HABITAT CORRELATES OF RED-LEGGED PARTRIDGE (*ALECTORIS RUFA*) BREEDING DENSITY ON MEDITERRANEAN FARMLAND

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RÉSUMÉ

La Perdrix rouge (*Alectoris rufa*), l'un des oiseaux-gibier du Paléarctique occidental les plus prisés, est en régression. On manque d'informations sur son utilisation de l'habitat dans les agrosystèmes de la région mediterranéenne. Des corrélations entre variables de l'habitat et densité de couples reproducteurs ont été établies dans une région d'agriculture mixte du sud du Portugal. Les couples de perdrix ont été dénombrés de 1992 à 1994 par la méthode des plans quadrillés. La localisation des territoires, le couvert végétal, les chemins de terre et les réseaux hydrographiques ont été cartographiés et incorporés dans un Système d'Information Géographique vectoriel. Des contours de densité des couples de perdrix ont été établis pour chaque printemps en utilisant le « kernel smoothing » et ont été confrontés à d'autres informations pour obtenir dans chaque contour de densité les proportions de type de couvert végétal, de densité de chemins, de densité de réseaux hydrographiques, de densité de bordures de champs, de diversité du paysage et de densité de couples. Des régressions linéaires simples et multivariées ont été employées pour mettre en rapport la densité des couples avec les variables indépendantes. La densité des chemins, la proportion de rizières et d'oliveraies abandonnées montrent une corrélation positive avec la densité des perdrix, résultat qui est en accord avec la tendance des perdrix à sélectionner des éléments déterminés du paysage avec des parties non cultivées. Contrairement aux plus anciennes, les jachères récentes sont positivement associées à des densités élevées de perdrix. Les pâturages sont négativement associés aux densités de perdrix, probablement à cause de leur végétation basse et des perturbations par le bétail. Des pratiques d'aménagement susceptibles de favoriser de plus hautes densités dans les habitats moins utilisés sont suggérées.

SUMMARY

Red-legged Partridges (*Alectoris rufa*) are highly prized declining gamebirds of the western Palearctic, for which there is a shortage of habitat use information on Mediterranean farmland. Habitat correlates of Red-legged Partridge breeding density were assessed on an area of mixed farmland, in southern Portugal. Partridge pairs were censused during spring 1992-94 by territory mapping. Partridge locations, land use, dirt tracks and water lines were mapped and incorporated into a vector-based Geographic Information System. Contours of partridge density were established for each spring through kernel smoothing and superimposed onto the remaining layers of information, to give the proportions of each land use,

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density of tracks, density of water lines, density of field boundaries, landscape diversity and density of breeding pairs within each contour region. Simple and multivariate linear regression were used to relate partridge density to the independent variables. Density of tracks, proportion of abandoned rice fields and of unharvested olive-tree groves were positively correlated with partridge density, which agrees with the reported tendency of partridges to select fixed features with uncultivated tracts within the arable landscape. Recent fallows were also associated with high partridge densities but old ones were associated with low densities. Grasslands were negatively associated with partridge density, probably owing to low vegetation and disturbance by domestic stock. Management practices that could favour higher breeding densities on less used habitats are suggested.

INTRODUCTION

Habitat use affects individual fitness of birds by influencing reproduction and survival. Accordingly, effective management of bird populations heavily relies on understanding and predicting their habitat needs. The Red-legged Partridge (*Alectoris rufa*) is a highly prized declining gamebird of the western Palearctic (Fontoura, 1992; Aebischer & Potts, 1994), managed for game exploitation throughout its distributional range and leading to a high demand of information on its spatial ecology.

Although several studies concerning habitat use of this species have been carried out, particularly since the 1970s (e.g., Coles, 1975; Potts, 1980; Ricci, 1985; Rands, 1986; Meriggi *et al.*, 1991, 1992; Lucio & Purroy, 1992), only a small number of these was conducted on Mediterranean farmland areas (e.g., Lucio & Purroy, 1987; Nadal *et al.*, 1990; Ricci *et al.*, 1990), covering a limited range of environmental situations. This shortage of information is particularly critical in the Iberian Peninsula, where about three quarters of the European Red-legged Partridges are found (Aebischer & Potts, 1994) and where game exploitation has a very important socio-economic value (Renatur, 1988; Bugalho, 1993).

