Influence of game crops on the distribution and productivity of red-legged partridges *Alectoris rufa* in Mediterranean woodlands

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Abstract

Red-legged partridges *Alectoris rufa* are one of the most important game species in extensively managed Mediterranean agro-forest systems. Population declines have led to management to increase their populations. This includes the creation of game crops, but their efficacy for red-legged partridges has not been tested. We developed in October 1996 an experimental introduction of 32 100x8 m plots in a 6.46 km^2 mixed agro-forest system area in Portugal. These plots were planted with either lupin *Lupinus* sp., vetch *Vicea* sp. or triticale *Triticum aestivum x Secale cereale*. The main goal of this study was the evaluation of the potential effect of game crops on partridge distribution and productivity, after controlling for the effect of habitat or other management actions. Partridge abundance and distribution were assessed during spring and summer 1997 by intensive territory mapping. We compared characteristics of territory centres with those of random points in relation to land uses, game crops, and location of water points or supplementary grain sites. The most important variable explaining partridge's location in spring was the density of supplementary water points. In summer, partridge territories were positively associated with the density of water points and lupin game crops, as well as olive trees. Productivity (number of young per territory in relation to adults observed) increased with the density of lupin game crops, but decreased with density of water points and vetch game crops and proportion of woodland within the territories. Overall, this study suggests that management for partridges in areas of agricultural abandonment, such as those in Mediterranean woodlands, would benefit from the introduction of leguminous game crops and water provision, though more studies are required for a more adequate optimization of these measures of habitat improvement, in particular about the specific cover of the crops and their spatial distribution so they provide adequate resources in summer for nestlings.

Keywords: Red-legged partridge; Game crops; habitat management; Mediterranean woodland management.

Introduction

Hunting is an important socioeconomic activity in many areas around the world, and in particular in southern Europe. In these areas, small game is commonly hunted in many areas associated to farmland or agro-forestry systems. As many other species associated to these habitats, farmland small game such as partridges have suffered severe declines in recent decades (e.g. Blanco-Aguiar 2007), through a combination of factors such as agriculture intensification, climate change and overexploitation. As a consequence of these declines, and in order to maintain hunting activities, many management techniques focused on increasing or maintaining post-breeding game populations have been implemented in many areas, particularly where economic interests are strong (Arroyo et al. 2012).

The most common management practices applied in Europe to increase small game populations are predator control, population supplementation through the release of captive-reared animals, and habitat management (providing supplementary food or water, or increasing the quantity or quality of habitats used by game species; Arroyo & Beja 2002, Beja et al. 2009, Rios-Saldaña 2010, Mustin et al. 2011). In relation to the latter, game crops (crops established primarily for the benefit of gamebirds) are widely used in certain areas managed for gamebird hunting (Arroyo & Beja 2002). Game crops are usually small blocks sown with mixtures of seeds attractive to game, that provide additional food at critical times of the year, nesting cover, protection from predators or green vegetation as a source of water in areas with dry summers (CTGREF 1975, Peeters & Decamps 1998, Reino et al. 2000, Stoate et al. 2003).

Several studies in France or the UK have concluded that winter game crops benefit gamebirds (e.g. Mollot & Granval 1996, Sage et al. 2005). However, other studies have shown contradictory results (e.g. Bro et al. 2004). Additionally, not much information exists about the impact of game crops on game populations in southern Europe, where the general level of intensification of agriculture is relatively low but where land abandonment in less-productive areas is also an issue. In these areas, summer is the most critical period for most species, due to the summer draught typical of Mediterranean type climates, so game crops should aim to provide resources (food, water, cover) for this time of the year, rather than in winter.

Portuguese *montados* (equivalent to the Spanish *dehesas*) are cork oak *Quercus suber* and holm oak *Q. rotundifolia* extensive agro-forestry systems of savannah-like physiognomy, particularly diverse in both human use and wildlife, being of high economic and conservation relevance in large tracts of the Mediterranean part of Iberia (Meeus 1993, Díaz et al. 1997, Sa-Sousa 2014). Typically, these open woodlands are multipurpose extensively managed areas, generating a high diversity of products (such as cork, firewood, game, domestic stock, cereals), and are frequently pointed out as an example of a sustainable way of land exploitation, with less conservation conflicts than other alternative land use options (Pinto-Correia 1993, Joffre et al. 1999).

