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How important is the availability of food resources for breeding birds at montados?

Exploring bird-arthropods relationships on a Mediterranean landscape

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How important is the availability of food resources for breeding birds at montados?

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Abstract

The management practices of Mediterranean oak systems can enhance their susceptibility to insect outbreak. At these habitats the insectivorous bird species are dominant within the breeding community. Accordingly, we aimed to assess the importance of arthropod community for breeding birds and identify which species may be related with insect outbreak (defoliator and buprestid beetles) at central Portugal in montado systems dominated by Cork Oaks *Quercus suber*. We used variance partition to determine the relevance of three environmental variable groups for birds: arthropod community, vegetation characteristics and management practices. As a result, arthropods presented the highest pure effect with 11.24% of variance explained from a total of 61.20%. Bird-arthropod relationships were direct when associated with a potential-prey or indirect mostly when dependent on a breeding site selection. Thereafter, linear regression was used for pest insect modeling in function of bird community parameters. The obtained regression coeficients indicated that Great Tit *Parus major*, alone or with other foliage-dwelling birds, and Short-toed Treecreeper *Certhia brachydactyla* were potential predators of defoliator insects. Whereas the Lesser Spotted Woodpecker *Dendrocopos minor* appeared to be an indicator of Buprestid outbreak. Consequently, the protection of hole-nesting birds can improve the conservation of oak habitats.

Key-words: montados birds arthropods vegetation management pest-outbreaks

Quão importante é disponibilidade de recursos alimentares para as aves nidificantes em montados?

Explorando as relações entre as aves e os artrópodes numa paisagem mediterrânica

Resumo

As práticas de gestão dos sistemas de carvalhos mediterrânicos podem aumentar a sua susceptibilidade a pragas de insectos. As aves insectivoras são dominantes entre a comunidade nidificante desses habitats. Neste sentido, em montados de sobreiro *Quercus suber* do Centro de Portugal procurámos determinar a importância dos artrópodes para as aves nidificantes e identificar quais as relações entre as aves e as pragas (desfolhadores e cobrilhas). Utilizámos partição de variância para determinar a importância de três grupos de variáveis para as aves: comunidade de artrópodes, características da vegetação e práticas de gestão. Os artrópodes apresentaram o maior efeito puro com 11,24% de variância explicada, de um total de 61,20%. As aves relacionaram-se directamente com estes pela associação a presas potenciais ou indirectamente, nomeadamente pela selecção do habitat de nidificação. Seguidamente as pragas foram modeladas em função das variáveis ornitológicas através de regressões lineares. Os coeficientes de regressão indicaram que o chapim-real *Parus major*, conjuntamente ou não com outras aves da folhagem, e a trepadeira *Certhia brachydactyla* foram potenciais predadores dos insectos desfolhadores. Por outro lado, o pica-pau-galego *Dendrocopos minor* aparentou ser indicador dos ataques das cobrilhas. Consequentemente, a conservação das aves nidificantes em cavidades pode contribuir para a conservação do montado.

Palavras-chave: montados aves artrópodes vegetação gestão pragas

Resumo alargado

Os sistemas de carvalhos, de que são exemplo os montados, possuem grandes abundâncias de artrópodes comparativamente com outras paisagens mediterrânicas. Os montados (e as *dehesas* espanholas) são sistemas agro-silvo-pastoris típicos da Península Ibérica cuja manutenção depende da acção humana. Contudo, as práticas de gestão neles conduzidas podem facilitar o aparecimento de pragas de insectos causadoras de desfolha, da redução da qualidade da cortiça e, em casos extremos, da mortalidade das árvores. Embora a comunidade de aves nidificantes desses sistemas seja composta essencialmente por espécies insectívoras, as relações das aves com a comunidade de artrópodes permanece mal estudada. Nesse sentido, procurámos (1) avaliar a importância dos artrópodes que habitam a vegetação lenhosa como recurso alimentar das aves nidificantes em montados; e (2) determinar as espécies de aves que possam ser predadoras das principais pragas de insectos dos sobreiros *Quercus suber*.

O estudo foi realizado numa área de montado de sobro no Ribatejo, propriedade da Companhia das Lezírias S.A., a qual é responsável pela sua gestão florestal e pecuária. Foram seleccionados 80 locais de amostragem correspondentes a dois tipos de áreas de acordo com a sua intensidade de exploração: 40 locais em áreas com maior intensificação (denominadas exploradas) e 40 locais com menor intensidade de exploração (áreas protegidas). Nestes locais realizámos pontos de escuta para delimitação dos territórios de aves e amostragens visuais das manifestações das pragas de insectos. Entre elas, foram registadas manifestações de larvas de mariposas (Lepidoptera) e de lagarta-verde *Periclista* spp. como desfolhadores e da cobrilha-dos-ramos *Coroebus florentinus* e cobrilha-da-cortiça *C. undatus* (Buprestidae, Coleoptera). Numa sub-amostra de 29 locais de acordo com sua representatividade na área de estudo (16 protegidos e 13 explorados) realizámos amostragens de artrópodes com recurso a garrafas de etanol e batimentos na vegetação. Em cada local da sub-amostra foi caracterizado o habitat com base nas características da vegetação e nas práticas de gestão.

Com os dados da sub-amostra, recorremos à partição de variância através da análise de correspondência canónica (CCA) para determinar a importância das variáveis ambientais para a comunidade de aves insectívoras. As variáveis foram divididas em três grupos: a comunidade de artrópodes que habita a vegetação lenhosa, características da vegetação e práticas de gestão. Como resultado, verificámos que a maioria das variáveis significativas pertenceu ao grupo da comunidade de artrópodes (ex. abundância de aranhas, mariposas e escaravelhos xilomicetófagos). Os artrópodes apresentaram o maior efeito puro

com 11,24% de variância explicada, de um total de 61,20%. A sua relação com a comunidade de aves ocorreu de modo (1) directo, pela associação destas a presas potenciais (mariposas e escaravelhos xilomicetófagos); (2) indirecto através da selecção do habitat de nidificação das aves com base em características da vegetação ou de práticas de gestão; (3) indirecto pela partilha de presas comuns com artrópodes predadores, como as aranhas. Comparativamente com as características da vegetação, as práticas de gestão revelaram-se mais importantes para a comunidade de aves, explicando uma parte importante da variância dos dois principais eixos do diagrama da CCA. A comunidade de aves foi bastante selectiva na densidade do subcoberto (como local de nidificação e de alimentação) como revelam os 31,94% de variância explicada para o primeiro eixo do diagrama.

As pragas de insectos foram modeladas para cada um dos dois tipos de exploração. Nesse sentido, utilizámos regressões lineares com as componentes da comunidade de aves (presenças, abundâncias e riquezas de espécies) como variáveis explicativas. Os coeficientes de regressão obtidos foram utilizados como indicadores das relações estabelecidas entre as aves e os insectos. Considerando a semelhança entre os locais de alimentação do pica-pau-galego *Dendrocopos minor* com os locais de postura da cobrilha-dos-ramos, os nossos resultados indicam que a relação entre ambos deva ser trófica. Uma vez que não se alimenta no tronco, o pica-pau-galego pode ser indicador da abundância de cobrilha-da-cortiça dada a maior propensão à nidificação da ave em locais com grande densidade de árvores afectadas pelo insecto. Relativamente aos desfolhadores, o chapim-real *Parus major* e a trepadeira *Certhia brachydactyla* foram registados como os seus principais predadores. Os resultados indicam que, nas áreas exploradas, o chapim-real foi o predador dominante dos insectos desfolhadores (tanto larvas de mariposa como lagartas-verde), devido à sua dieta e técnicas de captura generalistas. Nas áreas protegidas, a competição pelos insectos desfolhadores deverá ter sido maior e o chapim-real foi substituído por outras espécies de aves que também se alimentam na folhagem. As trepadeiras aparentaram igualmente ter algum impacto nos lepidópteros nas áreas exploradas, na medida em que procuram alimento nos troncos onde alguns desses desfolhadores desenvolvem parte dos seus ciclos de vida.