Birds will tend to select appropriate habitats among the available ones in such a way that the result is maximization of individual fitness (Badyaev *et al.*, 1996; Haila *et al.*, 1996). Average individual fitness in each habitat will tend to decline with increased density and individuals should assess the trade-off between potential reproductive success, survival and density to select habitat; the density in each habitat can thus be used to estimate its relative suitability (Knight & Morris, 1996). Our objective was to evaluate habitat variables that may have influenced Red-legged Partridge breeding density on an area of mixed Mediterranean farmland in southern Portugal.

STUDY AREA

The study site was a 19.84 km^2 agricultural farm of Alto Alentejo, southern Portugal, situated at 38° 30' North and 7° 39' West. The terrain was mostly flat, ranging in altitude from 210 to 255 m above sea level. Climate was Mediterranean, with hot dry summers and mild winters; average annual temperature is 15.6 °C and average annual total rainfall is 642.6 mm (I.N.M.G., 1991). Land uses in spring were: winter cereals (about 25 % of the area), grasslands (20 %), cork oak (*Quercus suber*) and holm oak (*Quercus rotundifolia*) stands (18 %), abandoned rice fields (14 %), fallow land (10 %; in the spring of 1994 approximately 60 % of these were first-year fallows and the remaining were more than two years old; in 1992 and 1993 all fallows were more than two years old), olive-tree (*Olea europaea*) groves (5 %), horticultural crops (0.9 %) and vineyards (0.8 %). The study area had almost no hedgerows, however, it was quite uniformly and densely traversed by dirt tracks, usually bordered on both sides by strips of herbaceous vegetation and low shrubs.

Cereal crops included wheat, oats, barley, and triticale; fertilizers were added twice during the growing season, during sowing and once afterwards; herbicides were applied but no insecticides were used. Grasslands were grazed by cattle and sheep and usually had low herbaceous vegetation, mostly 5-15 cm high. Most oak stands had a medium-height herbaceous layer and only a few shrubs, as they were occasionally grazed. Rice fields were abandoned in 1991; these included some flooded portions and a diverse mixture of herbaceous vegetation with different heights and some shrubs scattered along a grid of small fields. First-year fallows still had stubbles and low-density cereal strips together with arable weeds; older fallows had higher and denser herbaceous vegetation; fallows remained ungrazed at least until mid July. The olive groves were not harvested during the study period and usually had a herbaceous layer similar to the one of oak stands for similar reasons.

The farm was a recently managed game estate. During the study period the partridge numbers markedly increased, probably as a consequence of the implementation of shooting restrictions and predator control; the number of early spring breeding pairs being 58 in 1992, 80 in 1993 and 146 in 1994 (Borralho *et al.*, 1997). However, virtually no measures of habitat improvement were implemented apart from the random supply of cereal grain throughout the area.

MATERIALS AND METHODS

FIELD METHODS

In the spring of 1992, 1993 and 1994, we censused the partridge population by intensive territory mapping (Pépin, 1983). Since towards the end of the breeding season territories begin to break down and accuracy of mapping counts declines (e.g., Franzeb, 1976), we conducted territory mapping counts at the beginning of the breeding season, in March/April of each year. This period corresponded to the peak of pair formation in the study area (Borralho *et al.*, 1997).

The counts were performed after a preliminary reconnaissance and mapping of prominent features of the study area. We divided the area into 1-km^2 plots, that were intensively and similarly surveyed by two observers during the first three hours after dawn and before dusk. Observers plotted the locations of partridge sightings, calling birds, tracks and droppings on 1:15,000 aerial photographs and 1:25,000 topographic maps, recording the number and behaviour of detected individuals and the habitat associated with each location. Daily location maps were generated through this procedure. We also performed focal sampling of specific individuals and pairs to gather additional information on territorial boundaries and interactions with neighbouring birds. The counts were stopped when the cumulative number of detected birds plotted against cumulative searching effort levelled off (Borralho *et al.*, 1996).

We mapped the land use, dirt tracks, and water lines using the aerial photographs, topographic maps, and a Global Positioning System (GPS).

ANALYTICAL METHODS

We incorporated partridge locations, land uses, dirt tracks, and water lines into a vector-based Geograpbic Information System (GIS - ArcCAD). From the daily location maps generated by territory mapping, we compiled composite maps of the partridge locations. These composite maps were interpreted and individual territories were delineated using a range of 4-26 independent recordings.

