

# Landscape makers and landscape takers: links between farming systems and landscape patterns along an intensification gradient

Paulo F. Ribeiro · José L. Santos · Joana Santana · Luís Reino · Pedro J. Leitão · Pedro Beja · Francisco Moreira

Received: 22 February 2015 / Accepted: 28 September 2015 / Published online: 13 October 2015  
© Springer Science+Business Media Dordrecht 2015

## Abstract

**Context** Agricultural intensification is a leading cause of landscape homogenization, with negative consequences for biodiversity and ecosystem services. Conserving or promoting heterogeneity requires a detailed understanding of how farm management affects, and is affected by, landscape characteristics. **Objectives** We assessed relationships between farming systems and landscape characteristics, hypothesising that less-intensive systems act as landscape takers, by adapting management to landscape constraints, whereas more intensive systems act as

landscape makers, by changing the landscape to suit farming needs.

**Methods** We mapped dominant farming systems in a region of southern Portugal: traditional cereal-grazed fallow rotations; specialization on annual crops; and specialization on either cattle or sheep. We estimated landscape metrics in 241 1-km<sup>2</sup> buffers representing the farming systems, and analysed variation among and within systems using multivariate statistics and beta diversity metrics.

**Results** Landscape composition varied among systems, with dominance by either annual crops (Crop system) or pastures (Sheep), or a mixture between the two (Traditional and Cattle). There was a marked regional gradient of local landscape heterogeneity, but this contributed little to variation among systems.

---

**Electronic supplementary material** The online version of this article (doi:10.1007/s10980-015-0287-0) contains supplementary material, which is available to authorized users.

---

P. F. Ribeiro (✉) · J. L. Santos  
CEF – Forest Research Centre, Higher Institute of Agronomy, University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal  
e-mail: pfribeiro@isa.ulisboa.pt

J. Santana · L. Reino · P. Beja  
EDP Biodiversity Chair, CIBIO/InBIO – Research Network in Biodiversity and Evolutionary Biology, University of Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal

P. J. Leitão  
Geomatics Lab, Geography Department, Humboldt – Berlin University, Rudower Chaussee 16, 12489 Berlin, Germany

F. Moreira  
REN Biodiversity Chair, CIBIO/InBIO - Research Network in Biodiversity and Evolutionary Biology, University of Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal

F. Moreira  
CEABN/InBIO – Research Network in Biodiversity and Evolutionary Biology, School of Agronomy, University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal

Landscape beta diversity declined from the Sheep to the Crop system, and it was inversely related to agriculture intensity.

**Conclusions** Less intensive farming systems appeared compatible with a range of landscape characteristics (landscape takers), and may thus be particularly suited to agri-environmental management. More intensive systems appeared less flexible in terms of landscape characteristics (landscape makers), likely promoting regional homogenization. Farming systems may provide a useful standpoint to address the design of agri-environment schemes.

**Keywords** Agriculture intensification · Agri-environment schemes · Conservation · Compositional heterogeneity · Configurational heterogeneity · Biodiversity · Ecosystem services · Farming systems · Land use · Mediterranean

## Introduction

Landscape heterogeneity is considered a key factor for biodiversity conservation and ecosystem-service provisioning on farmland (e.g. Benton et al. 2003; Bassa et al. 2012; Schippers et al. 2015). During the past decades, however, farmland landscapes have become ever more homogeneous, which is often associated with the intensification of agriculture, and it is regarded as a major cause for the loss of biodiversity and of number of services such as habitat provisioning, pollination and water quality (e.g. Stoate et al. 2001; Tschardt et al. 2005; Kleijn et al. 2009; Stoate et al. 2009). As a consequence, agri-environment policies and management strategies have been devised to maintain or enhance farmland heterogeneity, involving for instance support to farmers for increasing the amount of natural habitats, the diversity of crop types or land uses (compositional heterogeneity), and the spatial complexity of patch shapes and of their distribution in the landscape (configurational heterogeneity) (Fahrig et al. 2011). In general, however, limited consideration has been given to the influence of farm management strategies on landscape characteristics, and vice versa, though these interactions can impact on farmer's income and thus limit the practical application of agri-environmental management (Fahrig et al. 2011; Bamière et al. 2011).

Farm management strategies are expected to affect both compositional and configurational landscape heterogeneity (Dunning et al. 1992; McGarigal and Marks 1995), as they shape for instance the type and diversity of crops, the size of fields to enable the use of heavy machinery, the amount and spatial distribution of natural habitats, and the prevalence of non-crop elements such as ponds, hedges, and scattered trees, among others (e.g. Deffontaines et al. 1995; Calvo-Iglesias et al. 2009; Carmona et al. 2010). On the other hand, however, farm management options are constrained by a number of biophysical and structural features such as soil quality, the presence of rocky outcrops, and the amount of forest habitats, which are also reflected in landscape pattern (e.g. Persson et al. 2010; Ribeiro et al. 2014). In this context, farm managers may have one of two contrasting approaches, either modifying the landscape to suit their needs (i.e., landscape makers), or adapting farm management to existing landscape constraints (i.e., landscape takers). The first approach is often associated to agriculture intensification, involving for instance levelling of fields, removal of hedgerows and rocks, and drainage of wetlands, to allow for the intensive production of certain crop types (e.g. Tschardt et al. 2005; Concepción et al. 2007; Ruiz and Domon 2009; Ferreira and Beja 2013; Lomba et al. 2014). The second approach is more associated with low-intensity systems, and implies farming strategies that can be implemented without major changes to landscape characteristics (e.g. Bignal and McCracken 1996; Lomba et al. 2015). Although this dichotomy probably represents the extremes of a continuum of farmer attitudes towards the landscape, it may provide a useful framework to understand how farm management shapes, or is shaped by, the landscape, and how this interferes with the development of agri-environment strategies for safeguarding farmland heterogeneity.

In common with other studies examining the relationships between agriculture and biodiversity and ecosystem services (e.g. Oñate et al. 2007; Calvo-Iglesias et al. 2009; Pointereau et al. 2010; Carmona et al. 2010; Bamière et al. 2011), the farming-system approach may provide a convenient starting point to describe the interactions between farm management and landscape characteristics, as it helps simplifying the very large range of activities carried out by farmers. The concept of farming system

stems from agricultural economics, and it is based on a comprehensive analysis of all farm management activities, including land use, animal husbandry, farming practices, resources involved, and the interdependencies between them, within a given political and socio-economic environment (Reboul 1976). Under this concept, farms may be aggregated based on the similarity of resource bases, production patterns and management strategies, which are likely to impact on the landscape in similar ways, and to show similar responses to biophysical conditions, as well as policy and market changes (Dixon et al. 2001; Ferraton and Touzard 2009). Therefore, it may be hypothesised that each farming system should be associated with a particular set of landscape characteristics, which may be more or less variable within each system depending on agriculture intensity level. Specifically, it may be expected that (i) more intensive farming systems should behave as landscape makers, transforming the landscape to meet their requirements, and thus showing low variability in landscape characteristics across areas farmed using the same system (i.e., low landscape beta diversity); and (ii) less intensive systems should behave as landscape takers, adapting to the constraints imposed by landscape features, and thus showing higher variability across areas under the same system (i.e., high landscape beta diversity).