Game hunting and its management are important activities on these systems, with the red-legged partridge *Alectoris rufa* being one of the most important game species exploited there (Borralho et al. 2000). Although red-legged partridges may be common on *montado* (Carvalho & Borralho, 1998), they tend to avoid large tracts of forested areas (Lucio & Purroy 1992, Meriggi et al. 1992). In sites experiencing a process of agriculture abandonment, such as in many cork oak *montados* (Pinto-Correia & Mascarenhas 1999), the planting of game crops conceivably may contribute to stopping or reversing population declines associated with the degradation of mixed farmland, potentially increasing partridge density and reproductive success, and reducing dispersion (Pépin & Blayac 1990, Lucio & Purroy 1992). Nevertheless, there is a lack of information to substantiate this supposition.

This study assessed whether distribution or productivity of red-legged partridges were affected by a set of experimental plots of game crops, of small size and low cost, in an area of mixed Mediterranean woodland with a high proportion of cork oak *montado*. We discuss results in relation to management for this game species.

Material and methods

Study area

The study was undertaken in a 6.46-km^2 hunting estate of mixed Mediterranean woodland, located in Alenquer municipality, central Portugal (at 39º07'N, 8º56'W). The climate in this area is thermo-mediterranean, with hot dry summers and mild winters and an average annual precipitation of 600 mm (Rivas-Martínez et al. 1990). Altitude ranged from 20 to 170 m asl. About 8% of the area was an agricultural lowland plain (Figure 1), mostly cultivated with irrigated crops. The remaining area was covered by cork oak *montado*, with and without shrubby understorey (ca. 20% and 38% of the area, respectively); these areas had a relatively high density of trees, so their physiognomy was that of open woodland rather than grassland with a few trees; forest stands of maritime pine *Pinus pinaster*, umbrella pine *P. pinea* and eucalyptus trees *Eucalyptus globulus* (17%); a mixed cork oak and maritime pine woodland with a patchy undergrowth vegetation of different heights (15%); and a small grove of olive trees. During the study period, the partridges were not hunted to allow the build-up of numbers. Red foxes *Vulpes vulpes*, Egyptian mongooses *Herpestes ichneumon*, and feral cats and dogs were controlled, cereal grain was made available at several feeding sites all year round, and water points were implemented.

Partridge distribution and game crops

In October 1996, 32 100×8-m single species plots were established in the study area. Plots were sown in autumn because autumn sowing is the common farming practice for all crops in this area, except for irrigated crops. These plots were sown with different covers aiming to provide cover and food in spring and, particularly summer: a leguminous crop (either lupin *Lupinus* sp. or vetch *Vicea* sp.) or a cereal crop (triticale *Triticum aestivum* x *Secale cereale*). 11 plots of each crop type were planted except for cereal, of which only 10 existed. The plots were distributed according to the following method: 30 random points were plotted on the wooded areas of the study site, and the nearest location to each point of easy access to tillage equipment (clearings, firebreaks and high points with sparser vegetation) was chosen to establish a game crop plot. The choice of random location responded to the fact that there were no *a priori* regards to what would be implemented in non-experimental conditions, as game crops were not implemented in the area prior to our study, and game managers are not landowners in most areas (Arroyo et al. 2012).

We assessed partridge abundance and distribution throughout the study area in spring and summer 1997. That year was similar in temperature and rainfall to others of the same decade, i.e. was not particularly hot or dry (e.g. see data for nearby Lisbon in PORDATA 2016). Partridge abundance and distribution was assessed by intensive territory mapping (Pépin 1983, Borralho et al. 1996). The study area was divided into 1-km^2 plots, which were intensively and similarly surveyed during the first three hours after dawn and preceding dusk, both by observers using a four-wheel-drive vehicle throughout the extensive track network of the study area, and by walking observers accompanied by pointing dogs in systematic transects in each plot. The locations of partridge sightings, calling birds, tracks and droppings were plotted on 1:5,000 and 1:25,000 topographic maps. Daily location maps were generated through this procedure and from these we compiled composite maps of partridge locations, which were interpreted to delineate territories. Partridge signs one day did not influence searches in day D+1. Counts were stopped when the cumulative number of detected birds plotted against cumulative searching effort levelled off (Borralho et al. 1996). From the composite location maps generated during the partridge counts, we determined the approximate centre of each territory using a Geographic Information System (GIS-ArcCAD). We believe our method is adequate to separate the range of different pairs/coveys. Average home range size of red-legged partridges before hatching is ca. 8 ha per pair (Sumozas 2008), and partridge density at that time was ca. 14 pairs per km2 (see results). In summer, we also evaluated for each territory the number of young and adults observed.