Embora, o chapim-real e a trepadeira sejam geralmente consideradas espécies florestais generalistas; a única espécie que ocorre preferencialmente em habitats de sobreiro é o pica-pau-galego. Consequentemente, a conservação das aves nidificantes em cavidades tidas como predadores ou indicadores de insectos praga, nomeadamente o pica-pau-galego, pode ter reflexos positivos na conservação do montado de sobro.

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1 Introduction

A Mediterranean landscape of evergreen oaks, like Portuguese montado and Spanish dehesa, supports higher arthropod abundances than other native forests (Blondel *et al.* 1991; Díaz and Pulido 1993; Illera and Atienza 1995; Camprodon and Brotons 2006). Montado is an agro-silvo-pastoral system highly sustainable at European scale, where livestock, cork (from Cork Oak *Quercus suber* montados), crops and hunting can be promoted simultaneously (Pinto-Correia and Mascarenhas 1999; Carvalho 2007; Bugalho *et al.* 2009). Further, livestock management influence oak and shrub development. Their exclusion can promote sapling recruitment and shrub expansion, increasing the system similarities with a natural oak forest (Castro *et al.* 2010); and creating microclimatic conditions suitable for many arthropods to develop their life cycles with higher success (Tovar-Sánchez *et al.* 2003; Cardoso *et al.* 2009). On the other hand, intensive management practices enhance the risk of insect pest outbreak (Martí *et al.* 2005; Carvalho 2007; Bugalho *et al.* 2009). At montados, leaf-eaters, bark and wood boring beetles are responsible for canopy defoliation, cork quality reducing and tree mortality (Ferreira and Ferreira 1991; Branco and Ramos 2009).

Phytophagous arthropods abundance determines the success of bottom-up and top-down effects among trophic levels, as plants productivity and breeding success of predatory birds (see Dickson and Whitham 1996; Dajoz 2000; Murakami and Nakano 2000; Southwood *et al.* 2004). This can be particularly relevant in oak habitats, where almost the entire bird community is insectivorous, at least during breeding period (*e.g.* Guitián 1985; Díaz and Pulido 1993; Illera and Atienza 1995; Atiénzar *et al.* 2009). According to several diet studies of farm and woodland birds, the amount of a particular food item in the diet composition is strongly correlated with the preferential prey availability in nature (*e.g.* Kuitunen 1989; Illera and Atienza 1995; Naef-Daenzer *et al.* 2000; Pimentel and Nilsson 2007). This issue has been explored in order to test the efficiency of bird predation on insect pest control (Connor *et al.* 1999; Murakami and Nakano 2000; Mols and Visser 2002; Valente and Branco 2008). However, despite the known importance of birds as insect predators, few studies have explored ecologic relations between breeding birds and woody-vegetation arthropods at oak habitats (*e.g.* Blondel *et al.* 1991; Díaz and Pulido 1993; Sanz 2001). Moreover, the importance of arthropods as a determinant factor for bird occurrences compared with vegetation characteristics and management practices remains poorly understood (see Tellería and Santos 1994; Cherkaoui *et al.* 2009; Godinho and Rabaça 2010). Therefore, our study aims to (1) evaluate the importance of woody-vegetation arthropod community as food resource to breeding birds of montados; and (2) assess which bird species may be potential predators of main Cork Oak insect pests.

2 Methods

2.1 Study area

Field work was conducted in Ribatejo, a central province of Portugal (8˚48'W and 38˚50'N) (Fig.1). The study area is located in Companhia das Lezírias S.A., a public ownership farm where rice, wine, cork, wood and livestock are produced. Slope is soft and altitude ranges between 15-50m a.s.l.. Climate is typically Mediterranean with hot and dry summers and moderate rainy winters: mean temperature ranges from 8˚C in January to 22˚C in July and monthly precipitation ranges from 25mm to 150mm (Instituto do Ambiente 1999). The 8,000ha of woodland area are dominated by montados of Cork Oak sorted in plots with different tree maturities, cork-harvesting ages and shrubby densities. Cork is harvested from oak trunks each nine years throughout ownership. Maritime Pine *Pinus pinaster* and Stone Pine *P. pinea* occur mixed with oaks (representing always ≤10% of trees) or planted on small stands (≤350ha). In the region, the occurrence of outbreaks of Cork Oak pests is reported at least since the 60's of the XX Century, when the buprestids *Coroebus florentinus* and *C. undatus* (Coleoptera, Buprestidae), the moths *Tortrix viridana* and *Lymantria dispar* (Lepidoptera) and the sawfly *Periclista andrei* (Hymenoptera, Tenthredinidae) have been the dominant species (Baeta-Neves *et al.* 1972).

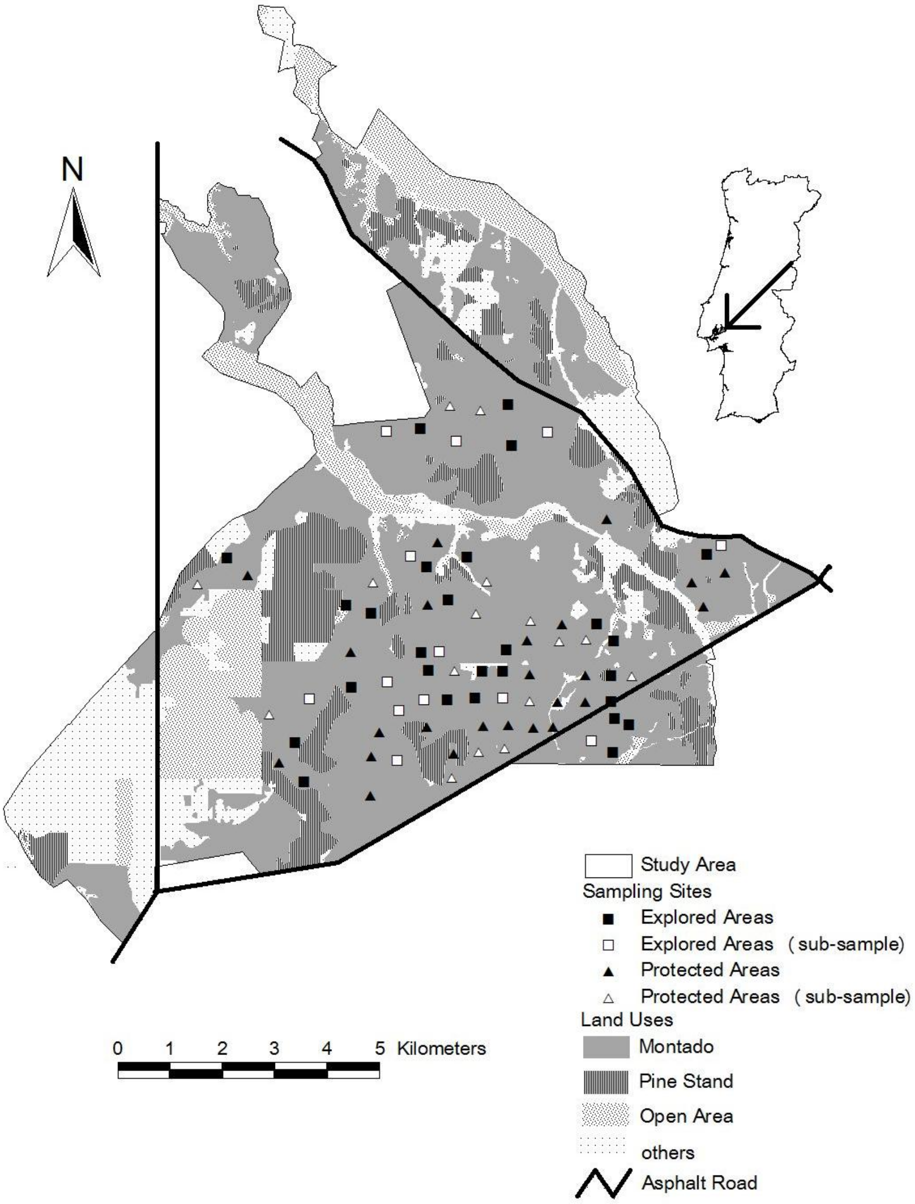

Fig. 1: Map of the study area showing the locations of sampling sites and land uses. Open symbols (☐ and Δ) indicate the sites that belong to the sub-sample used for CCA analysis.

