colors of the wind?

Stephen Schwartz

Chapter 6

Effects of land use on Vertebrate diversity in a forest-farmland mosaic

6. EFFECTS OF LAND USE ON VERTEBRATE DIVERSITY IN A FOREST-FARMLAND MOSAIC

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6.1. Abstract

It is generally accepted that reserves alone will not be able to effectively preserve biodiversity in order to halt the species loss that has occurring, at unprecedented rates. Thus, understanding distributional patterns of species occurrence and richness at regional or landscape scale, even in unreserved territories, is essential to design effective management policies for biodiversity conservation. Central Portugal is a profoundly human-altered landscape, currently dominated by agricultural fields and monoculture production forests of *Pinus pinaster* and *Eucalyptus globulus*. Patterns of amphibians, birds and mammals' distribution were assessed in these habitats and in a mixed forest, by means of presence/absence data analysis. The conservation value of each sampled habitat was also calculated. In total, 87 vertebrate species were identified in the study. Overall, agricultural lands presented the greatest species richness, constituting important habitats for fauna. Among forested areas, the mixed forest held more species than both monocultures. Small patches of traditional agriculture and the mixed forest presented the highest conservation value. The results indicate that landscape heterogeneity is crucial to sustain highly diverse communities. Different taxa responses are discussed and some land-planning measures are suggested to improve regional biodiversity conservation.

6.2. Introduction

Biodiversity is fundamental to ecosystem functioning and, in addition to its intrinsic value, assures essential goods and services to mankind. However, precisely as a consequence of human activities, biodiversity is being lost at unnaturally rapid rates (e.g. Sala et al., 2000; Western and Pearl, 1989; Wilson, 1988), constituting a major environmental issue worldwide. Anthropogenic pressures such as land-use change and habitat fragmentation or loss are globally amongst the most important direct drivers of biodiversity loss in the recent past (e.g. Chapin III et al., 2000; Fischer and Lindenmayer, 2007; van Vuuren et al., 2006), thus representing a key theme for conservation research.

Nowadays, production industries like agriculture and forestry represent the dominant human land uses (Morris, 1995) and have been the leading promoters of wide-reaching landscape modifications (Millenium Ecosystem Assessment, 2005). In Iberia, as in Europe, natural vegetation has been deeply modified (Amo et al., 2007). For instance, Central Portugal's landscape was once covered with mixed woodland dominated by oak species (*Quercus* spp.) (Bingre and Damasceno, 2007; Ramil-Rego et al., 1998). A long history of human occupation largely converted land to agriculture and forestry practically eliminating the totality of natural vegetation. Nowadays, the majority of forested areas (more than 78%) are composed of maritime pine *Pinus pinaster* and *Eucalyptus globulus* (CNIG, 1995; DGRF, 2007), which are faster growing and economically profitable species mainly exploited for timber and paper production industries.

The concern with the growing encroachment of human activities has triggered a considerable amount of research worldwide, scrutinizing their impact on nature. Most studies focusing on the effects of intensive agriculture and production forestry relate some negative outcome of such practices on biodiversity (e.g. Lindenmayer et al., 2003; Matson et al., 1997; McLaughlin and Mineau, 1995; Norris et al.; Pedersen et al., 2010; Stoate et al., 2001; Wickramasinghe et al., 2004). Nevertheless, the existing literature also presents a few exceptions to this main trend. For instance, Burel et al. (1998) found that intensification of agriculture does not necessarily lead to a decrease in species richness. Stephens and Wagner (2007) and Carnus et al. (2006) reviewed some studies where wildlife diversity was marginally different or even higher in forest plantations, in comparison to natural woodlands. It becomes clear that the responses to human pressure vary according to the analyzed taxonomic groups and depend upon the general framework of each research.

Understanding distributional patterns of species occurrence and richness at regional or landscape scale is essential to design effective management policies for biodiversity conservation. In this context, some authors have pointed out the importance of the unreserved matrix, where production lands are included, as natural reserves alone will be insufficient to effectively protect biodiversity (Araújo et al., 2011; Fischer et al., 2006; Franklin, 1993; Lindenmayer and Franklin, 2002; Margules and Pressey, 2000). Also, there is a lack of studies considering multiple species groups within one region, in order to obtain a more comprehensive scenario of the whole ecosystem and identify keystone features for biodiversity conservation (Norris et al., 2010; Tews et al., 2004).

This study was conducted in a typically fragmented rural landscape of Central Portugal, mostly covered by the two aforementioned monoculture plantations and agricultural fields. We aimed to analyze biodiversity patterns in the different human-altered habitat types comparing terrestrial vertebrate species richness and community composition. As organisms respond differently to environment features depending on their taxonomic group (e.g. Atauri and de Lucio, 2001; Burel et al., 1998; Moreno-Rueda and Pizarro, 2007; Sauvajot et al., 1998; Stephens and Wagner, 2007), we monitored amphibians, birds, bats and small and medium-sized mammals in order to draw a more realistic assessment of biodiversity in the studied habitats. It was intended to calculate the conservation value of each habitat type and infer about the adequacy of current main land uses of Central Portugal for biological conservation. Further, discuss land use management measures and conservation actions that should improve or protect vertebrate fauna, conceivably with application to other geographical areas.

6.3. Methods

Study area

The study was conducted in a 25 000 ha area, located in Central Portugal and centered at Bussaco National Forest (maximum elevation of 547 m.a.s.l. at Cruz Alta 40˚22’13’’N, 8˚21’59’’W). Bussaco is a wall fenced old-growth woodland with approximately 105 ha which constitutes an exclusive natural heritage, representing one of the best dendrological collections in Europe, where tree species from the entire globe can be found. This forest started being planted during the 17th century and some of the most representative species of trees are *Cupressus lusitanica* Mill., *Quercus robur* L., *Q. pyrenaica* Willd., *Castanea sativa* Mill., *Acer pseudoplatanus* L., *Fraxinus americana* L., *Ulmus minor* Mill., *Sequoia sempervirens* (D.Don) Endl., *Pseudotsuga menziesii* (Mirbel) Franco and *Cedrus atlantica* (Endl.) G. Manetti ex Carrière. Bussaco keeps also a patch of the primitive Mediterranean forest (Paiva, 2004; Santos, 1993), with native shrub and tree species such as *Laurus nobilis* L., *Arbutus unedo* L., *Viburnum tinus* L., *Ilex aquifolium* L, *Ruscus aculeatus* L., *Phillyrea latifolia* L. and several *Quercus* species.

