Factors affecting the distribution of Red-legged Partridges *Alectoris rufa* in an agricultural landscape of southern Portugal

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Over the last 30 years, major population declines and, in some cases, distributional range contractions have been detected for several bird species associated with farmland in Europe, mainly due to agricultural intensification or abandonment.1–3 Population declines have been particularly severe for many galliform species, of which the Grey Partridge *Perdix perdix* is the best studied.4 The fact that the majority of Galliformes are gamebirds subjected to highly variable levels of shooting pressure and management throughout their ranges, introduces an additional level of complexity when evaluating the environmental factors affecting their demographic trends and space use.5,6

Red-legged Partridges *Alectoris rufa* are highly prized gamebirds of the Western Palearctic, of which over 95% of the global population have been suffering a severe decline, particularly since the 1980s.7,8 Habitat degradation and loss are indicated as the main causes,7,8 together with overshooting and management neglect, particularly in the Iberian Peninsula,10,11 where about three-quarters of the total Red-legged Partridge population is found.

The combined elements of a delicate conservation status and a high socio-economic value lead to a high demand for data on the spatial ecology of the Red-legged Partridge.12 Although some studies on habitat use of this species have been performed in Iberian farmland environments,13,14 there is a severe shortage of information at the landscape level (but see Péiró & Blanc15). Because the lack of information at this spatial scale is particularly serious for bird species suffering population declines associated with habitat degradation, the evaluation of their patterns of habitat use and distribution within farmland landscapes is a priority for ornithological and conservation research.2 In this study, we evaluated the main environmental factors affecting the spring distribution of Red-legged Partridges in an agricultural landscape of southern Portugal, where different arable systems and hunting regimes have been implemented.

The main factors affecting the spring distribution of Red-legged Partridges *Alectoris rufa* were evaluated in a 1550-km² landscape of southern Portugal, where different arable systems and hunting regimes were implemented. Partridge surveys were performed in April 1995 along 90, 250-m transects. Partridge locations and a number of environmental variables were incorporated and manipulated in a vector-based GIS. A multivariate logistic model of partridge detection was fitted using forward stepwise selection, and was validated using a jack-knife approach. The probability of detecting Red-legged Partridges within the landscape was positively affected by game management, structural diversity of cover, proportion of olive tree groves and wheat fields along the transects. Conservation implications of the results and research priorities are discussed.

Factors affecting the distribution of Red-legged Partridges *Alectoris rufa* in an agricultural landscape of southern Portugal

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The combined elements of a delicate conservation status and a high socio-economic value lead to a high demand for data on the spatial ecology of the Red-legged Partridge.12 Although some studies on habitat use of this species have been performed in Iberian farmland environments,13,14 there is a severe shortage of information at the landscape level (but see Péiró & Blanc15). Because the lack of information at this spatial scale is particularly serious for bird species suffering population declines associated with habitat degradation, the evaluation of their patterns of habitat use and distribution within farmland landscapes is a priority for ornithological and conservation research.2 In this study, we evaluated the main environmental factors affecting the spring distribution of Red-legged Partridges in an agricultural landscape of southern Portugal, where different arable systems and hunting regimes have been implemented.
METHODS

Study area

The study was carried out in a 1550-km² agricultural landscape of Baixo Alentejo, including parts or all of five counties (Ferreira do Alentejo, Aljustrel, Castro Verde, Ourique and Almodôvar: 37°20′–38°10′N, 7°55′–8°29′W). Within this area three agricultural systems were recognized: (1) high-input intensive agriculture; (2) low-input extensive agriculture; and (3) montado agro-forestry system (open Holm Oak Quercus rotundifolia and Cork Oak Q. suber woodland, equivalent to the Spanish dehesas).