2.2 Sampling methods

We selected our sampling sites (n=80) according to their exploration intensity. We surveyed forty sites with reduced density of mature Cork Oaks, with a recent cork-harvesting and scarcity of shrub due to grazing effects (thereafter called explored areas). By opposition to sites with reduced human perturbation, where young trees were protected, thereafter called protected areas (n=40). Bird sampling and visual assessment of pest insects were conducted at 80 sites. The remaining surveys were performed in 29 representative sites of montado: 16 protected and 13 explored areas. Similarly, the selected Cork Oaks trees for individual sampling procedures were representative within each site, based on the age of the last cork harvesting, diameter at breast high (DBH) and density of saplings at 1m around the tree. Thereafter, for simpler reading, oak will be used for Cork Oak.

2.2.1 Bird surveys

In each sampling site a point count census with limited distance (100m bandwidth) and a counting period of 10 minutes was conducted (Bibby *et al.* 2000). Bird surveys were carried out twice during the 2009 breeding season: the first visit was performed between middle March and middle April and the second one month later. Surveys were carried out by two experienced observers with similar identification skills and distance estimation training. The censuses were carried out between 6.00am and 11.00am, when birds are more active, avoiding days with adverse weather conditions such as moderate rain or strong wind.

2.2.2 Arthropod surveys

Three different methods were selected to survey the arthropod community: (1) bottle traps baited with ethanol; (2) beats in vegetation; (3) visual assessment of pest outbreaks (defoliators, bark and wood boring beetles). Since the first two methods (performed at once at later May 2009) proved unsuitable for pest sampling, we carried out the visual assessment one year later.

Bottle traps with ethanol (70%) were attached to oak trunk at 1.5m high; placed in two trees c. 100m apart, for a period of five days (see Ferraz *et al.* 1999). Such method is particularly suitable to collect small Hymenoptera, Diptera and Coleoptera (Montgomery and Wargo 1983; Byers 1992). The beats on woody vegetation were made using a wooden pole for beating at one square metre of vegetation, 20 times by individual plant, and a tray for specimen's collection, as Araneae, Hemiptera and Coleoptera (Marshall et al 1994; González-Megías and Gómez 2003; Cardoso *et al.* 2009). In each site we sampled four oaks and six shrubs of the two commonest species. Shrubs were not surveyed at sites with less than 26% of understory cover. This technique accounted for sampling shrub-dweller arthropods and, combined with ethanol traps, for tree arthropods. All collected samples were made avoiding air temperatures bellow 12˚C, wind speed over 10km/s and rainy or cloudy days; and specimens were conserved frozen until their identification at laboratory.

The visual assessment was conducted on five oaks during three consecutive days in order to exclude time effect between sites related to metamorphosis development of defoliators (see Murakami and Nakano 2000; Sanz 2001; Southwood *et al.* 2004). Defoliation impact was sampled by estimating the proportion of young leaf damaged at one metre square of canopy (at northern and southern sides), which is an indicative measure of caterpillar abundance (Sanz 2001). Taxonomic identification was based on the shape of leaf damage: chew inward from the leaf edge for Lepidoptera and elliptical holes on blade for Sawflies *Periclista* spp. (Toimil 1987; Ferreira and Ferreira 1991). For bark and wood boring beetles (Buprestids and Cerambycids) we recorded the number of affected trees by their activity. The Buprestid *C. florentinus* damage was identified by the presence of typical small dead branches on outer-canopy (perennial over years due to unpruning practices); and *C. undatus* by the presence of feeding galleries of larvae under cork layer (Ferreira and Ferreira 1991; Soria *et al.* 1992). Harvesting reveals their presence by displaying old galleries marked on bark (Branco and Ramos 2009), therefore we sample the attack that occurred until 8 years before. Beetle holes on trunks were recorded according to their size: ≤2mm diameter for bark beetles's presence (Platypodidae and Scolitydae); larger diameters for Cerambycids (Cerambycidae) (Ferreira and Ferreira 1991; Van Halder *et al.* 2002).

2.2.3 Vegetation characteristics and management practices

The richness of woody vegetation was recorded for tree species and shrub genus. Exceptionally, Gum Cistus *Cistus ladanifer* was sorted from congeneric plants due to differences in aromatic properties and in plant habit: tallest and straightest steams than lesser Cistus. We determined the age and health status for ten oaks according their DBH and presence of *Biscogniauxia mediterranea*, respectively. This fungus is the agent of charcoal disease, causing a serious damage on trees at physiologic stress (Van Halder *et al.* 2002; Branco and Ramos 2009).

The cover of woody vegetation was sampled in percentage classes for shrubs and oak saplings (as indicative measure of grazing effects) and for oak trees. We recorded the distance between consecutive ten oaks and the age of last cork harvesting for ten representative trees. The cover and tallness of saplings were estimated at one metre around the trunk base of five of these trees. We also registered the sites with artificial regeneration of oaks. Spatial management features, as distances to pine stands, agricultural areas and asphalt roads, were obtained using ArcGis 9.1 (ESRI 2004).

2.3 Analyzed variables

For each bird species and each visit we determined the maximum number of breeding territories (using territorial males), which based on Bibby *et al.* (2000) represents the minimum of territories at that site. We excluded from data treatment non-territorial birds (*e.g.* Spotless Starling *Sturnus unicolor*), non-insectivorous species (*e.g.* Goldfinch *Carduelis carduelis*), aerial-feeding birds (*e.g.* Barn Swallow *Hirundo rustica*), omnivorous birds even during breeding season (*e.g.* Blackbird *Turdus merula*). Bird territories at 29 sites were used as response variables in order to determine the importance of arthropods as their food resource. We excluded the rarest (occurrence at ≤5 sites) and commonest species (≥25 sites) in order to reduce their noise on further analysis. Explanatory variables (binary) were sorted in three groups: arthropods community, vegetation characteristics and management practices (Appendix I). In the vegetation set we included natural traits of oak forests, as richness of woody vegetation, age and tree health status. The DBH for mature oaks was based on Montero and Cañellas (2003; see Appendix I). Whereas human actions, like spatial planning and agroforestry practices, were grouped into the management set.

Collected arthropods were identified and grouped according to their taxonomical representation, ecological functional value for montados (*e.g.* phytophagous, nutrient cycling agents etc.) and dietary relevance for birds (see Ferreira and Ferreira 1991; Dajoz 2000; Szentkirályi and Krištín 2002; Appendix I). Groups with less than 25 individuals were not included in analysis. Sites with ≥5% of total abundance of a given group were used as a presence. Non-fliers or less mobile groups (spiders, mites, ants, weevils and aphids) were separated according oak or shrub provenience. Visual assessment data was also included within arthropod group as explanatory variables. Defoliator's variables were obtained using the average of their attack at canopy's northern and southern sides of each oak.

For assess the potential predatory birds of pest insects, we used the number of affected oaks as response variables (maximum of five oaks). Bark beetles and Cerambycids data were not used due to their scarcity on study area. We used bird richness, presence or abundance as explanatory variables. Within each exploration-intensity area type, the rarest birds (≤20% presences) were considered as binary variables and the remaining species as continuous variables. Accordingly, Nightingale *Luscinia megarhynchos* was treated as two different variables. The richness of species per forage habitat was established according to the preferencial use of a given substrate (≥15% of forage observations based on references listed on Appendix II). All collected variables were submitted to Spearman correlation test. For variable pairs with |≥0.7| of correlation coefficient, we retained the most biologically meaningful variable for further analysis (*e.g.* Galantinho and Mira 2009; Santos *et al.* 2009).