We performed habitat stratification of the study area by means of photo-interpretation and field validation, and came out with five dominating habitats within the fragmented landscape: Bussaco Forest, monocultures of *Pinus pinaster* and *Eucalyptus globulus*; large agricultural fields (machine-laboured mosaic of fields) and small patches of traditional agriculture (mainly produce gardens, hand-laboured, for domestic consumption), surrounded by vast areas of eucalyptus plantations These small patches located near little rural villages and had always a water body, a small river or a pond in the environs.

We selected 30 sites (6 replicates for each habitat type) where we sampled all groups except medium-sized mammals, which were sampled in 30 different transects. To increase spatial independence, sites were separated by a minimum of 1km, except in Bussaco Forest, due to spatial limitation (in this case sites were at least 250m apart). All samplings occurred between September 2007 and November 2009.

Being a Mediterranean area with some Atlantic influence, in the study area summers are hot (maximum 39°C) and winters mild (minimum -1°C). Annual average precipitation is of 804 mm, mostly concentrated on autumn and winter. However, Bussaco presents a fresher and rainier microclimate, with a mean annual precipitation of 1525 mm.

Amphibians

Considering the diversity of amphibians' life histories, habitat preferences and different means of locomotion, more than one technique is needed to adequately sample all species present in an area (Corn, 1990; Ryan et al., 2002). Thus, in each of the 30 sampling sites, we carried out the following combination of methods. Adult amphibians were surveyed by night transects (500m per sampling site; carried out between half an hour after sunset and up to three hours later, with rainy weather and temperature >12°C) (Heyer et al., 1994) and active day time-constrained searches (30min searching under logs, stones, leaves, rubble, etc) (Corn, 1990). Adults, larvae and eggs were searched in permanent or temporary ponds or creeks, with a hand-net, for 30 min (Heyer et al., 1994).

We completed three sampling rounds, between December 2008 and July 2009, trying to coincide with the reproductive periods of most species.

Birds

Bird counts were carried out by means of 50 m fixed-radius point counts of 10 min duration, which is a standard and widely used method (Bibby et al., 2000; Gibbons, 1996; Gregory et al., 2004; Rabaça, 1995; Ralph et al., 1993). Censuses began at sunrise and lasted four hours, and were made only on days with favorable weather conditions (i.e. no strong wind, rain or mist) and always by the same trained observer (MM), which recorded all visual or auditory contacts. Birds flying over the sampling plot ("fly-overs") were not counted, in order to eliminate temporal visitors passing through the study site. Attention was paid not to recount individual birds.

Six sampling rounds were undertaken between April 2008 and May 2009, two per breeding season (April and May 2008 and 09), one during migration period (September/October 2008) and one during wintering (January 2009). In each sampling round, censuses were performed in a few days minimizing the potential effects of changes in bird activity within the season.

Bats

In each of the 30 sampling sites, bats were acoustically surveyed on a 500 m line transect, walked at a constant pace for 15 minutes with an ultrasound detector (Pettersson D240X, Pettersson Elektronik AB, Uppsala, Sweden). Detected bat passes (10x time-expanded) were digitally recorded (Edirol R-09, Roland, Los Angeles, USA) as Wav files (sampling rate 44.1 kHz and 16 bits/sample) for subsequent analysis.

A total of seven survey rounds were conducted, between May and October of two consecutive years (three in 2008 and four in 2009). Samplings were carried out only with favorable weather conditions (no strong wind, mist, rain and temperature > 10°C), starting half an hour after twilight and ending up to three hours later.

Field recordings were analyzed with the software Bat Sound Pro version 3.31b (Pettersson Elektronik AB, Uppsala, Sweden) and temporal and frequency parameters (such as frequency of maximum energy (FmaxE), bandwith (BW), pulse duration (Dur) and inter-pulse interval (IPI)) were measured in order to identify bat species (or groups of species, when identification to species level was not possible) by comparison with available literature (e.g. Ahlen and Baagoe, 1999; Barataud, 2002; Lundy and Montgomery, 2009; Obrist et al., 2004; Parsons and Jones, 2000; Russ, 1999; Russo and Jones, 1999, 2002; Teixeira, 2009; Zbinden and Zingg, 2009) and data bases (Barataud, 1996). Call sequences of low quality or with less than three call pulses were discarded.

Small mammals

Small mammals were surveyed by live-trapping, which is the most used method to study rodents and insectivores (Gurnell and Flowerdew, 1990; Thompson et al., 1998) and has been successfully used to analyze patterns of richness, composition and abundance of these communities. In each sampling site we set a line of 30 aluminum traps (17,5x6x6cm) separated 10 m from each other and baited with a mixture of sardines and hamster food. Cotton was provided as nesting material. Whenever possible, traps were set under the cover of stones, shrubs or herbs to provide camouflage and some thermal insulation (Torre et al., 2007). Traps were left in the field for three consecutive nights and visited every morning. Captured animals were removed and released alive away from sampling sites, after identification, weighting and sexing.

We performed a total of six sampling rounds between September 2008 and November 2009.

Medium-sized mammals

To survey medium-sized mammals we searched for indirect evidences of presence (mainly scats, but also tracks, feedings signs, etc.) in 30 transects of two km each. This method has been proposed as a valuable alternative to other survey methods (such as scent-stations, track-plates or trapping) in carnivore-habitat studies carried out at landscape or regional scale (e.g. Barea-Azcón et al., 2007; Stander, 1998; Virgós et al., 2002). Those other methods can become very expensive and time-consuming, which is impracticable in large-scale studies. Furthermore, when correctly applied, the use of “signs” offers a reliable snapshot of the current use of species over the units of a large sampling area and a more correct estimate of the presence of all species, in relation to other indirect methods which may depend on the efficacy of attractants. Hence, this method can provide important information of the potential conservation value of habitats for species (Virgós, 2001).

We performed a total of eight sampling rounds, three-months spaced, between September 2007 and June 2009. In order to minimize problems related with seasonal patterns in dung deposition or differences in decay rates, all transects were cleared from scats 30 days before the actual sampling – *clearance plot* (Hill et al., 2005; Sutherland, 1996).

Each identifiable sign and respective geographical coordinates were registered for the following mammal species: *Erinaceus europaeus*, *Vulpes vulpes*, *Mustela nivalis*, *Martes foina*, *Meles meles*, *Lutra lutra* and *Genetta genetta*.

Data analysis

All data from the sampling rounds at each sampling site were pooled and analyzed as presence/absence data. The diversity was evaluated taxonomically quantifying species richness (S = number of species) per habitat type. A cluster analysis based on χ^2 distances and correspondence analysis (CA) was applied, in order to elucidate the relationships between species compositions and habitat types.