In this paper we address these issues by assessing how farming systems are related to both landscape compositional and configurational heterogeneity, based on a case study developed in an agricultural landscape of southern Portugal. Using a typology of farming systems developed previously (Ribeiro et al. 2014), we mapped the spatial distribution of farming systems (i.e., a map of landscape units composed of blocks of contiguous farms sharing the same farming system) and characterised landscape patterns at the farming-system level (i.e., a spatial scale intermediate between the farm and the landscape levels), seeking to answer the following questions: (1) are landscape patterns different across farming systems?; (2) if yes, are these differences more associated to landscape composition or configuration?; (3) are there significant differences in landscape variability (beta diversity) across areas within each farming system?; and (4) is this landscape variability associated with the intensity of the farming system? Implications of the results for designing agro-environment policies to retain farmland heterogeneity are then discussed.

## Methods

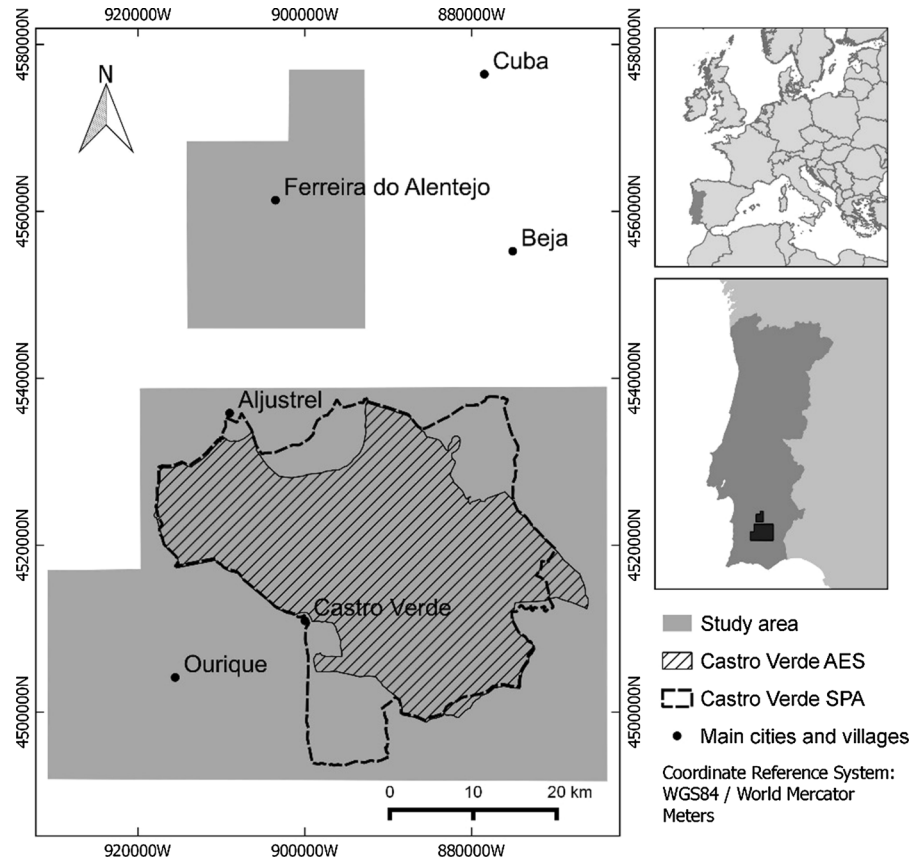
### Study area

The study was carried out on a high nature value farmland area with ca. 210,000 ha in southern Portugal (approx. lat.: 38°N; long.: 8°W) (Fig. 1). The landscape is dominated by lowland agricultural systems, with undulating relief and altitudes ranging between 100–200 m above sea level. Climate is Mediterranean, with hot dry summers and mild rainy winters. The area encompasses the Special Protection Area (SPA) of Castro Verde, designated under EU Directive 79/409/CEE (Birds Directive) to protect populations of globally threatened species such as lesser kestrel (*Falco naumanni*), great bustard (*Otis tarda*) and little bustard (*Tetrax tetrax*) (BirdLife International 2004). The typical landscape is a mosaic of dry cereal crops in rotation with long term fallows, and low density livestock grazing (Delgado and Moreira 2000). Since 1995, part of the area has benefited from an agri-environment scheme under the European Common Agricultural Policy (CAP) aiming to protect traditional farming systems (Santana et al. 2014). This scheme encourages agricultural practices considered favourable to conservation, including support to traditional rotation of cereals and fallows, the maintenance of low livestock densities, the growth of crops benefiting steppe birds, and the creation and maintenance of wildlife watering spots (Santana et al. 2014). In recent years the traditional farming system has been declining, with many farmers converting to specialized livestock systems, or to more intensive crop systems where soil quality and water availability makes it possible (Ribeiro et al. 2014).

### Farming systems and landscape patterns

In a previous study using spatially explicit agricultural data at the farm level, Ribeiro et al. (2014) identified four main farming systems occurring in the region in 2000–2002: (1) the Traditional system, typically comprising farms with a mosaic of dry cereals and fallows in rotation, and pastures grazed by sheep at moderate densities; (2) the Crops system, including farms with dry cereals and other annual (mostly irrigated) crops, and with no pastures, no livestock and little fallow land; (3) the Cattle system, comprising farms dominated by pastures and small areas of dry

**Fig. 1** Location of the study area in southern Portugal, showing the Special Protection Area (SPA) of Castro Verde, the area included in the Agri Environment Scheme (AES) of Castro Verde, and the main urban areas