The following layers of information were incorporated and manipulated in the GIS: the locations of game crops, land uses, locations of supplementary water points and the locations of feeding sites where cereal grain was regularly provided. For each territory centre and for 134 random points distributed throughout the study area, we assessed the following variables in a radius of 250 m around each point: percentage of different land uses (arable land, olive trees, montado, woodland); density of field edges (m/ha); density of game crop plots of each type (number/ha); density of supplementary feeders (number/ha) and density of supplementary water points (density/ha).

To assess the influence of game crops on partridge distribution, we compared the characteristics of random points with those of territory centres, both in spring and summer. By using the territory centres, the analyses concerned mostly the scale of habitat selection related to the location of home ranges, i.e., the dispersal scale (*sensu* Morris 1992). For this, we used Generalized Linear Models, using "type of point" as a response variable (with Territory=1, and Random point = 0, binomial error distribution, logit link function). As explanatory variables, we included all the variables mentioned above (land uses and those related to game management). We checked for potential collinearity and redundancy of the explanatory variables by analysing the Variable Inflation Factor (VIF). Land use variables are explained as a combination of the other ones (as they are expressed as percentages), and thus had very high VIF values (> 20). The one with highest VIF value was "*montado*". When excluding this variable, all explanatory variables had VIF values <2, well below the threshold suggested for eliminating them (Zuur et al. 2010); therefore, all variables except "*montado*" were included in the analysis.

Models were implemented with function glm in R (R Development Core Team, 2014). Using a multimodel inference approach, model-averaged parameter estimates were derived on the basis of corrected Akaike's information criteria (AICc) for the subset of models constructed from combinations of these variables that had a ΔAICc < 2. This approach takes into account that when data is inadequate to reach strong inferences from a single best model, and several models may be equally useful to describe variation in data, more robust inferences on effect size and its precision may be made from combining all alternative models in the set (Burnham & Anderson 2002). Information-theoretic approaches are preferable over hypothesis testing approaches particularly in observational studies, where randomization or replication is not achievable (Burnham & Anderson 2002). In this approach, P values and statistical significance are not relevant to address the strength of evidence for the models. Estimates of the relative importance of predictor variables can instead be made by summing the Akaike weights across all the models in the set where this variable occurs (Burnham & Anderson 2002). We thus also calculated the relative importance of each variable as the sum of Akaike weights across all the models in the set where that variable occurred. We only discuss the effects of variables for which the standard errors were smaller than the average coefficient, because otherwise effect size was considered too imprecise. Multimodel inference was implemented in R software by the functions 'dredge' and 'model.avg' from the 'MuMIm' library.

Secondly, we evaluated (for summer censuses only) variations in partridge productivity (number of young/number of adults observed) across territories. For this, the response variable was log-transformed (Gaussian error distribution). We included the same explanatory variables and model selection procedure as above.

Results

Our survey rendered 94 red-legged partridge territories in spring, occupied by partridge pairs. In summer, our survey rendered 93 territories, occupied by 1 (n = 53) to 5 (n = 3) adults, and 0 (n = 55) to 13 (n = 1) juveniles. Average productivity (mean ± SD) was 1.26 ± 1.87 young/adult (n = 93). When juveniles were observed (n = 38), covey size was 3.8 ± 2.7 (median = 4).

A number of equivalent models with relatively low explanatory power explained the location of partridge territories in spring (Table 1). According to model-averaged parameter estimates, the most important variable explaining location of partridge territories at that time was the density of supplementary water points (appearing in all of the best models), which increased the likelihood of a point including a partridge territory (Fig. 2). The proportion of arable land appeared in 3 of the 8 best models, but the estimate of the effect size of this variable included 0 (Table 2). The density of cereal game crops appeared in 1 of the 8 best models, but this variable had the lowest relative importance, and its effect was not adequately estimated (Table 2).

In summer, location of partridge territories was positively associated with the density of supplementary water points, the density of lupin game crops and the proportion of olive tree fields (appearing in all of the best models, Tables 1 and 2, Fig. 3).