2.4 Data analysis

2.4.1 Canonical correspondence analysis and variance partitioning

In order to assess the importance of arthropods for bird community (n=29) we computed a variance partitioning using canonical correspondence analysis (CCA), following Heikkinen *et al.* (2004) procedure. Firstly, we performed a CCA for each group of environmental data using CANOCO for Windows 4.5 (ter Braak and Šmilauer 2002). Individual variables were submitted to Monte Carlo permutation test with 999 permutations and incorporated in the analysis for $p \leq 0.05$ (*e.g.* Godinho and Rabaça 2010). As result, we obtained the most significant variables and the entire explained variance per each group. A fourth CCA with all selected variables was computed to obtain the total explained variance of the whole model. Performing three CCA using all combinations, we obtained the group pure effects (I, II and III). Subtracting from these results the respective pure effect value we obtained shared variance between two groups (a, b and c). The value of variance shared between the three groups was calculated by subtraction of obtained values (I, II, III, a, b and c) from the total explained variance (see Galantinho and Mira 2009).

2.4.2 Linear regression modeling

The symptoms of commonest pest insects (n=80) were modeled in function of ornithological variables through linear regression analysis. In order to evaluate the spatial-autocorrelation suffered by pest insects, we calculated spatial filters for each area type. Filter selection was based on eigenvalue ≥3 and graphic analysis of Moran's I values. To reduce autocorrelation we selected the set of filters with Moran's I between -0.2 and 0.2 (see Fortin 1999). The obtained filters were used as as explanatory variables on modeling (Appendix II).

We performed univariate modeling in order to identify which ornithological variables were significant for a given insect pest ($p \leq 0.15$), using SAM 4.0 (Rangel *et al.* 2010). For each insect we computed all possible models with the significant variables. Models were sorted according to their Akaike's information criterion corrected for small samples (AICc). We selected the model with lower AICc, which represents the best explanation of our data (Burnham and Anderson 2002; Galantinho and Mira 2009; Santos *et al.* 2009). The total amount of explained variation for each insect model was given using adjusted r^2, being higher when the model accuracy is high.

3 Results

The total number of bird species recorded was 65 for whole study area. Per point counts the average richness was 17.00±3.67 (or 13.89±2.92 considering only the insectivorous species). Chaffinch *Fringilla coelebs* and Woodlark *Lullula arborea* were the most frequent species with 99% and 90% of occurrence frequency, respectively. In the case of collected arthropods, the total number of recorded families was 100, with 24.59±6.49 of average richness at sites. The most frequent families were Cetoniidae (Coleoptera) and Formicidae (Hymenoptera) recorded at all sampled sites and Sarcophagidae (Diptera) at 97% of the sites.

3.1 Factors affecting bird occurrences

The amount of variation explained for the bird community by the fourteen selected environmental variables was 61.20% (Fig. 3). The most significant variables for the final CCA analysis were the abundance of parasitic hymenopterans, oak and shrub mites, oak spiders, bark beetles and moths, road proximity, two shrub densities and high abundance of mature trees (PARHY, MITEO, MITES, SPIDO, BARKV, MOTH4, ROAD1, SHRC2, SHRC4 and MATU4, respectively; see Fig.2; Appendix I). Some vegetation and management variables were significant only for the respective partial analysis (Tab. 1).

The highest pure effect obtained (11.24%) belonged to the arthropod community group, which shared with vegetation characteristics the largest fraction of explained variance (a=13.70%). The remaining shared effects were also high: 11.73% for arthropods and management practices (b) and 11.02% for management and vegetation. Nevertheless, the variance shared for all groups together represented only 4.53%. The first axis, influenced by the shrub cover (SHRC2 and SHRC4 at positive and negative sides, respectively), explained 31.94% of bird community composition. Whereas, the second axis was slightly influenced by tree maturity (MATU4) at positive side and road proximity (ROAD 1) at negative, explained 19.86% of variance.

Using all environmental variables together, the total explained variance on bird species ranged from Stonechat *Saxicola torquata* (35.61%) to Nightingale (75.94%) (Tab. 2). The percentage of variation explained by arthropods community ranged from 10.88% for Great Tit *Parus major* to 57.56% for Zitting Cisticola *Cisticola juncidis*. The values for management practices ranged from Zitting Cisticola (7.16%) to Nightingale (66.78%); and from Great Tit (7.45%) to Short-toed Treecreeper *Certhia brachydactyla* (50.57%) for vegetation characteristics.

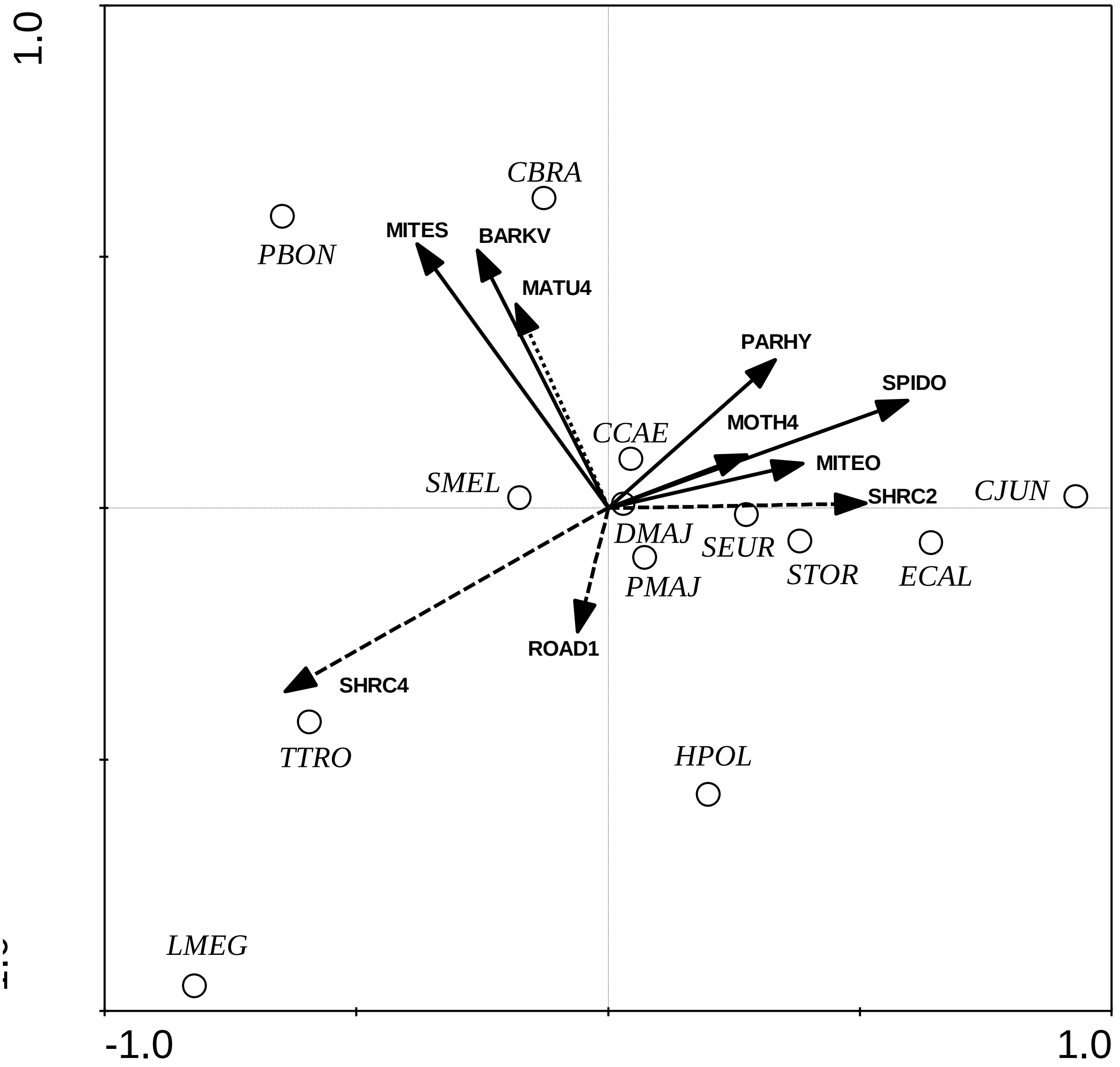

Fig. 2: Canonical correspondence analysis ordination diagram with birds (○) and environmental variables (arrows) significant when the three groups were used: arthropods community (solid line), vegetation characteristics (dotted line) and management practices (dashed line). For species and environmental variables codes see Appendix I.