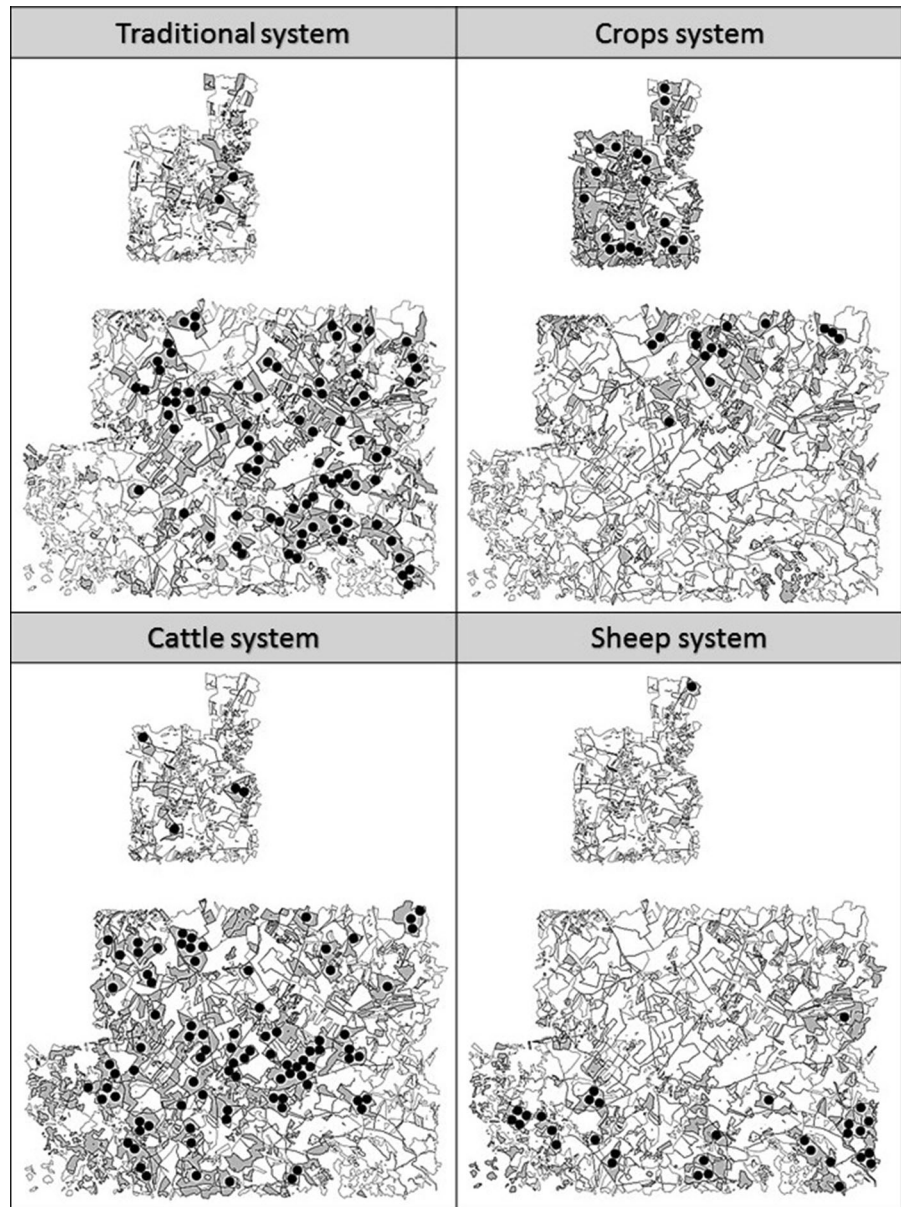
cereal, and with high densities of grazing cattle; and (4) the Sheep system, including farms with a crop composition similar to the Cattle system, but with lower livestock densities and composed strictly by sheep.

The intensity of each farming system was estimated following Brookfield (1972, 1993), from estimations of farm income per hectare, calculated by multiplying the unitary gross margin of the different crops and activities (Rosário 2005) by their relative proportions in each farming system. Although agricultural intensity is often measured from the input side (e.g., fertilizers or pesticides consumption per unit of land; Turner and Doolittle 1978; Lambin et al. 2000; Dietrich et al. 2010), here we measured it from the output side (e.g. tons of cereal or beef per unit of land) because data on input consumptions was unavailable, and because it does not involve any presumptions about the effect of inputs on productivity. Since we were comparing farming systems with distinct productions, we used a monetary surrogate to measure

and compare outputs across farming systems (Turner and Doolittle 1978; Dorsey 1999).

A digital map of farming systems was produced in a geographical information system, by merging all neighbouring farms classified in the same system (Fig. 2). In this way we obtained geographic landscape blocks, each corresponding to groups of farms under a single farming system. A random sample of 1 km<sup>2</sup> circular land plots (ca. 564 m radius) was then extracted from the farming systems map, subject to three criteria: (i) each plot should be completely enclosed within the same farming system; (ii) plots should not overlap; and (iii) a minimum of 30 plots should be extracted per farming system, with no upper limit. A sample of 241 circular land plots was thus obtained, of which 85 were in the Traditional system, 33 in the Crops system, 91 in the Cattle system, and 32 in the Sheep system (Fig. 2). Plots were then overlaid on a land use/land cover map (LUC) of the study area, representing the agricultural landscape in the spring of 2001.

**Fig. 2** Distribution of the randomly selected circular land plots (black dots) used to extract landscape variables within the Traditional, Crops, Cattle and Sheep farming systems in the study area (grey areas) in 2000–2002



Mapping considered 13 LUC categories (Table 1), based primarily on farm parcel level data on agricultural land uses, extracted from a spatially explicit database maintained by the Portuguese Ministry of Agriculture (Ribeiro et al. 2014), and complemented with the following data: (i) shrubland and (ii) “montado” (open cork oak *Quercus suber* and holm oak *Q. rotundifolia* woodlands) cover, obtained from the 1990 digital land cover map (IGP 2012); and (iii) bare soil cover (including ploughed fields), mapped using

Landsat ETM + (Landsat 7) imagery (dated April 1, 2001). The shrubland and “montado” layers were updated using aerial photographs from 2001, thereby correcting for eventual changes that occurred since 1990. The proportion of the different LUC categories summed more than one, because we considered the land uses (e.g., crops) occurring under the tree canopy of “montado” (e.g., Bugalho et al. 2011).