To assess the conservation value of each habitat for each taxa, four criteria were used: species richness, rarity, vulnerability and a combined index of biodiversity (Rey Benayas and de la Montaña, 2003). Rarity can assume several forms, as a response to different combinations of geographical range, local abundance, habitat specificity and habitat occupancy (Rabinowitz, 1981; Rey Benayas et al., 1999). There are no official criteria in Portugal categorizing species of all considered *taxa* according to their geographical range into rarity classes. Thus, in this study, rarity of species *i* was defined as the inverse of its occurrence in the study area ($1/n_i$), where n_i is the number of sampling points where the species was present. For each habitat *h*, the rarity index was

$$\sum_{i=1}^{S}\left[\left(\frac{1}{n_{hi}}\right)/S_h\right] \qquad \text{(eqn 1)}$$

where S_h was the number of species found in the habitat.

The vulnerability of a species was quantified attributing a score to the respective category given by the Red Data Book of Portuguese Vertebrates (Cabral et al., 2005). Scores were assigned to conservation status as follows: 5 for endangered and critically endangered species, 4 for vulnerable, 3 for near-threatened, 2 for insufficiently known and 1 for introduced and least-concern species. We are aware of the subjectivity of the scores assigned; however any other choice would have been subjective as well. For a habitat, the vulnerability index was calculated as

$$\sum_{i=1}^{S}[V_{hi}/S_h] \qquad \text{(eqn 2)}$$

where V_{hi} is the vulnerability score of the respective species present in the habitat.

For each habitat and taxonomic group, a combined index of species richness, rarity and vulnerability was calculated, following Rey Benayas and de la Montaña (2003):

$$\sum_{i=1}^{S}[(1/n_{hi})V_{hi}] \qquad \text{(eqn 3)}$$

We also calculated the Standardized Biodiversity Index proposed by the same authors, in order to measure species richness, rarity and vulnerability of all *taxa* in each habitat. This index is standardized by dividing the combined index of biodiversity of each taxonomic group in each habitat by its mean across all habitats, and then the several standardized combined indices are summed. The Standardized Biodiversity Index formula is:

$$\sum_{j=1}^{J} 1/m_j \sum_{i=1}^{jS} \left[\left(1/n_{ji}\right)V_{ji}\right] \qquad \text{(eqn 4)}$$

where m_j refers to the mean combined index of biodiversity of the taxonomic group *j* across and *J* is the number of considered taxonomic groups.

Within each *taxa*, the relationships between the four criteria (species richness, rarity, vulnerability and the combined index of biodiversity) calculated for each habitat (N=5) were scrutinized using Pearson's correlation.

6.4. Results

A total of 87 vertebrate species were detected in this study (Table 6.1 and Table 6.2). Naturally, the group that presented more species was the birds, followed by the mammals. Amphibians presented the smallest species richness.

In terms of habitats (Table 6.1), agricultural fields revealed the greatest species richness, proving to be very important for local vertebrate communities. Forest habitats enclosed less expressive species richness. Among these habitats, the mixed forest of Bussaco presented the highest number of species, constituting the preferred and most important woodland type. Among monocultures, maritime pine stands constituted the poorest habitat, but the results were nevertheless very similar to those of eucalyptus plantations.

Concerning habitat use by species, cluster analysis (Fig. 6.1) clearly divided species from habitat-exclusives to generalists, being the largest obtained group constituted by species that occurred in all habitats. Hence, a great part of the vertebrates did not show any association to a particular habitat type. However, correspondence analysis (Fig. 6.2) elucidated that several associations are apparent. Axis 1 distinctively shows a gradient from closed to open habitats, representing forested to agricultural areas. The second axis is associated to habitat complexity, which changes from monocultures and large farmlands to Bussaco mixed forest and traditional producing gardens, respectively. The distribution of species along these two gradients allows their categorization as forest, open space or generalist species. For example, the majority of amphibians can be considered generalists, only *Discoglossus galganoi* and *Chioglossa lusitanica* demonstrate visible habitat type preferences. Birds were the most numerous class and showed the clearest habitat type distinctions, presenting a more obvious segregation between forest and open space species. For instance, swallows (*Riparia riparia, Delichon urbicum and Hirundo rustica*) are obvious open space flyers. Among mammals, bats and carnivores constitute the most generalist orders, with few species presenting clear habitat preferences (e.g. *Rhinolophus ferrumequinum*, *Rattus norvegicus*).

The generality of threatened species could not be related to a particular habitat type, with each *taxon* exhibiting particular trends.

Table 6.1. Taxonomic (Class, Order) species richness for the five habitat types. S is the species richness.

	S	Bussaco forest	Pine forest	Eucalyptus forest	Large agriculture fields	Small agriculture fields
Amphibia	9	7	5	5	6	9
Anura	5	3	2	2	4	5
Caudata	4	4	3	3	2	4
Aves	53	27	21	23	44	39
Apodiformes	1	1	0	1	1	1
Ciconiformes	1	0	0	0	1	0
Columbiformes	3	2	1	1	3	2
Coraciiformes	1	0	0	0	1	1
Cuculiformes	1	0	0	1	1	1
Falconiformes	2	1	1	0	2	1
Passeriformes	42	21	17	18	33	31
Piciformes	2	2	2	2	2	2
Mammalia	25	22	20	21	19	21
Chiroptera	12	11	12	11	9	9
Carnivora	6	6	5	5	4	6
Insectivora	2	2	1	2	2	2
Rodentia	5	3	2	3	4	4
Total number	87	56	46	49	69	69

Table 6.2. List of vertebrate species in the study area. *(1)* abbreviated species names, *(2)* conservation status in Portugal (Cabral et al., 2005). *Myotis* spp. *small* is a group that includes *Myotis nattereri, M. emarginatus, M. mystacinus, M. daubentonii* and *M bechsteinii.*