Tab. 1: Canonical coefficients and intraset correlations of significant environmental variables with the first two axes of canonical correspondence analysis, respective F and P-value for individual analysis of each group (arthropods community, vegetation characteristics and management practices) and for all groups analyzed together. For variable codes see Appendix I.

	Canonical Coefficients			**Intraset Correlations**			
Group	**Code**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**	**F**	**P-value**
Arthropods Community	PARHY	0.3420	0.6513	0.2905	0.4302	1.927	0.0390
	MITEO	0.4028	0.3295	0.3400	0.1577	1.890	0.0390
	SPIDO	0.3843	0.2401	0.5146	0.3884	3.149	0.0030
	MITES	-0.5059	0.4615	-0.4123	0.3697	1.891	0.0420
	BARKV	-0.4364	0.5541	-0.3164	0.3921	2.783	0.0060
	MOTH4	0.4980	-0.2746	0.2155	-0.0035	2.098	0.0280
Vegetation Characteristics	HALIM	1.0168	-0.1449	0.5381	0.0474	2.759	0.0160
	MATU2	-0.6767	-0.3216	-0.2718	-0.4516	2.441	0.0150
	MATU4	-0.5346	0.5951	0.0371	0.5666	2.273	0.0170
	FLES1	-0.0991	0.5549	-0.0568	0.5137	1.796	0.0500
Management Practices	HARL3	-0.0957	0.9098	-0.0479	0.4751	1.899	0.0470
	ROAD1	0.2259	-0.4970	0.1408	-0.3122	1.910	0.0410
	SHRC2	-0.3977	-0.5627	-0.4909	-0.2348	1.883	0.0460
	SHRC4	0.7810	-0.2338	0.6957	0.0290	3.766	0.0020
All Groups	PARHY	0.2222	0.3323	0.3030	0.2669	2.090	0.0017
	MITEO	0.4829	0.2394	0.3527	0.0801	2.025	0.0170
	SPIDO	0.3528	-0.2812	0.5431	0.1936	1.955	0.0340
	MITES	-0.2971	0.7510	-0.3463	0.4753	2.385	0.0090
	BARKV	-0.3131	0.6673	-0.2368	0.4646	2.453	0.0110
	MOTH4	0.2687	-0.5286	0.2514	0.0959	2.148	0.0210
	MATU4	0.1263	-0.0338	-0.1668	0.3674	1.797	0.0470
	ROAD1	0.0191	-0.1789	-0.0553	-0.2223	2.133	0.0210
	SHRC2	0.3730	0.2926	0.4673	0.0085	1.738	0.0470
	SHRC4	-0.1494	-0.6245	-0.5865	-0.3301	3.766	0.0020

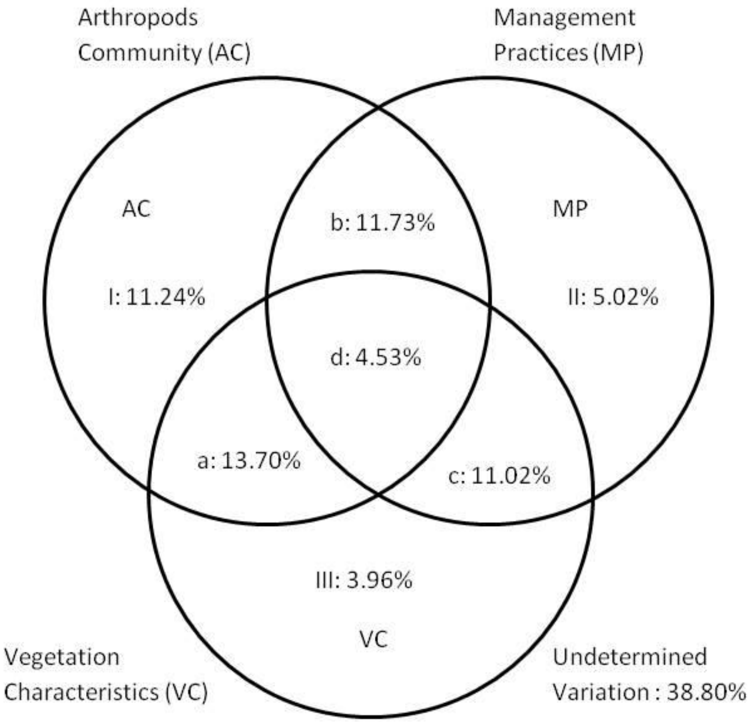

Fig. 3: Variation partitioning diagram according to the three variable groups and fractions of explained variance: pure effect of arthropods community (I); pure effect of management practices (II); pure effect of vegetation characteristics (III); combined effect of arthropods community and vegetation characteristics (a); combined effect of arthropods community and management practices (b); combined effect of vegetation characteristics and management practices (c); combined effects of three environmental variable groups (d).

Tab. 2: Variance explained (%) based on canonical correspondence analysis for each bird species according to the individual environmental variable groups (arthropods community, vegetation characteristics and management practices) individually or together. For bird species codes see Appendix I.

Species Code	Arthropods Community	Vegetation Characteristics	Management Practices	All Groups
CBRA	45.45	50.57	8.21	70.51
CJUN	57.56	39.78	7.16	60.09
CCAE	29.02	18.03	31.49	60.15
DMAJ	31.86	33.00	3.53	47.27
ECAL	64.60	33.29	27.98	67.15
HPOL	20.84	17.03	27.44	52.70
LMEG	41.38	38.67	66.78	75.94
PMAJ	10.88	7.45	21.25	52.03
PBON	55.17	15.93	39.87	68.63
STOR	33.42	12.93	14.42	35.61
SEUR	14.96	23.95	44.22	50.56
SMEL	20.98	32.08	21.01	48.60
TTRO	41.48	42.14	38.64	64.99

3.2 Insect outbreak modeling

The coefficients obtained through linear regression analyses were used as indicators of the relationships established between birds and pest insects. Lesser Spotted Woodpecker *Dendrocopos minor* (DENMIN) was positively correlated with the abundances of both buprestid species at protected areas. Whereas, at explored areas insects presented a positive relation with Tree Sparrow *Passer montanus* (PASMON) and Crested Tit *Lophophanes cristatus* (LOPCRI; Tab. 3). The latter also appeared negatively correlated with *C. florentinus* abundance on protected areas. Other variables inversely related to buprestid abundance were Iberian Chiffchaff *Phylloscopus ibericus* and Rock Sparrow *Petronia petronia* presences and Nightingale and Stonechat abundances (PHYIBE, PETPET, LUSMEA and SAXTOR, respectively). On the other hand, defoliators were inversely correlated with foliage-forager species richness (FOLIAG), Great Tit (PARMAJ) and Short-toed Treecreeper (CERBRA) abundances and with presence of three ground foragers: Zitting Cisticola (CISJUN), Rock Sparrow (PETPET) and Woodchat Shrike *Lanius senator* (LANSEN). Stonechat, Nuthatch *Sitta europaea*, Lesser Spotted Woodpecker and Cirl Bunting *Emberiza cirlus* were positively associated with defoliators (SAXTOR, SITEUR, DENMIN and EMBCIR, respectively). The r^2 adjusted ranged between 0.108 and 0.553 for *C. undatus* and *C. florentinus* attacks at protected areas, respectively (Tab. 3). The residuals of the later model presented the highest values of spatial autocorrelation, which we used three filters for their computation.

Tab. 3: Linear Regression modeling results for main insect outbreaks for montados at explored and protected areas; presenting the regression coefficients (Coeff.), test-t results (T), the significance value (P-value), the lower obtained Akaike's information criterion corrected for small samples (AICc) and respective model accuracy (r^2adj) for each model. For variable codes see Appendix II.