To describe landscape pattern we used 15 variables quantifying the proportions and diversity of dominant

**Table 1** Summary statistics of variables used to characterize landscape composition and configuration in the 241 circular plots of 1 km<sup>2</sup>

Variable	Description	Mean $\pm$ SD (min–max)
Landscape composition		
CEREAL	Proportion of cereal crops	0.27 $\pm$ 0.23 (0–0.99)
FALLOW	Proportion of fallows	0.16 $\pm$ 0.19 (0–0.91)
BSOIL	Proportion of bare soil	0.01 $\pm$ 0.06 (0–0.75)
PASTURE	Proportion of permanent pastures	0.38 $\pm$ 0.31 (0–1.00)
SHRUB	Proportion of shrublands	0.02 $\pm$ 0.06 (0–0.40)
LEGUM	Proportion of leguminous crops	0.01 $\pm$ 0.05 (0–0.37)
FORAGE	Proportion of forage crops and temporary pastures	0.01 $\pm$ 0.04 (0–0.34)
FOREST	Proportion of forest	0.05 $\pm$ 0.14 (0–0.89)
PERMCROP	Proportion of permanent crops (olive groves)	0.01 $\pm$ 0.04 (0–0.42)
OTHACROP	Proportion of other annual crops	0.06 $\pm$ 0.15 (0–0.90)
BUILT-UP	Proportion of built-up areas (roads, buildings)	0.00 $\pm$ 0.01 (0–0.13)
WETLAND	Proportion of wetland areas (rivers, dams, reservoirs)	0.01 $\pm$ 0.03 (0–0.34)
MONTADO	Proportion of “montado”	0.22 $\pm$ 0.32 (0–0.98)
NUSES	Number of different land uses/covers (LUC)	3.9 $\pm$ 1.3 (1–8)
SDI	Shannon diversity index of LUC	0.87 $\pm$ 0.35 (0–1.73)
Landscape configuration		
NPATCH	Number of patches	6.0 $\pm$ 3.4 (1–20)
TEDG	Total edge density (meters/hectare)	63.7 $\pm$ 35.0 (0–185.1)
PSCOV	Patch size coefficient of variance (patch size standard deviation divided by the mean patch size)	111.2 $\pm$ 46.8 (0–285.9)
AWMSI	Area weighted mean shape index (area weighted sum of each patches perimeter divided by the square root of patch area for all patches and adjusted for the plot, divided by the number of patches)	1.44 $\pm$ 0.27 (1–2.49)

LUC types (landscape composition), and four variables describing configurational heterogeneity (landscape configuration) (Table 1). Variables were selected from a wide range of metrics commonly used in landscape ecology studies (McGarigal and Marks 1995), following the recommendation to avoid redundant or highly correlated variables (e.g. Cushman et al. 2008; Schindler et al. 2008; Bassa et al. 2012). Landscape variables were computed for each of the 241 circular land plots (Table 1), using the Patch Analyst extension to ArcGIS 10 (Elkie et al. 1999).

#### Data analysis

Landscape variables expressing proportions (Table 1) were arcsin(sqrt(x)) transformed and the remaining were log<sub>10</sub>(x + 1) transformed to improve normality and stabilize variances (McDonald 2009). Overall

local landscape patterns were explored using a principal components analysis (PCA) performed on a correlation matrix of the 19 transformed variables. Principal components (PC) with an eigenvalue larger than 1 were retained (Kaiser 1960), and a varimax rotation was applied to simplify and improve the interpretability of the solution. A one-way analysis of variance (ANOVA) was used to test for differences among the mean scores on each PC of plots classified in each farming system.

Linear discriminant analysis (LDA) was then performed on PC to assess the extent to which landscape patterns differed across farming systems, and whether the latter could be predicted from the former. A stepwise forward variable selection procedure was conducted using the Wilks' lambda test, starting with an initial model that includes the variable which separates groups the most, and then adding

further variables contingent on the Wilk's lambda criterion (Roever et al. 2014). The procedure was stopped when no additional variable was significant at  $p < 0.05$ . Prediction accuracy was assessed based on a confusion matrix, implemented with leave-one-out cross-validation. Because sample sizes were uneven among farming systems, we used Cohen's kappa to correct for agreements occurring by chance between observed and predicted categories (Titus et al. 1984).

Inertia ellipses were used to help visualizing the distribution of observations within each farming system along the axes in PCA and LDA plots, considering the default probability of ca. 66 % corresponding to a one standard deviation length. To characterise variability in landscape pattern among plots classified in the same farming system, we computed an adimensional beta diversity index (Anderson et al. 2006). Specifically, we computed the average Euclidian distance to group centroids within each farming system using the first two PC coordinates, and then standardized the index by dividing their values by the maximum distance obtained for the four farming systems.

Statistical analyses were implemented in R version 3.1.1 (R Development Core Team 2014) using the "psych" package (Revelle 2014) for the PCA, the "klaR" package (Weihs et al. 2005; Roever et al. 2014) for the Wilks' lambda test and the "MASS" (Venables and Ripley 2002) for the LDA. The "candisc" package (Friendly and Fox 2014) was used to extract the standardized canonical coefficients of the discriminant functions.

## Results

### Overall patterns

There was a spatial trend for the Crops system to be predominant in the northern section of the study area, while the Sheep system was more common in the South. Both the Traditional and the Cattle systems were more evenly spread throughout the study area (Fig. 2). The sampled landscape plots were dominated by pastures, cereal crops, and fallow fields, which together accounted for more than 80 % of the area (Table 1). The average number of different LUC was 3.9 per plot, and the average patch number was six.

"Montados" were common in the region, covering ca. 20 % of the area of the plots (Table 1).

The PCA returned seven PC with eigenvalues larger than one, together accounting for 69 % of the overall variance (Table 2). The first PC (hereafter named "Heterogeneity") represented a gradient of local landscape heterogeneity, showing a joint increase in the number of patches, edge density, patch size variation, shape complexity (AWMSI), land cover richness and diversity. The second PC ("Specialization") represented a gradient from landscapes dominated by annual crops (cereals and other annual crops) to landscapes dominated by permanent pastures, thereby separating landscapes associated with crop production from the ones specialized in livestock production. PC3 ("Permanent crops") was mainly related to increasing proportion of permanent crops (mainly olive orchards), and also of wetlands. PC4 ("Built-up areas") was associated to the presence of built-up areas, PC5 ("Leguminous crops") reflected the proportion of leguminous crops, PC6 ("Forage") represented the proportion of forage crops, and PC7 ("Fallows") was associated to both fallows and bare soil areas, with opposite coefficient signs. Plot coordinates in PC were significantly different across farming systems (ANOVA,  $p < 0.05$ ), except for PC4 ( $p = 0.340$ ) and PC5 ( $p = 0.422$ ) (Fig. S1 in supplementary material).

The highest average local landscape heterogeneity, revealed by the position of the group centroids along the heterogeneity axis (PC1), occurred in the Traditional system, followed by the Cattle and Crop systems, whereas the lowest heterogeneity was found in the Sheep system (Fig. 3a). However, the inertia ellipses suggested that the Sheep system was the most variable spatially, as its landscape plots were found highly scattered along the entire heterogeneity axis (PC1). In contrast, the Crop system presented the lowest dispersion of plots along this axis (Fig. 3a).

### Discrimination of farming systems based on landscape patterns

Variable selection using Wilks' lambda returned five PCs that significantly contributed to the separation of farming systems (Table 3), which were subsequently used in the LDA. Built-up areas (PC4) and Leguminous crops (PC5) were discarded because they failed to improve the group separation power of the model.