Additionally, partridges at this time appeared to select areas with more field edges, arable land and cereal game crops, and avoid areas with more supplementary feeders and more woodland (Table 2, Fig. 3).

Productivity (number of young per territory in relation to adults observed) decreased with density of water points but increased with density of lupin game crops. Additionally, productivity declined with density of vetch game crops and proportion of woodland within the territories, although the relative importance of these variables was lower (Table 2, Fig. 4).

Discussion

According to our results, game crops sown with lupin appear to have some positive influence on the location of partridges in summer, particularly of larger coveys, in our study area. In contrast, the influence of game covers sown with cereal was less important, and vetch game crops were apparently avoided. This suggests that game crops sown with lupin provide cover or food resources necessary for partridge chicks (Buenestado et al. 2008, Sumozas 2008), Average productivity observed in the study area (1.26 young per adult) was in the lower range compared with that observed in hunting estates in central Spain (Díaz-Fernández et al. 2013). This may indicate, among other things, that food supply during chick the rearing period is low (as also supported by the relatively small covey sizes observed), or that predation is high (as also supported by the large proportion of adults without juveniles). The fact that productivity was positively associated with lupin game crops, but negatively with vetch game crops, suggests that cover may be more important than food resources in these crops (lupin is higher and denser than vetch, but both are rich in nutrients being leguminous), and that the resource sought when using game crops is protection from predators. However, these assumptions should need to be tested in future studies.

The fact that location of partridge territories in spring was apparently not associated with game crops suggests that they are not selected for nest cover, possibly because they were too small and partially fenced, or because habitats providing nest cover were not limiting for the study population. To our knowledge, this is the first study evaluating the effect of game crops on farmland game in the Iberian Peninsula, so it is not possible to compare our results with others. Additionally, our study was made in only one year, and results may be biased if environmental conditions were not usual for the area. However, 1997 was quite similar regarding weather conditions to other years of the same decade (PORDATA 2016), and we thus believe that our data can be representative of game crop use by partridges in general conditions. Our results overall emphasize that environmental conditions are more limiting in summer than spring in Mediterranean climates, and indicate that management aiming to improve environmental conditions during the summer period are likely to be beneficial for red-legged partridges. Nevertheless, it would be important to further study effectiveness of game crops in extreme weather conditions (e.g. in dry years), and develop studies to optimize these measures of habitat improvement, in particular about the specific cover of the crops so they provide adequate resources (either cover, food, or both) in summer for nestlings.

Other management variables were also important, in particular the provision of supplementary water points. Location of partridge territories was strongly associated to areas with high density of supplementary water points both in spring and summer. The importance of water on partridge distribution in Southern Portugal has already been described (Borralho et al. 1998). Together, these results highlight the importance of water areas with dry climates such as southern Iberian Peninsula, and indicate that water availability may be a limiting factor there. Thus, they support that supplementation of water is a useful management tool for this species in these areas. However, it has been suggested that artificial water points may act as areas for transmission of diseases and infections (Villanua et al. 2006), so it would be important to further assess this in future studies, if using this management tool.

Surprisingly, and at odds with the above-mentioned results, young/adult ratio was negatively related to the density of supplementary water points. This may reflect density-dependence effects (if more partridges locate their territories close to water points, local density may be higher and this may have negative effects through competition for food, Bro et al. 2003), or else also indicate, as suggested above, higher disease transmission to nestlings around water points. More research should look at these aspects in the future.

In contrast to what was found for supplementary water points, we found a negative effect of availability of supplementary food devices on location of partridge territories in summer, and no effect on productivity. In other areas of the Iberian Peninsula (central Spain), supplementary food has been associated to higher productivity and density of red-legged partridges (Díaz-Fernández et al. 2013). However, in central Spain, supplementary food and water were usually placed together, so it was difficult to separate the influence of both management tools (Díaz-Fernández et al. 2013). This could however indicate that food is more limiting in central Spain than in *montado* areas in Portugal at the time of the study, or else that other factors are more influential than grain provision. One way or other, given that grain is one of the highest expenses in game management in farmland areas in the Iberian Peninsula (Díaz-Fernández 2012), this raises questions about the cost-efficiency of using supplementary grain for partridges in other areas with similar land cover, as in central and southern Portugal. Further studies should try to quantify this in order to optimize management.