In the intensive category there is a greater frequency of heavy soils (>55%), with continuous arable cultivation and very few trees, and much of the area is irrigated. Wheat and barley are the main cereal crops, and silage grass, sunflower, sugar beet and oilseed rape are also grown. There are short rotations with little or no fallow. The extensive agriculture category is characterized by thin soils, with few trees and a high proportion of fallows (over 50% of the area) extensively grazed by sheep and cattle. Fallow periods often last five years or more and there is no irrigation. Wheat, oats and triticale are frequently grown. The montado system is similar to extensive agriculture but combined with Holm and Cork Oak trees at up to 20 trees ha⁻¹ (x = 10.5 trees ha⁻¹, se = ± 0.7), and there is also grazing by pigs. There is no irrigation and the fallows also cover over 50% of the area. Typical crops are similar to those of the extensive category, although forage lupins may be included. Almost no hedgerows are found in the landscape, irrespective of agricultural system. Mean farm size was 51 ha in the intensive category, 139 ha in extensive agriculture and 56 ha in montado.

Two mutually exclusive hunting regimes are implemented in the study area, as in most of the country: (1) a public hunting regime with no economic exploitation of game, where all licensed hunters are allowed to hunt, with no limitation of overall hunting bags, and with no implementation of management measures; and (2) an associative or private hunting regime with economic exploitation of game, where game bags are controlled and a variety of management actions are undertaken (predator control, provision of cereal grain and water, implementation of small areas of game crops).

Field methods

In April 1995, partridge surveys were performed on 90, 250-m transects, along randomly selected bearings from 1-km grid intersections, stratified by land use categories. An observer walked along each transect once, in the first three hours after dawn or the two hours before dusk, recording the occurrence of partridges using visual and auditory cues. A total of 25 transects were in areas of intensive agriculture, 33 in extensive agriculture and 32 in montado. Of these, 33 were established on game-managed sites and 57 on unmanaged sites, without prior knowledge of the distribution of hunting regimes. There were no differences in the occurrence of the hunting regimes between land use categories (χ² = 0.25, P > 0.05).

A set of environmental variables was recorded for each transect (variables and data sources are listed in Table 1). Of these, tree density estimates (Holm and Cork Oaks) were based on counts made within a 25-m belt on each side of the transect line. Vegetation structure was sampled over the first 50 m of each transect, by mapping vegetation height on millimetric paper and proportional cover determined for each of seven height classes; a Shannon diversity index of these height classes was computed for each transect as a measure of structural diversity. The proportions of land use classes along the transects were determined as the proportion of transect length crossing each crop type.

Statistical analyses

The environmental information collected was incorporated and manipulated in a vector-based geographic information system (GIS - ArcCAD). In order to evaluate the main factors affecting the distribution of Red-legged Partridges in the study area, a multivariate model of partridge detection was computed using logistic regression.

The variables entering the model were selected by means of forward stepwise selection, using likelihood-ratio tests to determine the variables to be entered (at a probability level of 0.05). In addition, Wald tests were
performed for the selected variables. Both likelihood-ratio and Wald criteria test the null hypothesis that the coefficient of the variable is zero, and can be regarded as a way to evaluate the relative importance of the selected variables on the distribution of the partridges. A correlation matrix of the predictor variables was generated using Spearman’s correlation.

The goodness-of-fit of the model was assessed by comparing the predicted to observed values in a $2 \times 2$ classification table (using a cut-off probability value of 0.5 to predict detection), determining the percentage of correctly classified locations. Furthermore, we calculated the phi coefficient ($\phi$) of the table.\(^{23}\)

As the number of partridge detections was low, we measured the performance of the model using a jack-knife validation procedure.\(^{24,b}\)

## RESULTS

In all, we detected Red-legged Partridges along 12.2% of the transects (i.e. 11 positive detections). The computed logistic model was:

$$P = \frac{1}{[1 + e^{-(5.03 + 2.85GM + 2.32CD + 4.41OL + 1.93WT)}]}$$

where $P$ is the probability of partridge detection along the transects, GM refers to the implementation (value 1) or no implementation (value 0) of game management, CD is structural diversity of cover, OL is the proportion of olive tree groves along the transect, and WT is the proportion of area covered by wheat.

None of the selected variables was significantly correlated ($P > 0.05$). However, CD was positively correlated with the 20–40 cm, 100–400 cm and 400–800 cm vegetation height classes, with the proportion of oats and with diversity of land uses; OL was positively correlated with the proportion of ploughed land; and WT was positively correlated with the proportion of the 60–80 cm height class and negatively correlated with the proportion of fallows, montado and density of field edges ($P < 0.05$).