**Table 2** Standardized loadings of variables on the principal components (PC) retained (eigenvalues > 1) from a principal components analysis of landscape metrics, and rotated using varimax

Variables	PC1	PC2	PC3	PC6	PC4	PC7	PC5
NPATCH	<b>0.91</b>	0.02	0.07	0.09	−0.01	−0.04	0.01
TEDG	<b>0.91</b>	0.23	0.07	0.02	−0.05	−0.11	0.01
NUSES	<b>0.78</b>	0.08	0.27	0.31	0.15	−0.01	0.06
AWMSI	<b>0.75</b>	0.01	0.01	−0.35	0.00	−0.02	0.05
SDI	<b>0.73</b>	0.31	0.20	0.13	−0.04	−0.25	0.04
PSCOV	<b>0.72</b>	0.04	−0.04	0.13	−0.03	0.12	−0.03
PASTURE	−0.28	<b>−0.79</b>	−0.27	0.01	0.22	0.10	0.19
CEREAL	0.08	<b>0.78</b>	−0.16	−0.01	−0.01	0.07	0.27
OTHACROP	0.06	<b>0.53</b>	0.13	−0.03	0.15	0.00	−0.11
PERMCROP	0.06	0.09	<b>0.77</b>	−0.18	0.22	−0.01	0.11
WETLAND	0.12	0.08	<b>0.72</b>	0.10	−0.02	0.05	0.05
FORAGE	0.26	−0.11	−0.07	<b>0.72</b>	0.05	0.00	0.05
SHRUB	<b>0.53</b>	−0.37	−0.11	<b>−0.55</b>	−0.08	0.11	−0.03
BUIL-UP	0.18	0.10	0.17	0.19	<b>0.75</b>	0.14	−0.05
MONTADO	−0.30	−0.18	0.06	−0.07	<b>0.54</b>	−0.17	−0.25
FOREST	0.08	−0.28	0.39	0.34	−0.46	0.11	−0.39
FALLOW	0.23	0.23	−0.05	−0.06	−0.12	<b>−0.71</b>	−0.34
BSOIL	0.05	0.15	0.03	−0.07	−0.07	<b>0.71</b>	−0.28
LEGUM	0.08	−0.04	0.17	0.05	−0.14	−0.05	<b>0.78</b>
Proportion of variance	0.24	0.11	0.08	0.07	0.07	0.06	0.06

Variables are sorted by loading values (values >0.50 in bold) and PC are sorted by explained variance

Variable acronyms are in Table 1 and the ecological interpretation of PC are in Table 3

**Table 3** Summary of the Wilk's lambda stepwise forward variable selection test performed on the 7 PC

Variables	Wilks' lambda	F statistics overall	<i>p</i> value overall	F statistics	<i>p</i> value
Specialization (PC2)	0.622	47.932	0.000	47.932	0.000
Forage (PC6)	0.564	26.107	0.000	8.183	0.000
Fallows (PC7)	0.523	19.404	0.000	6.117	0.001
Permanent crops (PC3)	0.486	16.180	0.000	5.914	0.001
Heterogeneity (PC1)	0.453	14.253	0.000	5.660	0.001
Built-up areas (PC4)	0.445	12.094	0.000	1.408	0.241
Leguminous crops (PC5)	0.438	10.543	0.000	1.292	0.278

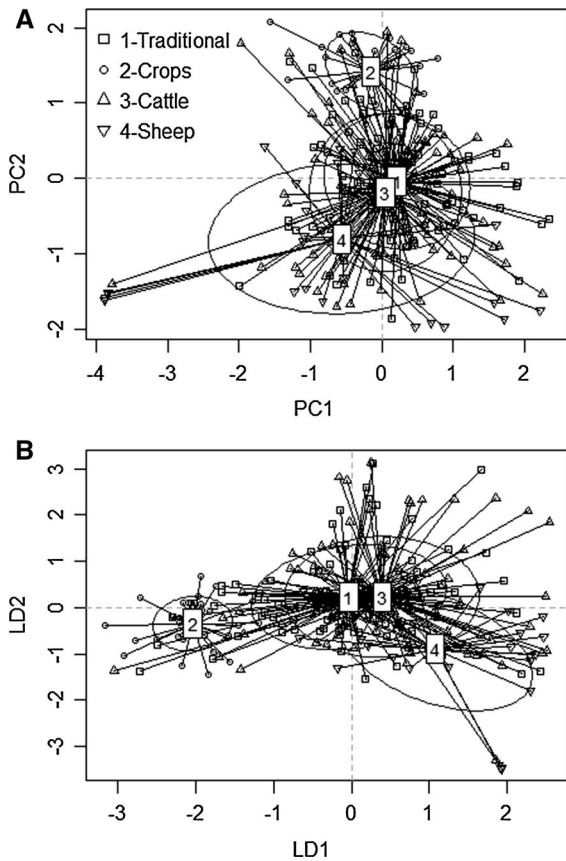
With a 0.05 threshold for the appropriate *p* value of the F-statistic of the partial Wilk's lambda (*p* value), PC4 and PC5 were discarded

The first discriminant function (LD1) captured most of the between-group variance (78 %), mainly separating the Crops from the other systems (Fig. 3b). Specialization (PC2) was the most important variable contributing to LD1 (Table 4), with landscapes associated to the Crops system showing higher proportions of cereals and other annual crops, whereas landscapes associated to the Sheep system had a higher proportions of pastures. The Traditional and Cattle systems were both located close to the origin (Fig. 3b), indicating that they were little differentiated by the

specialization gradient described by PC2. However, there was a tendency for landscapes in the Traditional system to be closer to the Crops system, due to their higher proportion of cereals. Likewise, the Cattle system tended to be closer to the Sheep system due to their higher proportion of pastures.