Various land use variables influenced partridge distribution (at least in summer) and productivity, with a general positive effect of arable land and olive trees, and negative effect of woodland agreeing with previous results (Lucio & Purroy 1992, Borralho et al. 1999). Among landscape features, field edge density was positively related to location of partridges in summer. The importance of field edges for this species has been mentioned in many studies (Lucio & Purroy 1992, Peiró et al. 1993, Vargas et al. 2006), influencing nesting selection and success (Casas & Viñuela 2010, Villanúa et al. 2011) and survival (Buenestado et al. 2009). In this study, we found no influence between this variable and productivity, but this may be related to the small variation in field edge density found among the different study territories. Additionally, results could be influenced by the spatial distribution of different habitats and partridge territories, so future studies should evaluate this.

Overall, our results indicate that management for partridges in areas of agricultural abandonment, such as those in Mediterranean woodlands, would benefit by including the use of game crops and the provision of water, although it would be useful to think about the spatial design of devices to minimize negative effects of the latter, and about the specific cover of the crops so they provide the most needed resources in summer (either cover protection, food or both).

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Table 1. Variables included in the best models (delta AICc<2) explaining location of partridge territories (comparison between territories and random points) or partridge productivity (young/adult ratio). Edges: density of field edges; GC1: density of game crops sown with lupin within territory; GC2: density of game crops sown with vetch within territory; GC2: density of game crops sown with cereal within territory; Water: density of water points; Feeder: density of feeders; Arable: % of arable land; Wood: % of forested area; Olive: % of olive trees.

Model	Edges	GC1	GC2	GC3	Water	Feeder	Arable	Wood	Olive	Df	delta	weight
Spring location												
1					X					2	0.00	0.211
2					X		X			3	0.25	0.187
3	X				X					3	0.65	0.152
4					X	X	X			4	1.46	0.102
5					X	X				3	1.49	0.100
6	X				X		X			4	1.79	0.086
7					X					3	1.87	0.083
8				X	X				X	3	1.97	0.079
Summer location												
1	X	X			X	X			X	6	0.00	0.133
2	X	X			X	X		X	X	7	0.29	0.115
3	X	X			X	X			X	7	0.67	0.095
4		X			X	X			X	6	0.75	0.092
5	X	X			X				X	5	0.80	0.089
6	X	X	X		X	X			X	7	0.94	0.083
7		X			X				X	5	1.13	0.076
8	X	X			X				X	6	1.14	0.075
9	X	X	X		X	X		X	X	8	1.31	0.069
10		X			X	X			X	5	1.54	0.062
11	X	X	X		X	X			X	8	1.54	0.062
12		X	X		X	X			X	7	1.99	0.049
Productivity												
1		X			X					3	0.00	0.364
2		X			X			X		4	1.37	0.184
3		X	X		X					4	1.73	0.153
4		X	X		X			X		4	1.76	0.151
5		X			X				X	4	1.81	0.147

Table 2. Model-averaged coefficients for variables included in models with delta AICc<2. Also indicated is the Relative Variable Importance (RVI) of those variables. Highlighted in bold those where parameter estimates do not encompass 0 taking into account SE. Edges: density of field edges (m/ha); GC1: density of game crops sown with lupin within territory; GC2: density of game crops sown with vetch within territory; GC2: density of game crops sown with cereal within territory; Water: density of water points; Feeders: density of feeders; Arable: % of arable land; Woods: % of forested area; Olive: % of olive trees. In bold, variables with RVI>0.3

	Spring			Summer			Productivity		
	β	SE	RVI	β	SE	RVI	β	SE	RVI
Water	**5.44**	**2.23**	**1**	**7.81**	**2.89**	**1**	**-0.97**	**0.48**	**1**
GC1				**14.60**	**6.25**	**1**	**2.85**	**1.13**	**1**
GC2							**-1.46**	**1.35**	**0.32**
GC3	0.17	1.48	0.08	**6.18**	**5.82**	**0.26**			
Arable	0.003	0.005	0.37	**0.01**	**0.007**	**0.45**			
Edges	6.75	18.45	0.20	**45.49**	**41.48**	**0.72**			
Feeders				**-3.68**	**3.20**	**0.76**			
Woods				**-0.009**	**0.007**	**0.18**	**-0.002**	**0.001**	**0.36**
Olive	-0.0005	0.007	0.08	**0.06**	**0.02**	**1**	0.002	0.003	0.13

Figure 1. Map of the distribution of land uses in the study area.