Response Variable	Variable Codes	Coeff.	T	P –value	AICc	r^2adj
	Constant	2.978	14.371	<0.001		
	PASMON	1.773	3.012	0.005		
C. florentinus at Explored Areas	MFILTER2	-3.721	-3.015	0.005	135.797	0.291
	Constant	3.75	11.438	<0.001		
	DENMIN	0.861	1.324	0.195		
	LOPCRI	-1.121	-1.512	0.141		
	PHYIBE	-0.991	-1.455	1.156		
	LUSMEA	-0.408	-1.748	0.091		
	SAXTOR	-0.815	-1.874	0.071		
	FFILTER1	-3.911	-3.053	0.005		
	FFILTER2	3.456	2.714	0.011		
C. florentinus at Protected Areas	FFILTER3	-1.601	-1.251	0.221	144.240	0.553
	Constant	3.472	19.882	0		
C. undatus at Explored Areas	LOPCRI	1.278	2.314	0.026	121.868	0.123
	Constant	3.594	15.055	<0.001		
	DENMIN	1.156	1.615	0.1115		
C. undatus at Protected Areas	PETPET	-1.094	-1.527	0.135	143.569	0.108
	Constant	1.38	3.164	0.003		
	CERBRA	-0.311	-1.081	0.288		
	DENMIN	2.069	3.303	0.002		
	EMBCIR	1.399	2.142	0.04		
	PARMAJ	-0.494	-1.709	0.097		
	SAXTOR	0.956	2.916	0.006		
Moth at Explored Areas	MFILTER1	2.92	2.222	0.033	140.674	0.437
	Constant	3.167	4.946	<0.001		
	CISJUN	-1.362	-3.047	0.004		
Moth at Protected Areas	FOLIAG	-0.383	-2.145	0.039	132.631	0.267
	Constant	3.897	12.754	<0.001		
	PARMAJ	-0.464	-1.627	0.113		
Sawfly at Explored Areas	PETPET	-1.642	-3.176	0.003	136.800	0.246
	Constant	3.066	9.838	<0.001		
	LANSEN	-1.943	-3.059	0.004		
Sawfly at Protected Areas	SITEUR	0.794	2.204	0.034	142.268	0.259

4 Discussion

4.1 Importance of arthropods for bird occurrences

In the present study we found relationships between birds and arthropods inhabiting woody-vegetation based on (1) direct trophic relationship, by associating birds to a potential-prey (moths or bark beetles); (2) indirect relationship, related with the selection of breeding site (depending on vegetation and management features) where arthropods are abundant; (3) indirect association by sharing a common prey. Spider and parasite occurrences can be proportionally related to high abundances of their respective preys and hosts (Dickson and Whitham 1996; Ferguson 2001; González-Megías and Gómez 2003). Therefore their association with bird abundances may be explained by indirect effects of these arthropods on phytophagous insects. However, spiders can have also some importance in bird diets (*e.g.* Guitián 1985; Kuitunen 1989; Szentkirályi and Krištín 2002). In the case of acari, which are dependent of micro-climatic conditions (Nicolai 1986; Ferguson 2001; Tovar-Shánchez *et al.* 2003), their relationships with birds are hard to explain.

Despite direct or indirect effects of arthropods on bird community, our results proved that arthropod community group was the most important among the collected variables: with the highest number of significant variables and the highest significant pure effect (Fig. 3). CCA diagram results revealed that oak moths can be more important as food resource for woodland and open-area generalist birds than to dense shrub species; whereas bark insects were associated with a bark bird, the Short-toed Treecreeper (Fig. 2). The high shared explained variance between arthropods and vegetation (a=11.02%; Fig. 3) is justified by the synchronization between plant phenology, larval development and breeding birds period (*e.g.* Blondel *et al.* 1991; Naef-Daenzer *et al.* 2000; Dajoz 2000; Ivashov *et al.* 2002; Pimentel and Nilsson 2007). Exceptionally, a generalist insectivorous birds as Great Tit (Guitián 1985; Naef-Daenzer *et al.* 2000; Mols and Visser 2002; Szentkirályi and Krištín 2002; Pimentel and Nilsson 2007) barely dependent on arthropods community composition (Tab. 2).

Management variables were more crucial than vegetation ones for the bird species arrangement over CCA diagram. However, the amount of explained variance was very similar between both groups, suggesting that birds respond to vegetation and management traits of oak trunks and shrubs as a whole. The edge effects, associated with road proximity, may have been attractable as breeding habitat for shrubby species (*e.g.* Melodious Warbler *Hippolais polygotta*). Moreover, plant stress and habitat fragmentation at these areas improves the oak susceptibility to xilophagous insect attack (van Balen *et al.* 1982; Ferreira and Ferreira 1991; Dajoz 2000; Fayt *et al.* 2005). As consequence, road edges had some importance for feeding habits of Great Spotted Woodpecker *Dendrocopos major* for the partial management practices CCA analysis. Comparatively to larger woodpecker, the treecreeper was most dependent of tree trunk characteristics. Accordingly, a high abundance of mature trees and not cork-debarked trunks enhance breeding opportunities for cavity nesting (van Balen *et al.* 1982; Tellería and Santos 1994) and improve the arthropod densities associated with fissured bark (Nicolai 1986; Dajoz 2000; Muñoz-López 2007). Notwithstanding, spatial differences on understory appeared to have higher influences at montado bird assemblage (see Rabaça 1990) even than tree traits. Probably, understory variables accounted with a substantial importance for Nightingale occurrence, which was the most specialized among the analyzed birds (see Tab. 2). Although, bird community have been distributed through to the shrubby gradient, none of the species appeared to be favored by the lowest shrub cover (≤26%, n=8). This dependence on shrub density may be related with their high abundance on arthropods (Camprodon and Brotons 2006). Two additional shrub characteristics appeared to be marginal for bird community when compared to their density: *Halimium* spp. (fairly abundant on arthropods, see Herrera 1988) and absence of fleshy fruits (crops mostly available on autumn, see Herrera 1984) (Tab. 1). As consequence insectivorous birds at montado were rather selective on understory density as breeding site and as food source, highlighting the relevance of management activities on their occurrences. Furthermore, the dependence of breeding birds on a rich source of arthropods is indicative of their potential on insect-pest predation.

4.2 Relations of birds and outbreak insects

Buprestid attack symptoms can be permanent on trees over several years. Since the abundance of ovipositing insects in one year improve breeding success and increase density of birds in the following years (see Newton 1998; Fayt *et al.* 2005), the potential predatory birds should be positively related with the recorded buprestid abundances. On the contrary, the rates of defoliation in oaks were observed in the same spring that the larvae were feeding on leaves (*e.g.* Ivashov *et al.* 2002; Mols and Visser 2002). Consequently the damage caused by defoliators is inversely related with high densities of small insectivorous passerines (Connor *et al.* 1999; Murakami and Nakano 2000; Sanz 2001).

The presence of Lesser Spotted Woodpecker was positively correlated with both *C. florentinus* and *C. undatus* at protected areas, suggesting an importance of this bird for montado conservation. Since the adult stage of *Coroebus* spp. is ephemeral (generally less than two months) and inconspicuous (Baeta-Neves *et al.* 1972; Muñoz-López 2007), the insects should suffer higher predation rates during the larval stage (up to two years). Several bird species, inversely correlated with Buprestids, forage on foliage and on ground, where only adult insects occurs. On the contrary, woodpecker forages preferentially on branches with similar traits to those are selected for *C. florentinus* ovipositing (Ferreira and Ferreira 1991; Snow and Perrins 1998; Muñoz-López 2007; Smith 2007). Take into account the food requirements of the woodpecker, it is not expected a high specialized predation on the coleopteran. However, in areas with high competition among birds per Lepidoptera larvae and with outbreak of buprestids, the woodpecker may adjust their diet for a higher consume of buprestids. Additionally, the high spatial autocorrelation of insect distribution may have included some noise on these relations increasing their explained variance. On the other hand, the relationship of woodpecker (and also Crested Tit) with *C. undatus* outbreak should not be a trophic association, since trunk foraging is clearly rejected by these birds (Herrera 1979; Carrascal 1987; Snow and Perrins 1998; Almeida and Granadeiro 2000). Birds and buprestid share preferences to mature oaks and dense shrubby layer selection (Rabaça 1990; Soria *et al.* 1992; Carvalho 2007; Atiénzar *et al.* 2009). Moreover, beetle attacks reduce plant defenses and consequently increase their suitability for trunk nesting (see Martín *et al.* 2005; Smith 2007). Therefore, the presence of such birds can be indicative of high *C. undatus* damage on oaks, more than a simple trophic relationship. However, the simple record of oak number affected by *C. undatus* could be unsuitable for exploring their relationships with bird species, justifying the lower values of explained variance.