Amphibia	(1)	(2)	Aves	(1)	(2)
Anura			Passeriformes		
Alytes obstetricans	Aobs	LC	*Passer domesticus*	Pdom	LC
Discoglossus galganoi	Dgal	NT	*Passer montanus*	Pmon	LC
Bufo bufo	Bbuf	LC	*Phoenicurus ochruros*	Poch	LC
Pelophylax perezi	Pper	LC	*Phylloscopus collybita*	Pcol	LC
Rana iberica	Ribe	LC	*Regulus ignicapilla*	Rign	LC
Caudata			*Riparia riparia*	Rrip	LC
Chioglossa lusitanica	Clus	VU	*Saxicola rubetra*	Srub	VU*
Salamandra salamandra	Ssal	LC	*Saxicola torquatus*	Stor	LC
Triturus marmoratus	Tmar	LC	*Serinus serinus*	Sser	LC
Lissotriton boscai	Lbos	LC	*Sitta europaea*	Seur	LC
Aves			*Sturnus unicolor*	Suni	LC
Apodiformes			*Sylvia atricapilla*	Satr	LC
Apus apus	Aapu	LC	*Sylvia communis*	Scom	LC
Ciconiformes			*Sylvia melanocephala*	Smel	LC
Ardea cinerea	Acin	LC	*Sylvia undata*	Sund	LC
Columbiformes			*Troglodytes troglodytes*	Ttro	LC
Columba palumbus	Cpal	LC	*Turdus merula*	Tmer	LC
Streptopelia decaocto	Sdec	LC	*Turdus philomelos*	Tphi	LC
Streptopelia turtur	Stur	LC	Piciformes		
Coraciiformes			*Dendrocopos major*	Dmaj	LC
Upupa epops	Uepo	LC	*Picus viridis*	Pvir	LC
Cuculiformes			**Mammalia**		
Cuculus canorus	Cucan	LC	Chiroptera		
Falconiformes			*Barbastella barbastellus*	Bbar	DD
Accipiter gentilis	Agen	VU	*Eptesicus serotinus*	Eser	LC
Buteo buteo	Bbut	LC	*Myotis myotis/blythii*	Lmyo	VU/CR
Passeriformes			*Myotis* spp. *small*	Smyo	
Aegithalos caudatus	Acau	LC	*Nyctalus lasiopterus*	Nlas	DD
Anthus pratensis	Apra	LC	*Nyctalus leisleri*	Nlei	DD
Certhia brachydactyla	Cbra	LC	*Pipistrellus pipistrellus/pygmaeus*	Pip	LC/LC
Carduelis cannabina	Ccan	LC	*Pipistrellus kuhlii*	Pkuh	LC
Carduelis carduelis	Ccar	LC	*Plecotus auritus/austriacus*	Ple	DD/LC
Carduelis chloris	Cchl	LC	*Rhinolophus ferrumequinum*	Rfer	VU
Cettia cetti	Ccet	LC	*Rhinolophus hipposideros*	Rhip	VU
Cisticola juncidis	Cjun	LC	*Tadarida teniotis*	Tten	DD
Corvus corone	Ccor	LC	Carnivora		
Cyanistes caeruleus	Ccae	LC	*Genetta genetta*	Ggen	LC
Delichon urbicum	Durb	LC	*Lutra lutra*	Llut	LC
Estrilda astrild	East	NA	*Martes foina*	Mfoi	LC
Emberiza cirlus	Ecir	LC	*Meles meles*	Mmel	LC
Erithacus rubecula	Erub	LC	*Mustela nivalis*	Mniv	LC
Fringilla coelebs	Fcoe	LC	*Vulpes vulpes*	Vvul	LC
Ficedula hypoleuca	Fhyp		Insectivora		
Garrulus glandarius	Ggla	LC	*Crocidura russula*	Crus	LC
Hirundo rustica	Hrus	LC	*Erinaceus europaeus*	Eeur	LC
Lophophanes cristatus	Lcri	LC	Rodentia		
Lullula arborea	Larb	LC	*Apodemus sylvaticus*	Asyl	LC
Motacilla alba	Malb	LC	*Microtus lusitanicus*	Mlus	LC
Motacilla cinerea	Mcin	LC	*Mus domesticus*	Mdom	LC
Periparus ater	Pate	LC	*Mus spretus*	Mspr	LC
Parus major	Pmaj	LC	*Rattus norvegicus*	Rnor	NA

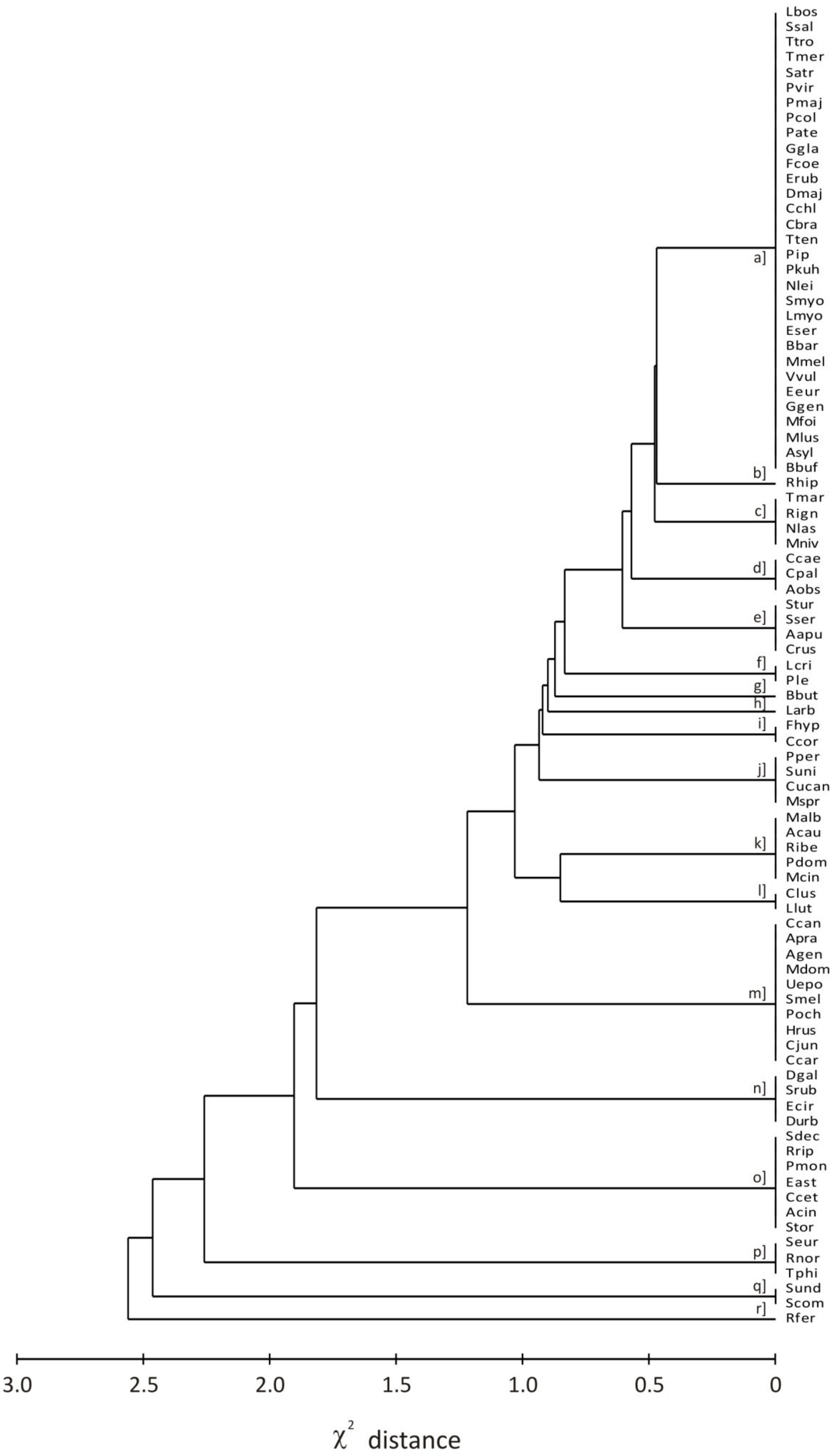

Fig. 6.1. Cluster analysis of the species relationships. Abbreviations as in Table 6.2.