Figure 2. Modelled probability (and 95% CI) that a given spot would hold a partridge territory in spring in relation to game management in *montado* woodland in Portugal.

Figure 3. Modelled probability (and 95% CI) that a given spot would hold a partridge territory in summer in relation to game management in *montado* woodland in Portugal.

Figure 4. Modelled relationship between partridge productivity (young/adult ratio, and 95% CI) and game management in *montado* woodland in Portugal.

Figure 1

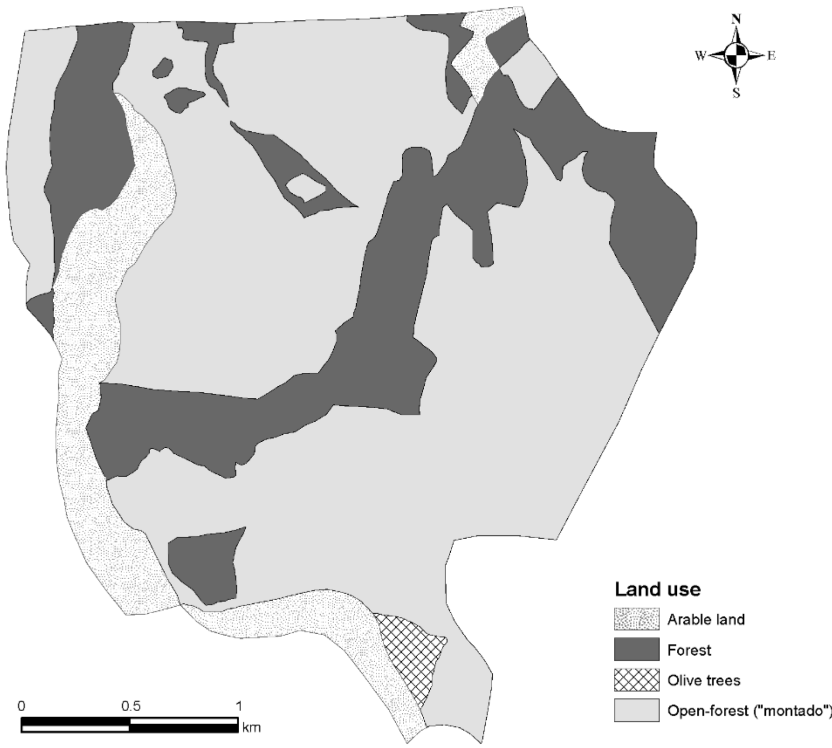

N
W
E
S
Land use
Arable land
Forest
Olive trees
Open-forest ("montado")
0
0.5
1
km

Figure 2.

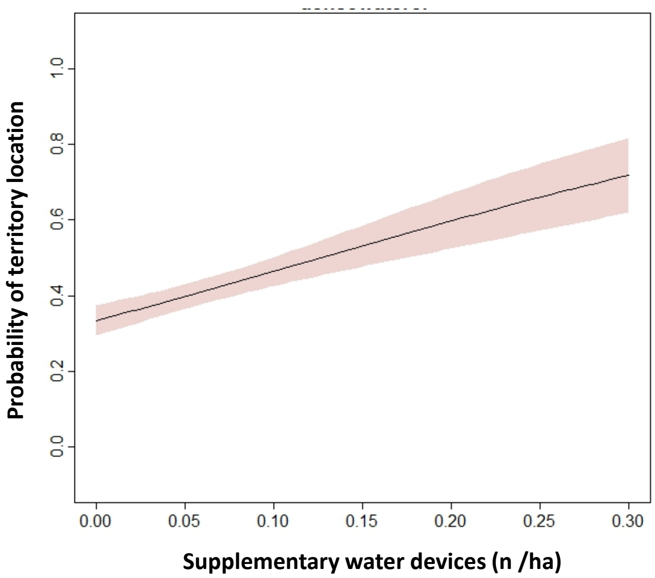

Probability of territory location
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Supplementary water devices (n /ha)

Figure 3.