The results obtained for defoliator modeling indicated that the generalist Great Tit was the dominant predator at explored areas. These sunny areas can be preferential selection to bird foraging due to either higher success in prey detection and predator avoidance (see Carrascal and Alonso 2006). Moreover, under-leaf feeding of sawflies larvae and their unpalatable traits makes them available only for tolerant birds with hanging abilities, like tits (see Boevé and Pasteels 1985; Connor *et al.* 1999). However, at closer canopies, birds that usually forage on caterpillars at inner-foliage (see Snow and Perrins 1998; Almeida and Granadeiro 2000) appeared to be stronger competitors which could justify the reduced dominance of Great Tits in these areas comparatively to the explored ones.

Trunk dweller birds may have different responses to outbreaks of defoliators. Tree trunks are used for some moth species as ovipositing or pupation sites and as pathways for moth and sawfly larvae accessing to canopy (for feeding) or to the soil (for pupate) (Ferreira and Ferreira 1991; Van Halder *et al.* 2002; Muñoz-López 2007). Our results suggest that treecreeper should exercise some predation on a certain moth state, since the trunk traits preferred for bird (discussed above) are suitable substrate for moth development. On the contrary, Nuthatch abundance appeared positively correlated to sawfly outbreak.

Accordingly, Murakami and Nakano (2000) found that Nuthatch can affect canopy defoliation, by consuming ants which are predators of defoliators. At ground level, where sawfly pupate up to three years (Ferreira and Ferreira 1991) and several montado birds forage, only a reduced number of birds had presented an inverse correlation with defoliators: Zitting Cisticola, Woodchat Shrike and Rock Sparrow. Other species, as Stonechat and Cirl Bunting, occurs at wood-edges where moth outbreak has higher probability to occur (Snow and Perrins 1998; Dajoz 2000; Van Halder *et al.* 2002; Carvalho 2007). Although, many dropped insects can be found on the ground, we expect that such birds have little affectation on defoliator populations. As a consequence, such issues enhance the action of birds that forages on foliage and trunks on defoliator control at montados.

4.3 Conclusions

During breeding season, insectivorous birds at montados were highly dependent on woody-vegetation arthropod community. The relationships obtained between birds and arthropods were direct when associated with a potential-prey or indirect mostly when dependent on a breeding site selection. Some natural vegetation characteristics and management practices conducted at montados, as tree maturity, shrub density and road proximity, were obtained as a significant to bird occurrences. Such variables have a known relevance for breeding-habitat traits but also, indirectly, as arthropods supply. A mosaic landscape with an intermediate density of mature trees and a diverse density of understory cover allow to maintain a rich bird community at montados. A reduced shrub density should not improve the abundance of any bird species on the studied habitats. Consequently, livestock rate must be managed according to the carrying capacity of the system.

Hole-nester birds, namely Great Tit, Short-toed Treecreeper and Lesser Spotted Woodpecker, were the most relevant species for insect pest control. The woodpecker appeared associated to buprestid damage, as a potential predator of *C. florentinus* and as indicator of *C. undatus* abundance. Great Tit can reduce the damage of defoliators mostly at explored areas, being replaced by a diverse foliage dwelling bird community at protected ones. Additionally, treecreeper should play a substantial role on caterpillar consume. However, Great Tit and treecreeper are regarded as woodland generalists, the woodpecker is between the few birds that occur preferentially at Cork Oak habitats. The diverse relationships established among birds and insects at the two different exploration areas, enphatizes the relevance of the said mosaic (with protected and explored areas) for a most effective pest control by the bird community. Therefore, the conservation of hole-nester birds like the Lesser Spotted Woodpecker can be the key for protection of managed oak habitats.

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Appendix I: Insectivorous bird species and three groups of environmental variables: arthropods community, vegetation characteristics and management practices; respective designation, code and classes. For collected arthropods (*) we used only the sites with high abundance (i.e. ≥5% of total abundance at one site) as a presence.

Variables	Code	Classes
Response Variables (insectivorous bird species)		
Abundance of Short-toed Treecreeper *Certhia brachydactyla*	CBRA	
Abundance of Zitting Cisticola *Cisticola juncidis*	CJUN	
Abundance of Blue Tit *Cyanistes caeruleus*	CCAE	
Abundance of Great Spotted Woodpecker *Dendrocopos major*	DMAJ	
Abundance of Corn Bunting *Emberiza calandra*	ECAL	
Abundance of Melodious Warbler *Hippolais polyglotta*	HPOL	
Abundance of Nightingale *Luscinia megarhynchos*	LMEG	
Abundance of Great Tit *Parus major*	PMAJ	
Abundance of Bonelli's Warbler *Phylloscopus bonelli*	PBON	
Abundance of Stonechat *Saxicola torquata*	STOR	
Abundance of Nuthatch *Sitta europaea*	SEUR	
Abundance of Sardinian Warbler *Sylvia melanocephala*	SMEL	
Abundance of Wren *Trogolodytes troglodytes*	TTRO	
Arthropods Community		
Family richness of collected insects	INSE	INSE1: 0-19; INSE2: 20-29; INSE3: ≥30
High abundance of collected fungi beeatles (mostly Cryptophagidae and Mycetophagidae, Coleoptera)*	FUNGI	
High abundance of collected saprofagous flies (mostly Muscidae and Sarcophagidae, Diptera)*	SAPRO	
High abundance of collected aphids at shrubs (Aphididae, Homoptera)*	APHIS	
High abundance of collected parasitic hymenoptera at oaks (mostly Platygastridae and Torymidae, Hymenoptera)*	PARHY	
High abundance of collected weevils at oaks (Curculionidae, Coleoptera)*	WEEVO	
High abundance of collected weevils at shrubs (Curculionidae, Coleoptera)*	WEEVS	
High abundance of collected mites at oaks (mostly Oribatidae, Acarina)*	MITEO	
High abundance of collected mites at shrubs (mostly Oribatidae, Acarina)*	MITES	
High abundance of collected spiders at oaks (Araneae)*	SPIDO	
High abundance of collected spiders at shrubs (Araneae) *	SPIDS	
High abundance of collected ants at oaks (Formicidae, Hymenoptera)*	ANTSO	
High abundance of collected ants at shrubs (Formicidae, Hymenoptera)*	ANTSS	
High abundance of collected bark beetles (Scolytidae and Platypodidae, Coleoptera)*	BARKC	
High abundance of collected Saproxylic beetles (mostly Cetoniidae and Cerambycidae, Coleoptera)*	SAPRX	
Presence of Bark Beetle holes at oak trunks (Scolytidae and Platypodidae, Coleoptera)	BARKV	
Presence of Cerambycid holes at oak trunks (Cerambycidae, Coleoptera)	CERAM	
Proportion of oaks attacked by *Coroebus undatus* (Buprestidae, Coleoptera)	CUND	CUND1: 0-20%; CUND2: 21-40%; CUND3: 41-60%; CUND4: 61-80%; CUND5: 81-100%
Proportion of oaks attacked by *Coroebus florentinus* (Buprestidae, Coleoptera)	CFLO	CFLO1: 0-20%; CFLO2: 21-40%; CFLO3: 41-60%; CFLO4: 61-80%; CFLO5: 81-100%