The between-group variance captured by the second function (LD2; 16 %) was much lower than that of LD1, thereby showing a much lower discrimination ability of farming systems. Nevertheless, LD2 contributed to a weak separation of Traditional and Cattle





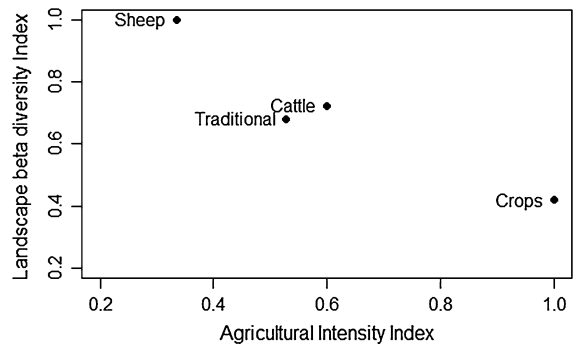
**Fig. 3** Scatterplot of the 241 landscape plots in the first two axis extracted from a principal components analysis with varimax rotation (a) and in the first two axis of a linear discriminant analysis (b). The centroids and inertia ellipses are provided for each farming system

**Table 4** Standardized canonical coefficients of the discriminant functions

Variable (PC)	LD1	LD2	LD3
Specialization (PC2)	<b>-0.97</b>	0.05	0.23
Forage (PC6)	0.14	<b>0.79</b>	0.25
Fallows (PC7)	0.28	-0.04	<b>0.88</b>
Perm. Crops (PC3)	-0.40	-0.04	-0.07
Heterogeneity (PC1)	-0.08	<b>0.66</b>	-0.28

Coefficients larger than 0.5 are indicated in bold

systems from the Sheep system, with the former being associated with higher local landscape heterogeneity (PC1) and higher proportion of forages (PC6) (Fig. S1 in supplementary material). The third discriminant function (LD3) captured a marginal 6 % of the



**Fig. 4** Relationship between the landscape beta diversity index and the index of agricultural intensification, for four farming systems identified in the study area

between group variance, and it was mainly associated with PC7 (Fallows).

The overall percent agreement rate achieved by LDA predictions with leave-one-out cross-validation was 55.7 % (Table S1 in supplementary material), corresponding to an overall Cohen’s kappa of 0.35 after correcting for chance agreements. In pairwise classification tables for individual farming systems, the proportions of correct classifications were much higher for the Crops (92.5 %; Cohen’s kappa = 0.68) and Sheep (87.1 %; Cohen’s kappa = 0.44) systems, than for the Traditional (65.6 %; Cohen’s kappa = 0.25) and Cattle (64.3 %; Cohen’s kappa = 0.24) systems.

### Landscape beta diversity and agricultural intensity

Landscape beta diversity was highest for the Sheep system, intermediate for the Cattle and Traditional systems, and lowest for the Crops system (Fig. 4). There was a significant inverse relationship between beta diversity and agricultural intensity ( $R = -0.96$ ,  $p = 0.030$ ), though care should be taken in the interpretation of statistical testing due to small sample sizes.

### Discussion

Our study pointed out some differences in landscape patterns across farming systems, and that these were far more associated to differences in landscape composition than in configuration. Also, we found differences in landscape beta diversity across farming

systems, and that there was an inverse relationship between beta diversity and agricultural intensity. Overall, therefore, our results agree with the idea that farms associated with the more intensive systems may operate under a narrower range of landscape patterns, thereby shaping the landscape to suit their needs. In contrast, less-intensive systems may be compatible with a wider range of landscape patterns, thereby adapting to existing landscape features. These results have implications for agri-environment policies, as they suggest that maintaining landscape patterns to achieve biodiversity and ecosystem service goals require due consideration of the farming systems operating in those landscapes.

Results of our study are in line with previous research showing that farming systems have an influence on landscape pattern and dynamics (e.g. Deffontaine et al. 1995; Calvo-Iglesias et al. 2009; Carmona et al. 2010). In our case, this relationship was mostly a consequence of differences in land uses and cover between systems, mainly associated with the higher amount of cereals and other annual crops in the Crop system, and with the higher amount of pastures in the Sheep system. The Traditional and the Cattle systems had an intermediate position in this gradient, though with stronger affinities between the Traditional and the Crop systems, and between the Cattle and the Sheep systems. This suggests, therefore, that one of the main mechanisms whereby farmers affect landscape pattern is through a decision to produce either crops or livestock, thus leading to a compositional dominance of either cereals and other crops or pastures, or a mix between the two in the Traditional system.

The relatively weak relation between farming systems and local landscape configuration (sensu Fahrig et al. 2011) observed in our study was unexpected, because there was in the study region a dominant gradient from simple to heterogeneous landscapes (with higher number of patches, more variable patch sizes, more complex shaped patches, and higher edge densities). However, farming systems were little differentiated along this landscape gradient, though there was a tendency for the highest local heterogeneity to be found in the Traditional system, followed by the Cattle and Crop systems, and then by the Sheep system. The highest heterogeneity found for the Traditional system was probably a consequence of the mixture of different

crop types and pastures characterising the system, which may promote a more complex patchwork of land uses. This is also in line with the major importance for biodiversity conservation of this system, because the diversity of land uses and cover is beneficial for a wide range of species with contrasting requirements, and for species requiring a blend of complementary habitats (e.g. Reino et al. 2010; Santana et al. 2014). It should be noted, however, that variability within each farming system was high, and so high to medium levels of local landscape heterogeneity could be found in areas dominated by any of the farming system.

In line with expectations, there was marked variation in landscape beta diversity among farming systems, with a tendency for a gradient from higher to lower beta diversity to be inversely related to agriculture intensification. The Sheep system is a case in point, corresponding to the less intensive system and the one showing the wider range of landscape patterns. Farmers may thus choose to specialise on sheep production largely irrespective of landscape patterns, either because this production system is not strongly constrained by the landscape or, in alternative, because the farmer's income is not sufficiently high to allow investment for changing the landscape to meet their needs. In contrast, the Crop system was the most intensive and was associated with the narrowest range of landscape beta diversity. This was probably because specialised crop production demands landscapes with specific characteristics, due for instance to the need of large fields where pivot irrigation systems and heavy machinery can operate. The Traditional and the Cattle systems were intermediate in the beta diversity and intensification gradients, probably because they can accommodate a relatively wide range of landscape patterns, though they may still be able to change the landscape where this is necessary to suit their needs.

Overall, our results are consistent with the landscape taker versus landscape maker dichotomy, with the Sheep system falling in the former category, the Crop system falling in the latter, and the Cattle and Traditional systems probably having an intermediate position. It should be borne in mind, however, that our study is based on a snapshot of farming systems and landscape patterns, and so it is unknown whether the most intensive systems actually changed the landscape to suit their needs (i.e., acted as true landscape

makers), or whether they were adopted in landscapes that were already suitable at the outset. Probably both mechanisms were influential, as there is evidence that temporal dynamics in farming systems are shaped by biophysical and structural characteristics of the territory such as soil fertility or the presence of forests limiting agricultural development (Ribeiro et al. 2014). There is also some evidence, however, that the most intensive systems actively change the landscape, by for instance increasing field size, removing hedgerows, ponds, scattered trees and non-crop elements, and reducing crop diversity (e.g. Tschardt et al. 2005; Concepción et al. 2007; Ruiz and Domon 2009; Ferreira and Beja 2013; Lomba et al. 2014).