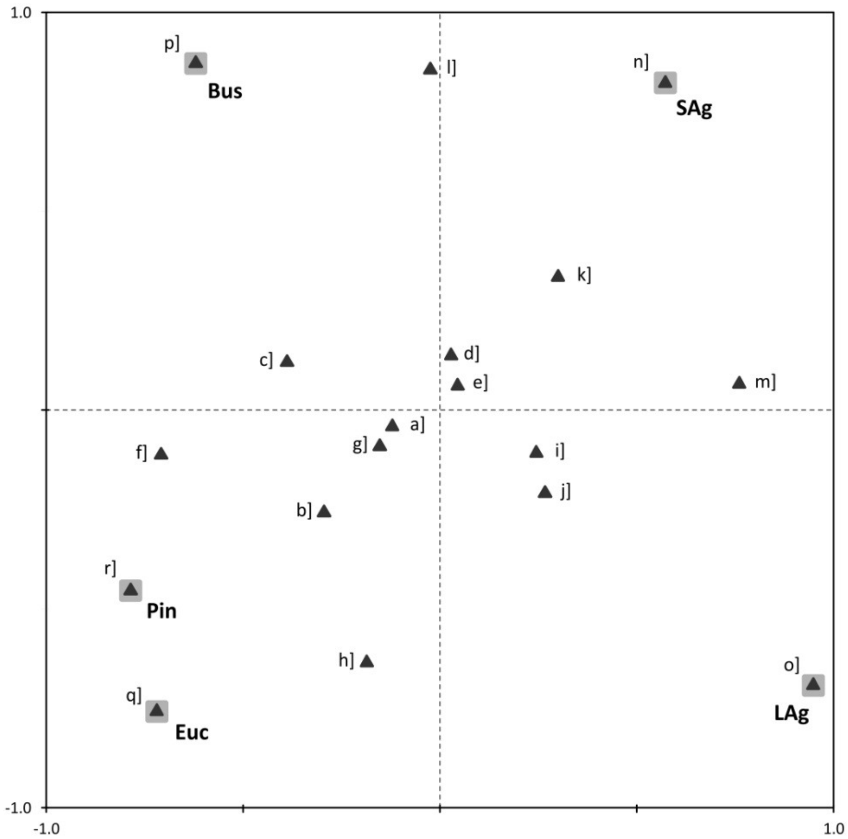

Fig. 6.2. Correspondence analysis biplot of species and habitats, where Bus – Bussaco forest, Pin – Pine forest, Euc – Eucalyptus forest, LAg – Large agriculture fields, SAg – Small agriculture fields. Letters from a] to r] represent the species groups defined in Fig. 6.1.

Ranking of habitats according to their conservation value varied with the taxonomic group and considered criteria (Table 6.3). For instance, species richness and vulnerability did not follow the same trend. Correlation analyses confirmed this result, as species richness and vulnerability were significantly correlated only in the case of amphibians (r=0.930, P=0.022). Similarly, species richness and rarity presented significant correlation only for amphibians (r=0.909, P=0.032), birds (r=0.915, P=0.029) and medium-sized mammals (r=0.970, P=0.006). This means the richest communities did not necessarily include the rarest and most vulnerable species. Combined index of biodiversity ranked habitats' value in different ways, depending on the considered *taxa*. However, the Standardized Biodiversity Index clearly pointed out small patches of traditional agriculture and Bussaco forest as the most valuable habitats in terms of conservation. As expected, eucalyptus stands constituted the habitats with the least conservation interest.

Table 6.3. Criteria calculated to assess the conservation value of each habitat per taxa and for all groups. Standardized Biodiversity Index per habitat. Habitat abbreviations as in Fig. 6.2.

		Bus	Pin	Euc	LAg	SAg
Amphibians	Sp. richness	7	5	5	6	9
	Rarity	0,082	0,078	0,076	0,079	0,129
	Vulnerability	1,429	1,000	1,000	1,000	1,556
	Comb. Index	0,874	0,390	0,381	0,474	2,465
Birds	Sp. richness	27	21	23	44	39
	Rarity	0,135	0,076	0,138	0,208	0,172
	Vulnerability	1,000	1,000	1,000	1,068	1,154
	Comb. Index	3,633	1,590	3,176	12,153	12,703
Bats	Sp. richness	11	12	11	9	9
	Rarity	0,075	0,152	0,075	0,067	0,059
	Vulnerability	2,182	2,333	2,182	2,222	2,000
	Comb. Index	2,069	6,069	2,069	1,637	1,152
Medium-sized	Sp. richness	7	6	6	5	7
Mammals	Rarity	0,136	0,076	0,076	0,051	0,136
	Vulnerability	1,000	1,000	1,000	1,000	1,000
	Comb. Index	0,955	0,455	0,455	0,255	0,955
Small mammals	Sp. richness	4	2	4	5	5
	Rarity	0,260	0,069	0,069	0,097	0,097
	Vulnerability	1,500	1,000	1,000	1,000	1,000
	Comb. Index	1,042	0,139	0,278	0,486	0,486
All groups	Sp. richness	56	46	49	69	69
	Rarity	0,125	0,096	0,104	0,159	0,143
	Vulnerability	1,286	1,348	1,265	1,203	1,290
	Comb. Index	8,572	8,643	6,358	15,005	17,760
Standardized Biodiversity Index		5,991	4,025	3,001	4,388	7,595

6.5. Discussion

First of all, we must highlight the importance of landscape scale and multiple group approach to understand the ecology and general scenario of a specific geographical region (Fischer and Lindenmayer, 2007; Tews et al., 2004). This becomes even more important in sites without ecological studies, such as our study area. In the Iberian Peninsula, only a few pattern-oriented, multiple group studies have been carried out (e.g. Araújo, 1999; Beja et al., 2009; Moreno-Rueda and Pizarro, 2007; Moreno-Rueda and Pizarro, 2009) and it is important to analyze simultaneously the results of several taxa in order to draw conclusions, as their specific responses to influencing factors are likely to differ (Moreno-Rueda and Pizarro, 2007; Sauvajot et al., 1998).