Based on the co-ordinates of the approximate centre of each territory, extracted using the GIS, we established contours of partridge density for each spring using kernel smoothing (Silverman, 1986) and the RANGES V (Kenward & Hodder, 1996) computer program. Successive contours represented a 10 % increase in partridge density and the minimum area of any single contour region was 0.52 km^2 ($\bar{x}$ = 1.40 km^2, SE = 0.13, n = 41, range = 0.52-3.26). The contour regions were transferred back to the GIS and superimposed onto the limits of the study area and the remaining layers of information (Fig. 1), to give the proportions of each land use class (LU), density of tracks (DT-m/km^2), density of water lines (DL-m/km^2), density of field boundaries (DB-m/km^2) and density of breeding pairs (D-pairs/km^2), within each contour region (Ward & Aebischer, 1994; Aebischer & Ward, 1997). We divided the land uses into cereal crops (Cr), grasslands (Gr), oak stands (Ok), abandoned rice fields (Ri), first year fallow (Fw1), fallow with more than two years (Fw2), olive-tree groves (Ol), horticultural crops (Ht) and vineyards (Vi); a Shannon's diversity index (e.g., Zar, 1984) of land uses was also calculated for each contour region (DV).

We used simple and multiple linear regression techniques to evaluate the relationships between density of breeding pairs and the habitat variables (e.g., Dodge *et al.*, 1990; Robertson *et al.*, 1993; Ward & Aebischer, 1994); statistical analyses were performed using the SPSS (Norusis, 1994) computer program. First, we fitted simple linear regressions for each year considering each independent variable and using D as the response variable. Secondly, we generated a multivariate model of D by pooling data across years and using two dummy variables (YR92 and YR93) to account for density variation between years; variables entering the model were selected through forward stepwise selection, after forcing the two year dummy variables to enter in step number zero; additionally, a correlation matrix of the selected variables was computed for the model. Before analyses, we logarithmically transformed the dependent variable [log (x + l)] to normalize the distribution of residuals and equalize the variances.

To check the validity of the multivariate model, we randomly selected and previously excluded from the analysis 25 % of the contour regions; once computed the model, we assessed if a significant linear relationship was found between observed and predicted densities of the selected contour regions, and if the slope did not differ significantly from one nor the intercept from zero (Robertson *et al.*, 1993).

The contour technique assumed that no partridges were present outside the study site; this was not true, although most of the adjacent unsurveyed land was unmanaged public hunting grounds most likely with very low partrige densities (Borralho *et al.*, 1997), so we forced contours that should remain open to be closed, consequently overestimating the size of low-density contour regions at the margins (Aebischer & Ward, 1997).

By using the territory centres in this period of the year, the analyses concerned mostly the scale of habitat selection related to the relocation of home ranges, i.e., the dispersal scale (*sensu* Morris, 1992). This scale seemed particularly important in this case, as significant reductions in partridge density due probably to pre-breeding dispersal were detected between January and March of each year in the study area, suggesting that the implementation of habitat management actions could increase the breeding density (Borralho *et al.*, 1997).

RESULTS

Thirteen regions of partridge density were defined in 1992 and 1993, and 15 in 1994 (see Fig. 1). Mean partridge density within the contour regions increased significantly from 3.69 pairs/km^2 (± SE = 0.77) in 1992, to 6.94 pairs/km^2 (± 1.39) in 1993, and to 8.22 pairs/km^2 (± 1.44) in 1994 (one-way ANOVA, $F_{2.38} = 3.46$, $P < 0.05$).

Density of tracks and proportion of abandoned rice fields (positively), and proportion of grasslands (negatively), were the only three habitat variables significantly correlated with partridge density during all three springs (Table I). Furthermore, the proportion of olive-tree groves (positively) and of fallows with more than two years (negatively), were significantly correlated with D in two springs, and similar non-significant associations were observed in the remaining one; the correlation with the proportion of first year fallow was significant in 1994, the only year during which this type of land use was found on the study site.

The multivariate model of D, computed from 75 % of the data (31 contour regions), was:

$$D = 0.236 + 0.020DT + 0.680\ Ol + 0.162Fw1 - 0.268YR92 - 0.189YR93;$$

$$(r^2 = 0.79,\ F_{5.25} = 18.67,\ P < 0.001).$$

Apart from the two dummy variables, which were necessarily negatively correlated, only DT and Ol were significantly correlated ($r_{29} = 0.46$, $P < 0.01$); the remaining variables were not significantly correlated.