Variables	Code	Classes
Arthropods Community (continuation)		
Proportion of oaks with ≥25% of their canopy attacked by Sawfly *Periclista* spp. (Tenthredinidae, Hymenoptera)	PERI	PERI1: 0-20%; PERI2: 21-40%; PERI3: 41-60%; PERI4: 61-80%; PERI5: 81-100%
Proportion of oaks with ≥25% of their canopy attacked moths (Lepidoptera)	MOTH	MOTH1: 0-20%; MOTH2: 21-40%; MOTH3: 41-60%; MOTH4: 61-80%; MOTH5: 81-100%
Vegetation Characteristics		
Richness of shrub genus	SHRR	SHRR1: 0-2; SHRR2: 3-6; SHRR3: ≥7
Richness of fleshy-fruits shrub genus (*Daphne gnidium*, *Phillyrea angustifolia*, *Myrtus communis* and *Rubus ulmifolius*)	FLES	FLES1: 0; FLES2: 1-2; FLES3: ≥3
Richness of aromatic shrub genus (*Cistus landanifer*, *M. communis* and *Lavandula* spp.)	AROM	AROM1: 0; AROM2: 1; AROM3: ≥2
Richness of tree species	TREE	TREE1: 1; TREE2: 2; TREE3: ≥3
Presence of lesser Cistus (*C. crispus*, *C. monspeliensis* and *C. salvifolius*)	LCIST	
Presence of Gum Cistus *C. ladanifer*	GCIST	
Presence of Halimium *Halimium* spp.	HALIM	
Presence of Daphne *D. gnidium*	DAPHN	
Presence of Phillyrea *P. angustifolia*	PHYLL	
Presence of Myrtle *M. communis*	MYRTL	
Presence of Bramble *R. ulmifolius*	BRAMB	
Presence of Lavander *Lavandula* spp.	LAVAN	
Presence of shrubby-oaks (*Quercus coccifera* and *Q. lusitanica*)	OAKS	
Presence of Maritime Pine *Pinus pinaster*	MPINE	
Presence of Stone Pine *P. pinea*	SPINE	
Proportion of mature oaks (≥30cm of DBH ≈ ≥40 years age)	MATU	MATU1: 0-25%; MATU2: 26-50%; MATU3: 51-75%; MATU4: 76-100%
Proportion of oaks attacked by *Biscogniauxia mediterranea*	BISC	BISC1: 0-20%; BISC2: 21-40%; BISC3: 41-60%; BISC4: 61-80%; BISC5: 81-100%
Management Practices		
Distance to the closest planted pine stand (metres)	PIND	PIND1: 0-299; PIND2: 300-999; PIND3: ≥1000
Distance to the closest agriculture tree-less area (metres)	AGRD	AGRD1: 0-299; AGRD2: 300-999; AGRD3: ≥1000
Distance to the closest asphalt road (metres)	ROAD	ROAD1: 0-999; ROAD2: 1000-2499; ROAD3: ≥2500
Average distance between ten consecutive oak trunks (metres)	TRUD	TRUD1: 0-6.0; TRUD2: 6.1-8.9; TRUD3: ≥9
Shrub density cover	SHRC	SHRC1: 0-25%; SHRC2: 26-50%; SHRC3: 51-75%; SHRC4: 76-100%
Cork Oak density cover	OAKC	OAKC1: 0-39%; OAKC2: 40-59%; OAKC3: 60-100%
Average area occupied with oak saplings around five trunk bases	SAPO	SAPO1: 0-20%; SAPO2: 21-40%; SAPO3: 41-60%; SAPO4: 61-80%; SAPO5: 81-100%
Average oak sapling tallest than 10cm around five trunk bases	SAPLT	
Sites with artificial regeneration of oak	REGEN	
Average age of the last cork harvesting at ten oaks	HARL	HARL1: 0-2; HARL2: 3-5; HARL3: ≥6
Sites with the same age of cork harvesting	HARVH	

Appendix II: Outbreak insect data (response variables) and ornithological explanatory variables, used to main cork oak insect pests modeling; variables and codes are described. Spatial filters selection according to the two exploration-intensity area type (explored and protected areas) was based on eigenvalue ≥3 and Moran's I graphic analysis. Richness of foraging substrate of birds was based on bibliographic references (Herrera 1979; Carrascal *et al.* 1987; Snow and Perrins 1998; Almeida and Granadeiro 2000): GROUND (Zitting Cisticola, Hawfinch, Corn Bunting, Cirl Bunting, Chaffinch, Woodchat Shrike, Woodlark, Nightingale, Crested Tit, Great Tit, Tree Sparrow, Rock Sparrow, Stonechat, Sardinian Warbler and Wren), SHRUB (Melodious Warbler, Nightingale, Iberian Chiffchaff, Sardinian Warbler and Wren), TRUNK (Short-toed Treecreeper, Great Spotted Woodpecker and Nuthatch), BRANCH (Short-toed Treecreeper, Lesser Spotted Woodpecker, Blue Tit, Crested Tit, Great Tit and Nuthatch) and FOLIAG (Hawfinch, Lesser Spotted Woodpecker, Chaffinch, Melodious Warbler, Blue Tit, Crested Tit, Great Tit, Bonelli's Warbler and Iberian Chiffchaff).

Variables	**Code**	**Variables**	**Code**
Response Variables		**Response Variables**	
Abundance of *Coroebus florentinus* at oak branches	COR_FLO	Abundance of Moths at oak canopy	MOT_SPP
Abundance of *Coroebus undatus* at oak trunks	COR_UND	Abundance of Sawfly *Periclista* spp. at oak canopy	PER_SPP
Explanatory Variables		**Explanatory Variables**	
Richness of ground foragers	GROUND	Abundance of Blue Tit *C. caeruleus*	CYACAE
Richness of shrub foragers	SHRUB	Abundance of Corn Bunting *E. calandra*	EMBCAL
Richness of trunk and principal branches foragers	TRUNK	Abundance of Chaffinch *Fringilla coelebs*	FRICOE
Richness of small branches foragers	BRANCH	Abundance of Woodlark *Lullula arborea*	LULARB
Richness of foliage foragers	FOLIAG	Abundance of Nightingale *L. megarhynchos* (Protec. Areas)	LUSMEP
Presence of Zitting Cisticola *C. jundicis*	CISJUN	Abundance of Great Tit *P. major*	PARMAJ
Presence of Hawfinch *Coccothraustes coccothrustes*	COCCOC	Abundance of Bonelli's Warbler *P. bonelli*	PHYBON
Presence of Lesser Spotted Woodpecker *D. minor*	DENMAJ	Abundance of Stonechat *S. torquata*	SAXTOR
Presence of Great Spotted Woodpecker *D. major*	DENMIN	Abundance of Nuthatch *S. europaea*	SITEUR
Presence of Cirl Bunting *E. cirlus*	EMBCIR	Abundance of Sardinian Warbler *S. melanocephala*	SYLMEL
Presence of Melodious Warbler *H. polyglotta*	HIPPOL	Abundance of Wren *T. troglodytes*	TROTRO
Presence of Woodchat Shrike *Lanius senator*	LANSEN	Spatial Filter nr. 1 of Explored Areas	MFILTER1
Presence of Nightingale *L. megarhynchos* (Expl. Areas)	LUSMEE	Spatial Filter nr. 2 of Explored Areas	MFILTER2
Presence of Crested Tit *Lophophanes cristatus*	LOPCRI	Spatial Filter nr. 3 of Explored Areas	MFILTER3
Presence of Tree Sparrow *Passer montanus*	PASMON	Spatial Filter nr. 4 of Explored Areas	MFILTER4
Presence od Rock Sparrow *Petronia petronia*	PETPET	Spatial Filter nr. 1 of Protected Areas	FFILTER1
Presence of Iberian Chiffchaff *P. ibericus*	PHYIBE	Spatial Filter nr. 2 of Protected Areas	FFILTER2
Abundance of Short-toed Treecreeper *C. brachydactyla*	CERBRA	Spatial Filter nr. 3 of Protected Areas	FFILTER3