The percentage of correctly classified cases was 91.1%, with $\phi = 0.50$, corresponding to $\chi^2 = 22.5 (P < 0.001)$. The existence of game management and cover diversity were the variables with the highest levels of significance in the likelihood-ratio and Wald tests (Table 2). Besides these variables, the probability of detecting Red-legged Partridges along the

### Table 1. Independent variables and data sources considered in the logistic regression model of Red-legged Partridge spring detection in Baixo Alentejo, southern Portugal, spring 1995.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game management: managed or unmanaged site</td>
<td>Field work, this study</td>
</tr>
<tr>
<td>Percentage of vegetation cover on the first 50 m of each transect, for the following height classes: 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm, 100–400 cm, 400–800 cm.</td>
<td>Field work, this study</td>
</tr>
<tr>
<td>Structural diversity of vegetation cover: Shannon diversity index of percentage vegetation cover</td>
<td>Field work, this study</td>
</tr>
<tr>
<td>Proportion of each land use class along the transects; the land uses considered were: plough, fallow, wheat, oats, rye, lupin, sunflower, and olive tree groves</td>
<td>Field work, this study</td>
</tr>
<tr>
<td>Tree density (trees/ha)</td>
<td>Field work, this study</td>
</tr>
<tr>
<td>Farming system: montado, extensive agriculture, intensive agriculture</td>
<td>Field work, this study, and ERENA(^{18})</td>
</tr>
<tr>
<td>Distance to the nearest water line (m)</td>
<td>1:25 000 topographic maps, GIS</td>
</tr>
<tr>
<td>Distance to the nearest dirt track (m)</td>
<td>1:25 000 topographic maps, GIS</td>
</tr>
<tr>
<td>Distance to the nearest road (m)</td>
<td>1:25 000 topographic maps, GIS</td>
</tr>
<tr>
<td>Average annual air humidity at 9 TMG (%)</td>
<td>Serviço Meteorológico Nacional(^{19})</td>
</tr>
<tr>
<td>Average annual rainfall (mm)</td>
<td>Serviço Meteorológico Nacional(^{20})</td>
</tr>
<tr>
<td>Average annual temperature (°C)</td>
<td>Serviço Meteorológico Nacional(^{21})</td>
</tr>
<tr>
<td>Total length of field edges within a 500-m buffer around the starting point of the transect (m)</td>
<td>1:30 000 aerial photographs of 1993, GIS</td>
</tr>
<tr>
<td>Diversity of land uses (Shannon index) within a 500-m buffer around the starting point of the transect</td>
<td>1:30 000 aerial photographs of 1993, GIS</td>
</tr>
</tbody>
</table>
transects was also markedly affected by the proportion of olive tree groves (Fig. 1). However, this type of cover was present in only four transects, reducing its overall importance as a factor affecting the distribution of partridges within the landscape.

The validation procedure confirmed that the model performed well in discriminating transects with and without partridge detections, in spite of the low number of encounters. The percentage of correctly classified cases using the jack-knife approach was 87.8%, corresponding to $\phi = 0.36$ and $\chi^2 = 11.7$ ($P < 0.001$).

**DISCUSSION**

Apart from the few areas where olive tree groves were found, the distribution of Red-legged Partridges during the breeding season was affected mainly by the implementation of game management and by the structural diversity of cover. Even though no quantitative data concerning the influence of game management on the spatial ecology of this species have been previously reported at the landscape scale, earlier studies have revealed higher population densities in game-managed sites than in adjacent unmanaged sites. Positive demographic trends of Red-legged Partridge populations after the implementation of management actions have also been reported, corroborating the positive effect detected in this study.