The linear relationship between observed and predicted values of partridge density within the contour regions selected for validation of the model (10 contour regions) was significant ($r^2 = 0.55$, $F_{1.8} = 9.66$, $P < 0.02$), and the slope of this regression (0.66 ± SE = 0.21) did not differ significantly from one nor the intercept (0.22 ± 0.19) from zero ($t_8 \leqslant 1.62$, $P > 0.05$).

DISCUSSION

The repeated pattern of higher partridge densities in areas of high density of tracks and high proportions of abandoned rice fiels and olive-tree groves, agrees with the reported tendency of Red-legged Partridges to select fixed features with uncultivated tracts within the arable landscape (Rands, 1986; Lucio & Purroy, 1987; Ricci, 1990; Rueda *et al.*, 1993).

In an area with few hedgerows, the dirt tracks seem to play the hedge's usual role of preferred strip-habitat for nesting (e.g., Rands, 1986; Ricci *et al.*, 1990). Most tracks of the study site were bordered by comparatively tall herbaceous vegetation and some shrubs, probably used as breeding cover; this agrees with

Figure 1. — Density contours of breeding pairs of Red-legged Partridge on an area of mixed Mediterranean farmland of southern Portugal, 1992-1994. The location of the approximate centre of each pair territory is shown as a dot, and the field boundaries are presented as broken lines.

TABLE I

Means of habitat variables within contour regions of Red-legged Partridge breeding density, and simple linear regression coefficients of density of partridge pairs vs. the habitat variables, on an area of mixed Mediterranean farmland in southern Portugal, 1992-1994.

Variable	Spring 1992			Spring 1993			Spring 1994		
	$\bar{x}$	SE	r_{11}	$\bar{x}$	SE	r_{11}	$\bar{x}$	SE	r_{13}
Density of field edges	4 062.8	301.3	– 0.09	4 234.2	253.8	0.42	4 360.6	405.2	– 0.33
Density of water lines	5 514.2	249.2	0.18	5 190.4	266.9	0.17	6 259.2	662.8	– 0.41
Density of tracks	3 189.2	330.7	0.79***	3 382.1	334.7	0.76**	2 937.8	357.7	0.85***
Diversity of land uses	0.55	0.03	0.13	0.59	0.03	– 0.53	0.57	0.04	0.19
Cereals	0.28	0.04	– 0.44	0.31	0.03	– 0.40	0.20	0.04	– 0.41
First year fallows							0.14	0.03	0.72**
Fallows > 2 years old	0.05	0.04	– 0.39	0.04	0.01	– 0.62*	0.02	0.03	– 0.70**
Grasslands	0.22	0.03	– 0.66*	0.15	0.05	– 0.76**	0.21	0.07	– 0.66**
Horticultural crops				0.01	0.01	– 0.11	0.01	0.01	0.45
Oak stands	0.22	0.04	0.16	0.20	0.04	– 0.29	0.20	0.05	– 0.08
Olive-tree groves	0.06	0.03	0.60*	0.08	0.03	0.80***	0.04	0.03	0.49
Abandonned rice fields	0.16	0.05	0.56*	0.20	0.05	0.88***	0.16	0.04	0.81***
Vineyards	0.01	0.01	0.47	0.01	0.03	0.12	0.01	0.04	0.06

*P < 0.05, **P < 0.01, ***P < 0.001.

noticeably high partridge densities estimated along dirt tracks during narrow strip transect counts, performed in the same area in spring (Borralho *et al.*, 1996). Therefore, our data corroborate the suggestion that the vegetation bordering dirt tracks constitutes a preferred nesting habitat in Iberian farmland environments (Lucio & Purroy, 1987, 1992; Rueda *et al.*, 1993).

On the other hand, very little, if any, information is available about the use of abandoned rice fiels and unharvested olive-tree groves by Red-legged Partridges. Besides occasional grazing by domestic stock, both habitats were virtually abandoned from an agricultural point of view. This implied that no chemicals were used and that they suffered little disturbance, which probably contributed to the detected positive correlations with partridge density. Moreover, the high humidity of abandoned rice fields allowed for a well developed layer of green herbaceous vegetation and shrubs, providing food, moisture and breeding cover. The olive-tree groves provided not only an important supply of olives, which are an energetic food readily consumed by partridges (Coles, 1975; Tavares *et al.*, 1996), available at least from October to April, but also a fairly high herbaceous cover for nesting.