The results obtained support the generally accepted concept that landscape heterogeneity is crucial to sustain highly diverse communities (Atauri and de Lucio, 2001; Moreno-Rueda and Pizarro, 2007; Russo, 2007), as for each considered vertebrate group, global species richness increased with habitat diversity. However, this assumption must be carefully considered, so that it is not confused with the effects of habitat fragmentation that, for example, may alter vast areas of a specific habitat essential for some specialist species (Atauri and de Lucio, 2001).

As previously stated for instance for birds (Farina, 1989), in Mediterranean regions, open and cultivated areas are generally attractive habitats for fauna, as they increase habitat heterogeneity, concentrate resources and provide diversity of food, nesting and refuge opportunities. Mosaic-like and mixed agricultural systems, such as those of the study area, present structural elements such as creeks, trees, ponds, hedgerows and other boundaries that raise habitat complexity (Russo, 2007) and thus provide conditions for the occurrence of more species (e.g. Heroldová et al., 2007). We compared two types of agricultural systems. The larger and more intensively cultivated fields presented the same number of species than the small agricultural patches of traditional agriculture, but had a lower conservation value. This finding is in agreement with those of Burel at al. (1998), which indicate that intensification of agriculture does not necessarily imply species richness to diminish. However, two caveats must be considered: firstly, although large farmland areas in effect comprise some agricultural intensification and habitat simplification, some traditional features are kept, yet with less expression, and several different cultures are exploited. Secondly, it must be noticed that species richness results are based on presence/absence data, which does not reflect communities' structure, in terms of diversity and evenness. In general, agricultural fields clearly constituted important habitats for all groups, however in terms of conservation value, traditional agricultural fields were the most habitat.

Among forest habitats, as expected, Bussaco mixed forest had the greatest species richness and conservation value, with a considerable differentiation from monocultures. The presence of a more diversified fauna in this habitat is easily explained by its structural complexity (Hobbs et al., 2002), associated with the vast vegetation assortment present and consequent numerous niche opportunities provided, along with the availability of water. In terms of species richness, maritime pine, an autochthonous species (Figueiral, 1995), was surprisingly the poorest habitat. Again, species richness data alone must not be taken as the only valuable measure of biodiversity. In the same study area, Matos et al. (*in prep*) used the abundance of each vertebrate class separately and demonstrated that eucalyptus stands were the biologically poorest habitats, presenting less diversity and being the less used habitats. In this study, the calculated conservation value corroborates such results. This is related to the structural simplicity of eucalyptus plantations, a consequence of their management for commercial purposes. Homogeneity and even-aged stand composition fail to provide adequate conditions for fauna subsistence or establishment, such as understory vegetation, nesting sites or feeding resources (Carrascal and Tellería, 1990; Crow et al., 2002; Endels et al., 2004; Fraterrigo et al., 2006; Lindenmayer et al., 2003). Short-rotational periods cause lack of snags or large-diameter trees (Tellería and Galarza, 1990; Torras and Saura, 2008), features required by some forest species. Also, being an exotic species, eucalyptus' phenology is not synchronized with the demands of native fauna (Proença et al., 2010). For example, *Eucalyptus globulus'* flowers during winter, consequently during native birds' breeding season fails to provide feeding resources. Besides, native bird species are not adapted to exploit their nectar or seeds (Tellería and Galarza, 1990). Having been recently introduced in the country, in comparison to maritime pine, eucalyptus have also a poorer invertebrate fauna (Zahn et al., 2009) and understory associated, which could offer food, refuge or nesting opportunities for several taxa. Thus, considering the factors that may explain eucalyptus' reduced biodiversity and the large extensions that they occupy we can consider that eucalyptus plantations are functioning as a transition habitat. Most vertebrates move between habitats, through the landscape, and at some moment may stop on eucalyptus, not necessarily breeding or residing there.

With respect to species or group associations to habitat types, there is a clear occurrence of several generalist species and a small number of specialists. Further research should be carried out in order to separate and explain patterns of occurrence, relating species' presence with more precise landscape or micro-habitat variables. It is plausible that certain species arise associated to some habitat not only because of land use type but due to some other geographical, environmental or fine-scale characteristics. Nevertheless, some aspects of species distribution through complexity level and forest-agriculture gradients are very explicit. For instance, open space, forest or generalist species are promptly classified. In general, birds presented more open space species, such as aerial feeding passerines (e.g. swallows), but obvious forest species were also identified, such as *Sitta europea* or *Parus cristatus*. One amphibian species (*Discoglossus galganoi*) was exclusive of small agriculture fields, which may be due to its preference for grass near water sites (Loureiro et al., 2010), found in this habitat. *Chioglossa lusitanica*, as well as the carnivore *Lutra lutra*, came up associated to complex habitats, similarly distant from Bussaco and small agriculture patches, what is certainly explained by the association of these species to water. In a general way, bats and carnivores seem to be generalists, but again, when considering further data (Matos et al., *in prep*) differences in the intensity of the use of habitats arise. Among small mammals, *Rattus norvegicus* was exclusive of Bussaco forest, however this should be due to methodological constraints involving traps' size and not represent the actual distribution of this species, known to be widespread (Rojas and Palomo, 2002). There was a visible association of *Mus domesticus* with both types of farmland, which is due to its commensal behavior and avoidance of forested areas (Sans, 2002).

Concerning the conservation value of the habitats, none presented a clearly distinct assemblage of threatened species. However, *Chioglossa lusitanica, Saxicola rubetra, Discoglossus galganoi* and *Accipiter gentilis* revealed a certain degree of association to agricultural features, what reinforces the previously described importance of these habitats for biodiversity conservation.

In terms of conservation, considering that the studied landscape is quite representative of Central Portugal, there are some general conclusions to policy-makers and land managers. This study supports that landscape heterogeneity is positive to overall species establishment and maintenance. Further, the importance of small patches of valuable habitats is confirmed by the fact that both small agriculture fields and Bussaco forest, patches with reduced areas and surrounded by large monoculture extensions, possess greater species richness and the highest conservation values. Therefore, the degradation of these high-value habitats must be avoided. Diverse forests, namely broad-leaved, and traditional agriculture should be improved or at least preserved, which concurs with previous research (Fischer and Lindenmayer, 2002; Rosalino et al., 2009). Also, production forests' contribute to biodiversity conservation may be augmented if some measures, promoting landscape heterogeneity and enhancing stand structural complexity, are applied (Fischer et al., 2006; Lindenmayer et al., 2003; Moreira et al., 2001; Sayer et al., 2004).