Our results have implications for policies and management strategies aiming to retain landscape heterogeneity on farmland, and thus to the conservation of biodiversity and ecosystem services (e.g. Fahrig et al. 2011). We found that more intensive farming systems were associated with reduced landscape beta diversity, thereby suggesting that agricultural intensification may contribute to landscape homogenization at the regional scale. The negative effects of homogenization have been demonstrated in several studies, both in our area (e.g. Reino et al. 2010; Santana et al. 2014) and elsewhere (e.g. Benton et al. 2003; Bassa et al. 2011, 2012), thereby pointing out the need to avoid regional dominance by a single, intensive farming system. Also, we found that less-intensive systems may occur under a relatively wide range of landscape patterns, suggesting that they may be better able than intensive systems to adapt to landscape constraints. As such, these systems may be more compatible with agri-environment schemes aimed at preserving heterogeneity or to retain important landscape features (e.g., ponds and hedgerows), because these should interfere little with farm management operations. As a consequence of the former two findings, it is likely that in a landscape with a mixture of farming systems with different intensity levels, agri-environment schemes should primarily target at the less intensive ones, with the double objective of promoting landscape features important for biodiversity and ecosystem conservation, and avoiding transitions between less- and more-intensive farming systems (e.g. Ribeiro et al. 2014). The latter may be particularly important, because intensification

often results in landscape changes that are damaging to biodiversity and ecosystem services (e.g. Stoate et al. 2001; Tschardt et al. 2005; Kleijn et al. 2009; Stoate et al. 2009), and these may be irreversible through voluntary policies like the agri-environment schemes due to the high costs required to compensate the investments and eventual loss of income by farmers. Furthermore, intensive systems may have limited flexibility to accommodate landscape patterns compatible with biodiversity conservation (e.g. hardly reversible loss of non-crop elements).

Overall, our results underline the importance of considering farming systems as a tool for designing agri-environment policies and to inform landscape management strategies. The farming system approach may be particularly useful because it explicitly recognises the existence of tracts of farmland that are managed similarly and, for this reason, react to the same market and policy changes, which eventually lead to changes on landscape composition and configuration, both at the local and at the regional level (Deffontaines et al. 1995; Calvo-Iglesias et al. 2009; Carmona et al. 2010; this study). As different farming systems often coexist in the same region, cost-effective design of agri-environment schemes should thus be based on a correct identification of dominant farming systems, on their compatibility with environmental management objectives, and on the priority and type of support that should be given to each one for promoting biodiversity conservation and the delivery of ecosystem services. This might provide an opportunity to tailor agri-environment schemes to socio-ecological specificities, without the high costs that would be needed for developing and implementing farm-level management strategies.

**Acknowledgments** This study was supported by the Portuguese Foundation for Science and Technology (FCT) through projects PTDC/AGR-AAM/102300/2008 (FCOMP-01-0124-FEDER-008701) and PTDC/BIA-BIC/2203/2012 (FCOMP-01-0124-FEDER-028289) under FEDER funds through the Operational Programme for Competitiveness Factors—COMPETE and by National Funds through FCT—Foundation for Science and Technology, and grants to PFR (SFRH/BD/87530/2012), JS (SFRH/BD/63566/2009) and LR (SFRH/BPD/93079/2013). Program CIÊNCIA 2007 provided support to PB and FM. Agricultural statistics were provided by the Instituto de Financiamento da Agricultura e Pescas—IFAP I.P., Portuguese Ministry of Agriculture. We thank the Editor and three anonymous reviewers for their valuable comments and suggestions that helped improve the manuscript.

## References

- Anderson MJ, Ellingsen KE, McArdle BH (2006) Multivariate dispersion as a measure of beta diversity. *Ecol Lett* 9:683–693
- Bamière L, Havlík P, Jacquet F, Lherm M (2011) Farming system modelling for agri-environmental policy design: the case of a spatially non-aggregated allocation of conservation measures. *Ecol Econom* 70:891–899
- Bassa M, Boutin C, Chamorro L, Sans F (2011) Effects of farming management and landscape heterogeneity on plant species composition of Mediterranean field boundaries. *Agric Ecosyst Environ* 141:455–460
- Bassa M, Chamorro L, Sans FX (2012) Vegetation patchiness of field boundaries in the Mediterranean region: the effect of farming management and the surrounding landscape analysed at multiple spatial scales. *Landsc Urban Plan* 106:35–43
- Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? *Trends Ecol Evol* 18:182–188
- Bignal EM, McCracken DI (1996) Low-intensity systems in the conservation of the countryside. *J Appl Ecol* 33:413–424
- BirdLifeInternational (2004) Birds in the European Union: a status assessment. Wageningen, The Netherlands: BirdLife International. [http://www.vwgdepeel.livnastensomeren.nl/downloads/BOCC\\_birds\\_in\\_the\\_eu.pdf](http://www.vwgdepeel.livnastensomeren.nl/downloads/BOCC_birds_in_the_eu.pdf). Accessed January 2015
- Brookfield HC (1972) Intensification and disintensification in Pacific Agriculture: a theoretical approach. *Pac Viewp* 13:30–48
- Brookfield HC (1993) Notes on the theory of land management. *PLEC News Views* 1:28–32
- Bugalho MN, Caldeira MC, Pereira JS, Aronson J, Pausas JG (2011) Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. *Front Ecol Environ* 9:278–286
- Calvo-Iglesias MS, Fra-Paleo U, Diaz-Varela RA (2009) Changes in farming system and population as drivers of land cover and landscape dynamics: the case of enclosed and semi-openfield systems in Northern Galicia (Spain). *Landsc Urban Plan* 90:168–177
- Carmona A, Nahuelhual L (2010) Linking farming systems to landscape change: an empirical and spatially explicit study in southern Chile. *Agric Ecosyst Environ* 139:40–50
- Concepción ED, Díaz M, Baquero RA (2007) Effects of landscape complexity on the ecological effectiveness of agri-environment schemes. *Landscape Ecol* 23:135–148
- Cushman SA, McGarigal K, Neel MC (2008) Parsimony in landscape metrics: strength, universality, and consistency. *Ecol Indic* 8:691–703
- Deffontaines JP, Thenail C, Baudry J (1995) Agricultural systems and landscape patterns: how can we build a relationship? *Landsc Urban Plan* 31:3–10
- Delgado A, Moreira F (2000) Bird assemblages of an Iberian cereal steppe. *Agric Ecosyst Environ* 78:65–76
- Dietrich J, Schmitz C, Müller C (2010) Measuring agricultural land-use intensity. Paper presented at HAWEPA 2010 workshop in Halle, 28–29 June
- Dixon J, Gulliver A, Gibbon D (2001) Farming systems and poverty—Improving Farmers’ livelihoods in a changing World. FAO and The World Bank, Rome and Washington DC
- Dorsey B (1999) Agricultural intensification, diversification, and commercial production among smallholder coffee growers in Central Kenya. *Econ Geogr* 75:178–195
- Dunning JB, Danielson BJ, Pulliam HR (1992) Ecological processes that affect populations in complex landscapes. *Oikos* 65:169–175
- Elkie P, Rempel R, Carr A (1999) Patch analyst user’s manual: a tool for quantifying landscape structure. Ontario Ministry of Natural Resources, Northwest Science and Technology, Thunder Bay
- Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ, Sirami C, Siriwardena GM, Martin JL (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecol Lett* 14:101–112
- Ferraton N, Touzard I (2009) Comprendre l’agriculture familiale: diagnostic des systèmes de production, Quae. Les presse agronomique de Gembloux, Wageningen
- Ferreira M, Beja P (2013) Mediterranean amphibians and the loss of temporary ponds: are there alternative breeding habitats? *Biol Conserv* 165:179–186
- Friendly M, Fox J (2014) Package “candisc”. Visualizing generalized canonical discriminant and canonical correlation analysis. R package version 0.6-5. Available from <http://cran.r-project.org> (Accessed Aug 2014)
- IGP (2012) Carta de Ocupação do Solo—COS’ 90 (1:25,000). Portuguese Geographic Institute. Available from <http://www.igeo.pt/produtos/CEGIG/COS.htm> (Accessed 9 May 2012)
- Kaiser H (1960) The application of electronic computers to factor analysis. *Educ Psychol Meas* 20:10
- Kleijn D, Kohler F, Báldi A, Batáry P, Concepción ED, Clough Y, Díaz M, Gabriel D, Holzschuh A, Knop E, Kovács A, Marshall EJP, Tschamtk T, Verhulst J (2009) On the relationship between farmland biodiversity and land-use intensity in Europe. *Proc Biol Sci* 276:903–909
- Lambin EF, Rounsevell MDA, Geist HJ (2000) Are agricultural land-use models able to predict changes in land-use intensity? *Agric Ecosyst Environ* 82:321–331
- Lomba A, Guerra C, Alonso J, Honrado JP, Jongman R, McCracken D (2014) Mapping and monitoring High Nature Value farmlands: challenges in European landscapes. *J Environ Manage* 143:140–150
- Lomba A, Alves P, Jongman RHG, McCracken DI (2015) Reconciling nature conservation and traditional farming practices : a spatially explicit framework to assess the extent of High Nature Value farmlands in the European countryside. *Ecol Evol* 5:1–14
- McDonald J (2009) Handbook of biological statistics. University of Delaware, Sparky House Publishing, Baltimore
- McGarigal K, Marks BJ (1995) FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. General technical report, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland
- Oñate JJJ, Atance I, Bardají I, Llusia D (2007) Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. *Agric Syst* 94:247–260