The absence of management incentives and of control over the numbers of birds shot can lead to very low partridge densities in public hunting grounds, which are probably acting as ‘sink’ areas, a feature previously reported for other game species in similar hunting situations. Negative effects of this unmanaged hunting regime were also detected for other game (Quail *Coturnix coturnix*) and non-game (Corn Bunting *Miliaria calandra*) bird species in southern Portugal, suggesting that the hunting regime is an important factor affecting several species in Portuguese farmland habitats. This importance is enhanced by the fact that game exploitation in this area can provide the necessary financial incentive for the preservation of extensive agricultural habitats of high conservation value, which might otherwise be made economically unsustainable under the European Union’s Common Agricultural Policy. Further research is needed, however, to compare the effects of both managed and unmanaged hunting on partridge populations with those of situations where no hunting and no management are implemented. This will

Table 2. Values of likelihood-ratio and Wald tests (1 df) for the variables selected for the logistic regression model, testing the null hypothesis that the coefficient of each variable in the equation is zero.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$-2 \text{ Log LR}$</th>
<th>Wald</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game management</td>
<td>9.17***</td>
<td>7.98***</td>
</tr>
<tr>
<td>Cover diversity</td>
<td>8.63***</td>
<td>6.81**</td>
</tr>
<tr>
<td>Olive tree groves</td>
<td>5.37*</td>
<td>6.12*</td>
</tr>
<tr>
<td>Wheat</td>
<td>4.09*</td>
<td>3.42</td>
</tr>
</tbody>
</table>

The likelihood-ratio (LR) test was used as the criterion to determine the variables excluded from the equation. *$P < 0.05$, **$P < 0.01$, ***$P < 0.005$
soon become particularly important, as the latter are likely to increase in Portugal in the near future owing to legislation changes (unlike today, land owners will be able to prevent the entry of hunters in unmanaged areas). On the other hand, it is necessary to evaluate the effect of particular management practices on partridge populations.

The positive effects of structural cover diversity and of olive tree groves on the probability of partridge detection agree with previously reported information. In fact, high cover diversity has been shown to favour Red-legged Partridge populations in Mediterranean areas, both on homogeneous lowland landscapes and on more diverse hilly areas. On the other hand, although the available data on the use of olive groves by this species are scarce, the extensification or abandonment of olive tree groves is becoming common in Portuguese agricultural landscapes, generating a habitat that provides seemingly suitable cover and food for breeding partridges, at least in the short term.

Red-legged Partridges tend to select fixed features with uncultivated tracts within arable landscapes. However, partridges also use cereal crops for breeding as may be the case in our study area. The inclusion of the proportion of wheat fields in the logistic model, irrespective of agricultural intensification, suggests that this crop type positively affected the probability of detecting Red-legged Partridges in both intensive and extensive agricultural areas, possibly due to the fact that in Baixo Alentejo ‘intensive’ farmland receives low inputs relative to that in northern Europe. Nevertheless, it remains to be seen whether the present levels of agricultural intensification in our study area affect partridge productivity (young raised per unit of area), which is arguably a more robust indicator of habitat quality.

Even though Red-legged Partridges are well adapted to moderately bushy areas, abandonment of arable cultivation tends rapidly to have negative impacts on partridge populations. This phenomenon, together with agricultural intensification, represents an important threat for farmland wildlife in southern Europe. In the short term, the implementation of a package of scientifically substantiated agri-environment measures could stop or slow down this trend of habitat degradation, representing a unique opportunity for the conservation of the avian communities of arable systems in the European Union. In many situations, however, there is a severe shortage of information to support practical management guidelines for the conservation of bird diversity, particularly in the Iberian Peninsula. Therefore, urgent research is needed to evaluate the effect of different management options on farmland birds in different environmental situations. For game species, such as the Red-legged Partridge, the accumulated experience and expertise of game managers may be applied to the adoption of those measures, if they prove to be appropriate to the overall agri-environment objectives. This implies that the evaluation of the impact of game management on non-game species and on biodiversity as a whole in agricultural systems should be prioritized.

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ENDNOTES

a. The phi coefficient may assume values between −1 (when all observations are incorrectly classified) and +1 (when all observations are correctly classified) and is related to the chi-squared statistic by the expression: \[ \phi^2 = \chi^2 / n, \]
where \( n \) is the total number of cases, therefore allowing evaluation of its level of significance.

b. When applying the jack-knife validation procedure, a single observation is removed from the data set, the remaining data are used to estimate the model parameters, and the fitted
The phi coefficient of this table were also computed.

REFERENCES


model is applied to this unused observation to predict the detection of partridges. We repeated this process for each observation in the data set, generating another 2 x 2 classification table of predicted versus observed values (also for a probability cut-off point of 0.5). Finally, the percentage of correctly classified observations and the phi coefficient of this table were also computed.