Such actions may involve the plantation of native trees among or contiguous to the stand or the adoption of different harvesting methods (Lindenmayer et al., 2006; Lindenmayer et al., 2010), in order to enhance structural complexity and heterogeneity.

Portuguese pine stands are currently facing a serious infection of the nematode *Bursaphelenchus xylophilus* (Mota et al., 1999) and it is expected that large extensions will be harvested, as a control measure. It is important that conservation recommendations and this kind of studies are taken into account, to avoid reforestation with detrimental species for overall biodiversity.

Compile biodiversity data and identify conservation goals are the first two steps in systematic conservation planning (Margules and Pressey, 2000). Considering that vertebrate species richness is only one assessment type and not the hindmost objective of conservation efforts, the study presented here demonstrates that rural and non-protected areas may also constitute valuable conservation areas. If correctly managed, human-altered landscapes, which include forests and agriculture, may represent habitats effectively contributing to biodiversity preservation. It is, though, fundamental, that planning seriously faces conservation knowledge and concerns.

Acknowledgements

All animals were handled meeting the terms of the Portuguese law (ICNB licenses nr. 106/2008/CAPT and 74/2009/CAPT). The authors are grateful to Dr. Jaime Ramos, for helpful comments on an earlier draft of this manuscript. Thanks to Luís Pascoal da Silva, Pedro Pereira and Nuno Pinto for fieldwork support. Milena Matos was supported by a PhD grant from Fundação para a Ciência e a Tecnologia (SFRH/BD/31146 / 2006).

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Se podes olhar, vê.
Se podes ver, repara.

José Saramago

Chapter 7

General discussion

7. GENERAL DISCUSSION

Understanding distributional patterns and habitat preferences of the fauna species inhabiting a region is crucial to ascertain appropriate conservation priorities and define sound management guidelines. This study was conducted in a typically fragmented rural landscape of Central Portugal, where no faunal research had been carried out before. The main findings achieved refer to this region but certainly present application to other similar geographic regions and may constitute methodological and notional basis to develop conservational studies elsewhere.

7.1. The importance of a multi-taxa approach

The term biodiversity is no more than an umbrella for the total range of life expressions that, so, is impossible to measure as a whole. Conservation studies usually rely on the use of surrogates, a set of chosen estimators that can be easy and rapidly evaluated to assess biodiversity trends and assumed to respond to a threatening process in a similar way that all species under consideration would. However, surrogacy based on a single taxa presents serious constraints that ultimately may conduce to limitative perspectives and misleading interpretations (Ficetola et al., 2007; Fonderflick et al., 2010). It is understood that responses vary, depending on the considered indicator (e.g. Sauvajot et al., 1998; Stephens and Wagner, 2007). Hence, in order to obtain a more comprehensive picture of an ecosystem's reality, multi-taxa approaches should be preferred. Further, simple indicators such as species richness, should be accompanied by deeper analyses of species community composition and by comparisons of species life-history traits among taxa and habitats (Fleishman et al., 2006; Tropek et al., 2008).

This study substantiates this theoretical context and allowed to identify keystone features, crucial for maintaining species diversity (Tews et al., 2004). Responses of the several taxa to land-use have been identified and individually discussed. It was noticed that, despite the general coherency of rejoinders, species and groups particularities cannot be disregarded. The importance of resources and processes varies among species, reiterating the necessity to consider habitat requirements of the several groups in landscape management and focused conservation planning.

7.2. Monitoring at the landscape scale

Comprehensive conservation requires strategies for managing whole landscapes including areas allocated to protection, but also to human use, production and exploitation. Land area that is managed for agriculture, forestry and human settlement probably detains the majority of biological diversity (Pimentel et al., 1992) but has largely been disregarded. There is a clear necessity for ecosystem or landscape approaches, which allow to gather knowledge even in poorly known or even unknown habitats and ecological subsystems (Franklin, 1993). Recently, the significance of monitoring at landscape and habitat level has been pointed, namely in the scope of conservation efforts to halt biodiversity loss (e.g. Balmford et al., 2005; Lengyel et al., 2008; Lindenmayer, 1999; Weber et al., 2004). Other studies showed that it is important to sample and monitor all available habitats among the considered landscape, even those with small representativity or of seeming low interest (Fischer and Lindenmayer, 2002; Panzacchi et al., 2010).

The research here presented constitutes an example of how monitoring wildlife at the landscape scale may be central. In this region and until now, main trends of animal diversity were unknown, as well as particular aspects or faunal requirements. Any political or land planning project has now consolidated data to base on, if conservation objectives are to be taken into consideration. It was also demonstrated that, indeed, small patches of habitat should not be overlooked in community studies. The small patches of traditional agriculture, embedded in large extensions of eucalyptus stands, and Bussaco National Forest, both habitats with much reduced areas turned out to be the most valuable habitats for the general fauna.

Sampling in several landscape units showed that landscape heterogeneity is crucial to sustain highly diverse communities, whatever the considered taxonomical group. The conceptual association of diversity with landscape complexity has been quoted before (e.g. Atauri and de Lucio, 2001; Bobretsov et al., 2005; Moreno-Rueda and Pizarro, 2007; Russo, 2007), but should not be confused with the negative effects of tragic habitat fragmentation, which alters landscape in such a way that resulting patches' size and isolation make territories incapable of maintaining populations (Fahrig, 2003). Landscape heterogeneity, providing a wealth of ecological opportunities, allows niche and habitat selection, which in turn enable sympatry (Rosenzweig, 1981), resource partitioning (Schoener, 1974), coexistence between competitors (Levin, 1974) and aid the persistence of predator-prey systems (Huffaker, 1958), all processes that contribute to the maintenance of species diversity.

7.3. Agriculture intensification

Traditional European “High Nature Value” farming systems (Baldock, 1998; Pienkowski, 1998) have been abandoned in the last decades, mainly due to structural economic changes and agricultural modernization policies (Olaizola et al., 2008), with several detrimental effects on flora and fauna diversity (McLaughlin and Mineau, 1995; Russo, 2007). For instance, many animal species that have developed strong preference for semi-natural habitats associated to extensive farming systems (Farina, 1997; Preiss et al., 1997), characterized by low vegetation, simple architecture and mosaic-like organization (Moreira and Russo, 2007), are now suffering the effects of habitat loss. Agricultural intensification has often been proved to negatively affect biodiversity in several ways, but more research is needed to validate the meaning of preserving traditional farming systems, as the world population growth will continue to place increasing demands on agricultural resources.