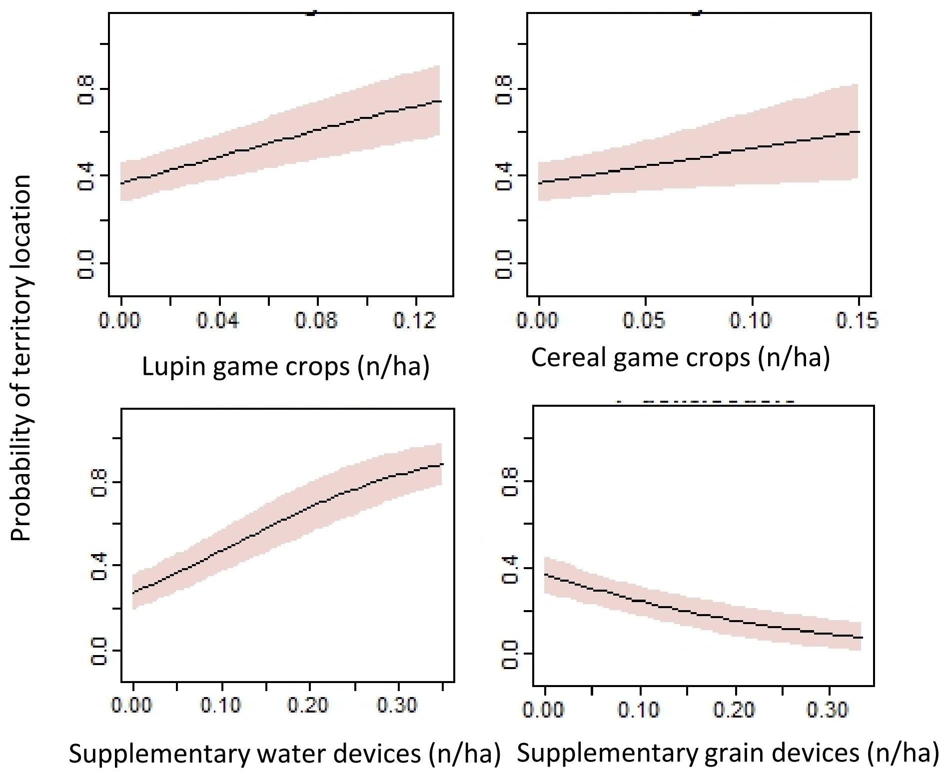
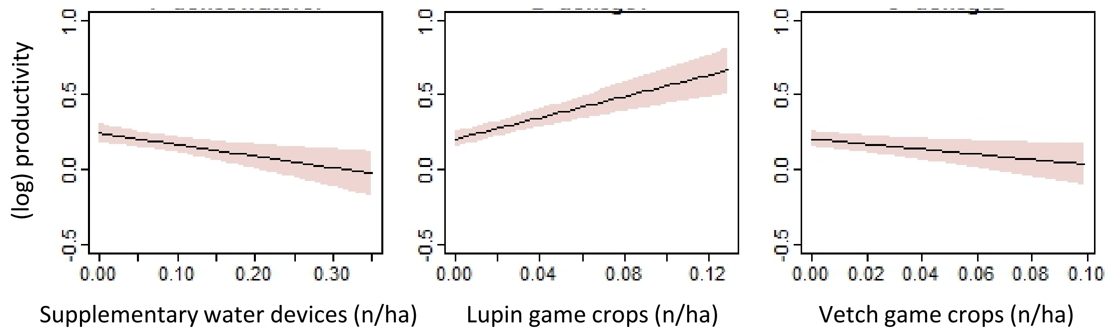

Probability of territory location
0.0
0.4
0.8
0.00
0.04
0.08
0.12
Lupin game crops (n/ha)
0.0
0.4
0.8
0.00
0.05
0.10
0.15
Cereal game crops (n/ha)
0.0
0.4
0.8
0.00
0.10
0.20
0.30
Supplementary water devices (n/ha)
0.0
0.4
0.8
0.00
0.10
0.20
0.30
Supplementary grain devices (n/ha)

Figure 4.


(log) productivity
1.0
0.5
0.0
-0.5
0.00
0.10
0.20
0.30
Supplementary water devices (n/ha)
0.00
0.04
0.08
0.12
Lupin game crops (n/ha)
0.00
0.02
0.04
0.06
0.08
0.10
Vetch game crops (n/ha)