- Persson AS, Olsson O, Rundlöf M, Smith HG (2010) Land use intensity and landscape complexity—Analysis of landscape characteristics in an agricultural region in Southern Sweden. *Agric Ecosyst Environ* 136:169–176
- Pointereau P, Doxa A, Coulon F, Jiguet F, Paracchini ML (2010) Analysis of spatial and temporal variations of High Nature Value farmland and links with changes in bird populations: a study on France. JRC Scientific and Technical Reports, Joint Research Centre of the European Commission
- Reboul C (1976) Mode de production et systèmes de culture et d'élevage. *Économie Rural* 112:55–65
- Reino L, Porto M, Morgado R, Moreira F, Fabião A, Santana J, Delgado A, Gordinho L, Cal J, Beja P (2010) Effects of changed grazing regimes and habitat fragmentation on Mediterranean grassland birds. *Agric Ecosyst Environ* 138:27–34
- Revelle W (2014) Package “psych”: Procedures for psychological, psychometric, and personality research. <http://www.personality-project.org/r> (Accessed Aug 2014)
- Ribeiro PF, Santos JL, Bugalho MN, Santana J, Reino L, Beja P, Moreira F (2014) Modelling farming system dynamics in High Nature Value Farmland under policy change. *Agric Ecosyst Environ* 183:138–144
- Roeber C, Raabe N, Luebke K, Ligges U, Szepannek G, Zentgraf M (2014) Package “klaR”: Classification and visualization. R package version 0.6-12. Available from <http://www.statistik.tu-dortmund.de>. Accessed Aug 2014
- Rosário MS (2005) Margens Brutas Padrão—Triénio de 2000. Gabinete de Planeamento e Política Agro-Alimentar, Lisboa
- Ruiz J, Domon G (2009) Analysis of landscape pattern change trajectories within areas of intensive agricultural use: case study in a watershed of southern Québec, Canada. *Landscape Ecol* 24:419–432
- Santana J, Reino L, Stoate C, Borralho R, Carvalho CR, Schindler S, Moreira F, Bugalho MN, Ribeiro PF, Santos JL, Vaz A, Morgado R, Porto M, Beja P (2014) Mixed effects of long-term conservation investment in natura 2000 farmland. *Conserv Lett* 7:467–477
- Schindler S, Poirazidis K, Wrška T (2008) Towards a core set of landscape metrics for biodiversity assessments: a case study from Dadia National Park, Greece. *Ecol Indic* 8:502–514
- Schippers P, Van Der Heide CM, Peter H, Sterk M, Vos CC, Verboom J (2015) Landscape diversity enhances the resilience of populations, ecosystems and local economy in rural areas. *Landscape Ecol* 30:193–202
- Stoate C, Boatman ND, Borralho RJ, Carvalho CR, de Snoo GR, Eden P (2001) Ecological impacts of arable intensification in Europe. *J Environ Manage* 63:337–365
- Stoate C, Báldi A, Beja P, Boatman ND, Herzon I, van Doorn A, de Snoo GR, Rakosy L, Ramwell C (2009) Ecological impacts of early 21st century agricultural change in Europe—a review. *J Environ Manage* 91:22–46
- R Development Core Team (2014) R: A language and environment for statistical computing. In: R Found. Stat. Comput. <http://www.r-project.org> (Accessed Feb 2014)
- Titus K, Mosher JA, Williams BK (1984) Chance-corrected classification for use in discriminant analysis: ecological applications. *Am Midl Nat* 111:1
- Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. *Ecol Lett* 8:857–874
- Turner BL, Doolittle WE (1978) The concept and measure of agricultural intensity. *Prof Geogr* 30:297–301
- Venables W, Ripley B (2002) Modern applied statistics with S, 4th edn. Springer, New York
- Weihl C, Ligges U, Luebke K, Raabe N (2005) klaR Analyzing German Business Cycles. In: Baier D, Decker R, Schmidt-Thieme L (eds) Data analysis and decision support. Springer, Berlin, pp 335–343