The findings of this study reinforce the importance of traditional farmlands for conservation. Even though the more intensively cultivated fields maintain some conventional features and practices and revealed to be important for some groups, the global conservation value of traditional fields was clearly greater. Even when large farmlands presented higher species richness or abundances, as in the case of birds, traditional fields showed more diverse and even assemblages. Results of small mammals agreed with previous work (Burel et al., 1998), indicating that this group’s diversity is less affected by the intensification of agriculture than that of other animal communities.

The detailed weight of the presence of water sites (ponds or creeks) among these patches was not directly evaluated, but seemed to play an important role for vertebrate communities. Bats, which forage on invertebrates largely found near water sites, and amphibians, which depend on water to live and reproduce, demonstrated particular preferences for these landscape units. This is mostly relevant as those two groups present high conservation interest. Both comprise several threatened species which populations are declining, and, in the case of amphibians, several Iberian endemisms.

In the studied region, despite their small areas within the landscape, patches of traditional agriculture constitute key habitats for species conservation, which must be promoted or, at least, protected. Some authors step further, stating that the only way to preserve vertebrate diversity in the Mediterranean region is through policies designed to keep traditional farming (e.g. Falcucci et al., 2007). Sustainability is a complex and difficult task, but at least at this geographical scale, the objectives of agriculture and biodiversity conservation are economically compatible and should be actively pursued (Paoletti, 1995), by finding strategies that strike a balance between biodiversity conservation and productivity as well as meeting the social and cultural demands of rural communities.

7.4. Forestry

Forest structure underlies habitat features such as microclimate, food availability and cover that influence organisms' fitness. Hence, strong correlation often exists between wildlife community composition and forest structure (Hansen et al., 1991). Forest management for commercial purposes is acknowledged to negatively affect biodiversity, as it simplifies both vertical (stratification) and horizontal (heterogeneity) woodland structural diversity (Lindenmayer and Franklin, 2002; Norris et al., 2010). Even-aged monocultural plantations represent ecologically simple hardwood systems, particularly in the case of exotic species and, therefore, often constitute habitats with poor biodiversity and conservation value. Very few species have habitat requirements met only by one tree species (Avery and Leslie, 1990).

In the study area, in comparison with the old-growth mixed forest, monocultures were actually poorer habitats in general terms of vertebrate species richness, diversity and conservation value. Eucalyptus stands, exotic plantations, consistently presented the lowest diversities and conservation value among all taxa except small mammals. In general, pine stands presented intermediate diversity and conservation values between eucalyptus and mixed forest. Attending to the vast extents these plantations, namely eucalyptus, occupy in the study area and Portugal, these results should raise conservationist concerns. Moreover, Portuguese pine stands are currently facing a severe infection of the nematode *Bursaphelenchus xylophilus* (Mota et al., 1999) and it is expected that large extensions will be harvested, as a control measure. It is highly probable that in the infected areas eucalyptus will replace the pines. If conservation aspects are to be faced seriously, reforestation with detrimental species for overall biodiversity, such as eucalyptus, should be avoided. This situation could provide an opportunity for research and biodiversity promotion, by adopting sound silvicultural and land-planning measures.

Enlightened forest management requires reliable information on the status and conditions of each forest (Noss, 1999). This study provides an important contribute in this aspect, not only at landscape, but also regional context. Some authors argue that monocultural plantations may offer important contributes in landscape regeneration, by attracting species and accelerating the ecological succession process (e.g. Lugo, 1997), but afterwards will support far less biodiversity than a natural or mixed forest (Sayer et al., 2004). However, there are ways in which the biodiversity of plantations can be enhanced, seeking a compromise between conservation and forestry. After gathering the knowledge (Lindenmayer, 1999), sustainable forest management deal with ecologically conscientious practices that maintain the forest ecosystem's integrity, productivity, resilience and biodiversity (Kotwal et al., 2008). Sound silvicultural approaches thus integrate ecological and economic objectives by aligning harvesting systems with natural disturbance processes (Klenner and Sullivan, 2009). Maintenance of connectivity between important habitats, retaining vegetation on logged areas throughout the landscape; maintenance of landscape heterogeneity, creating different forest type patches and clearings among or next to stands, avoiding clearcutting harvesting systems and enhancing rotational lengths are some management strategies that aid to achieve general biodiversity conservation principles at the landscape level (Lindenmayer and Franklin, 2002; Lindenmayer et al., 2006). Planting some autochthonous trees, maintaining a diversified understory, retaining of biological legacies such as large trees, snags and logs, that provide attributes of mature forest habitat, increase structural diversity and provide continuity in the regenerating forest (Franklin et al., 2002; McComb et al., 1993), within stands.

For nature conservation to be successful, it needs to be integrated into land-use practices over wide areas, linking productivity, land planning and research.

7.5. Bussaco National Forest

Bussaco has been largely described in terms of geological, religious, architectural, military, cultural and historical importance for decades. Labeled as *majestic arboretum*, this forest has also aroused interest of many renowned botanists (e.g. Tournefort, Goetze, Miller) over time, but surprisingly the fauna had never been studied before. As could be predicted attending to its exceptional floristic complexity and diversity, Bussaco also presents an impressive vertebrate diversity and great conservation value. Surrounded by large extensions of monocultural plantations, this relatively small woodland provides shelter, feeding and nesting resources for many species, which find there a suitable habitat. It was found to be important to all analyzed taxonomical groups, although to a less extent for small mammals, but particularly for birds, bats and amphibians.

Further research is needed, but it is likely that Bussaco is functioning as a swarming area for bats, which enhances even more the conservation value of this forest, taken into account that bats constitute very sensitive communities that are declining worldwide mainly due to human-induced environmental stressors such as habitat loss.

Amphibians are also fragile communities, which sensitivity is compounded buy their dependence on water and appropriate breeding sites. Preservation of amphibian biodiversity requires a combination of mature hardwoods and wetland habitats (Mitchell et al., 1997). Bussaco constitutes an important site for this fauna, sheltering several protected and endemic species.

It is understood that one of the most important ways of conserving biodiversity is to maintain and restore characteristic regional features (Pienkowski et al., 1996). This is even more relevant if the region comprises highly valuable attributes, as Bussaco National Forest proved itself to be. This way, it is reinforced that areas with no legal protection status may play a major complementary role in biodiversity conservation, and that comprehensive nature restoration or protection strategies must account for their value and integrate them on land use planning and management principles.

7.6. References

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