Contour regions with high proportions of first-year fallow also had high partridge densities, but older fallows seem to have been avoided. Recent fallows had cereal stubbles wich are preferred feeding areas for seed-eating birds (Wilson *et al.*, 1996), and provided a seemingly adequate breeding cover of cereal strips and arable weeds, which agrees with the detected trend. Older fallows, however, had a much denser and taller vegetation, probably with less feeding value, at least for adults, and making difficult the partridges' movements within them. Evidence from this study seems to indicate that rotational set-aside (equivalent to l-year fallow) is preferable for Red-legged Partridge breeding, as it seems to happen for the Grey Partridge (*Perdix perdix*) (Watson & Rae, 1997). Nevertheless, there are several management actions that can improve the value of older fallows for wildlife, within the relevant directives of the European agricultural policy (e.g., Havet, 1996). In particular, the establishment of game crops in some of these areas is likely to be beneficial for partridges (Ponce-Boutin, 1996); it is also possible that summer grazing of the older fallows at low stocking densities can improve their value for partridges by reducing vegetation density and height, and by favouring the invertebrate fauna (Wilson *et al.*, 1996).

Grasslands, however, had low partridge density throughout the study period. The low vegetation, trampling and general disturbance caused by domestic stock may have accounted for this. If possible, it would be desirable to arrange for the domestic stock to be kept away from partridge grounds from the end of March to the beginning of July (Coles, 1975). Nevertheless, pastures were also avoided during summer, when the vegetation was sparse and dry (Borralho *et al.*, 1998). Besides controlling the presence and density of domestic stock, it would be beneficial to establish patches of taller vegetation within the grasslands as escape and nesting cover (Castro Pereira *et al.*, 1996), preferably protected with barbed wire to reduce damage by livestock.

High landscape diversity has been shown to favour higher Red-legged Partridge densities on Mediterranean areas, both on homogeneous lowland landscapes (Lucio & Purroy, 1987) and on more diverse hilly areas (Meriggi *et al.*, 1992), but neither land use diversity nor the density of field boundaries seem to have affected the breeding densities in our study site. The preference for heterogeneity is a common feature of a large number of bird species, as different habitats may be optimal relative to different requirements (Dunning *et al.*, 1992;

Haila *et al.*, 1996), and this is frequently correlated with the use of ecotones as preferred nesting sites (Lucio & Purroy, 1992; Sparks *et al.*, 1996). The absence of any significant correlation between these variables and partridge density in our study area, could have been related to the low variability of landscape diversity between contour regions; in fact, the coefficients of variation of DV were comparatively low, ranging only from 5 to 7 % (see Table I). The lack of hedgerows at field edges could also have contributed to this pattern.

The contour regions approach avoids the use of the common option of superimposing a grid of squares on the study area to relate habitat characteristics within the cells with their partridge densities (or other target-organisms) (e.g., Lucio, 1991; Meriggi *et al.*, 1992). Unlike the contours, the grid squares are arbitrarily placed with respect to the partridges' distribution, so will split up concentrations of birds and smooth out the true variations in density that exist; therefore, contours are inherently more accurate in highlighting areas of different densities (Ward & Aebischer, 1994). Nevertheless, even though the validation of the computed multivariate model indicated that it had good predictive value, it must be taken into account that no replicate areas were surveyed and that density is not necessarily a good indicator of habitat quality (Van Horne, 1983; Wolff, 1995). For instance, although the vegetation bordering the dirt tracks seems to be selected for breeding, it is possible that the reproductive success of pairs nesting there is negatively affected by the higher predation rate that frequently occurs in strip-habitats (e.g. Ricci *et al.*, 1990; Dunning *et al.*, 1992), reducing its value for the partridge population. Future research should favour the use of response variables that potentially constitute more robust indicators of relative habitat quality and population fitness (*sensu* Van Horne, 1983), such as number of young raised per unit of area, which depends on breeding density, fertility and survival of adults and young (Carvalho *et al.*, 1996).

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