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DENSITY AND HABITAT USE BY THE EUROPEAN WILD RABBIT (*ORYCTOLAGUS CUNICULUS*) IN AN AGRICULTURAL AREA OF NORTHERN ITALY

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ABSTRACT - Habitat selection by the European wild rabbit (*Oryctolagus cuniculus*) in agro-ecosystems is still poorly understood. From December 2005 to March 2008, we assessed pre- and post-breeding wild rabbit densities and habitat use at different range levels in an agro-ecosystem area of northern Italy. Rabbit presence/absence, based on faecal pellets, was assessed in July and August 2007 for 150 1-m radius plots. The range of the species was defined by Kernel Analyses (99% and 50% of the total positive plots) and Jacobs' index of selection was calculated for each habitat type. Moreover, we calculated the *w* index of selection and Manly's α index of preference to compare habitat use to availability within the range. Ten macro-habitat variables and 11 micro-habitat ones were measured and tested for difference between plots with and without rabbits. Discriminant Function Analysis was applied to test for variables that differed between the two types of plots. Wild rabbit density averaged 113.4 individuals per km^2 (SD = 19.88). Rabbits selected woods and field edges, which provide food in the proximity of refuges, avoiding open areas. The dense tree cover of woods would reduce rabbit detectability by raptors while the undergrowth provides shelter against terrestrial predator, reducing the risk of predation. On the basis of our results, management actions for rabbit conservation should aim to improve the ecotones between woods and arable lands and to preserve scrub and woodland.

Key words: Distribution, abundance, habitat selection, agro-ecosystems

RIASSUNTO - ***Densità e uso dell'habitat da parte del coniglio selvatico* (Oryctolagus cuniculus) *in un'area agricola dell'Italia settentrionale***. L'individuazione delle caratteristiche dell'habitat che determinano la qualità ambientale per il coniglio selvatico è importante per la conoscenza dell'ecologia della specie e per la gestione delle popolazioni. L'abbondanza e la distribuzione di un'importante specie preda come il coniglio selvatico sono dipendenti dalla disponibilità di cibo e di rifugi. E' noto che le zone con cespugliati frammisti a pascoli sono particolarmente selezionate dal coniglio selvatico, ma ad oggi la selezione dell'habitat da parte della specie nelle aree agricole intensamente coltivate è ancora poco conosciuta. In questo studio abbiamo stimato la densità del coniglio selvatico in

un'area agricola dell'Italia settentrionale e analizzato l'uso dell'habitat a livello di macro e micro-habitat, individuando i principali fattori ambientali che influenzano la distribuzione della specie. Abbiamo stimato le densità pre e post-riproduttive da dicembre 2005 a marzo 2008, in un'area di 9,9 km^2 situata nell'alta pianura lombarda, in provincia di Milano. La distribuzione del coniglio selvatico è stata stimata nei mesi di luglio e agosto del 2007 dalla presenza/assenza delle feci in 150 cerchi campione di 1 m di raggio. L'areale occupato dalla specie è stato definito mediante Kernel Analysis al 99% e al 50% sui cerchi positivi ed è stato calcolato l'indice di Jacobs di selezione per ogni tipo di vegetazione, confrontando l'uso nell'areale con la disponibilità dell'area di studio; inoltre, sono stati calcolati l'indice w di selezione e l'indice α di preferenza di Manly, confrontando l'uso all'interno dell'areale con la disponibilità dello stesso. Sono state misurate 10 variabili del macro-habitat e 11 del micro-habitat e ne sono state verificate le differenze tra cerchi di presenza e di assenza della specie. Successivamente, è stata utilizzata l'Analisi di Funzione Discriminante per evidenziare le variabili con maggior potere discriminante tra casi di presenza e di assenza. I risultati hanno mostrato come il coniglio selvatico selezioni i boschi e i margini dei campi che forniscono cibo e rifugio dai predatori, mentre evita i campi arati, i prati e gli incolti lontani dai boschi. La densa vegetazione arborea dei boschi può ridurre la contattabilità dei conigli da parte dei rapaci e il sottobosco protegge dai predatori terrestri. I risultati suggeriscono che la gestione dell'habitat a favore del coniglio selvatico debba essere improntata alla conservazione della vegetazione naturale arborea e cespugliare e dei bordi dei campi coltivati.

Parole chiave: Oryctolagus cuniculus, distribuzione, selezione dell'habitat, ecosistema agricolo, Italia settentrionale

INTRODUCTION

Habitat selection aims to satisfy the species requirements for food, shelter and reproduction (Bond *et al*., 2002). Sound knowledge about the habitat requirements of a species is essential for its conservation. This is particularly important for Mediterranean herbivores such as the European wild rabbit (*Oryctolagus cuniculus*), which, during summer has to deal with food and water shortage and a high predation risk. (Myers and Parker, 1975).

The European wild rabbit is considered a keystone species in Mediterranean ecosystems (Calvete *et al.*, 2004; Delibes *et al*., 2007), being the most important prey for a huge number of predators (Delibes and Hiraldo, 1981; Calvete *et al.*, 2004). In addition, this species strongly influences the environment. Burrowing markedly affects soil surface (Eldridge and Myers, 2001; Eldridge and Simpson 2002), faecal pellets enhance soil fertility (Dixon and Hambler, 1993; Willot *et al.,* 2000) and seed dispersion (Malo *et al.,* 1995; Malo and Suárez, 1996), while foraging influences the composition of the plant community (Foran, 1986; Crawley, 1990).

The species distribution in Europe is uneven. Whilst in northern Europe rabbits are spreading and are in places considered as a pest, in southern Europe the species has suffered a sharp decline during the last decades due to agricultural intensification and recurring epidemics of myxomatosis and hemorrhagic disease (Ross and Tittensor, 1986; Marchandeau *et al*., 2000). In Italy, the species is widespread in Sicily and Sardinia, with some high

density populations (Caruso and Siracusa, 2001). In northern Italy, it shows a clumped distribution, being mainly present in the River Po plain, with low density populations (Meriggi, 2001).
Several studies have shown that habitat structure affects wild rabbit distribution and abundance. In particular, mixed areas including scrub, which provide protection from predators, and pastures, which offer food resources, seem to be the most suitable habitat for the species (Rogers and Myers, 1979, Soriguer and Rogers, 1981). Wild rabbit abundance also depends on habitat fragmentation, the species reaching its highest density in continuous populations and mixed habitats of natural vegetation (Virgós *et al*., 2003; Farfán *et al.* 2008). For this reason, traditional low intensity farming probably benefits rabbits in contrast to modern intensive farming which promotes ecotone reduction. Many studies have also analysed wild rabbit abundance in relation to food availability, predation risk (Jaksic and Soriguer, 1981; Moreno *et al*., 1996; Lombardi *et al*., 2003) and habitat use in uncultivated areas (Palomares and Delibes, 1997; Lombardi *et al*., 2007). Nevertheless, habitat selection in agro-ecosystems has not been sufficiently studied, and information about the habitat requirements of the wild rabbit in Europe is scarce, particularly in Italy (Meriggi, 1988).
The aim of the present study was to define wild rabbit habitat requirements and to determine the main habitat factors influencing its distribution in an agro-ecosystem of northern Italy, where population density (about 1 rabbit per ha) was comparable to those recorded in Mediterranean habitats. The progressive spread of urban and industrial areas reduces water and vegetation availability for the species. Thus, the study of habitat selection in summer, when climate intensifies water shortage, allows us to highlight the basic factors influencing the distribution of wild rabbits in agro-ecosystems.

STUDY AREA

The study was carried out in a 9.9 km^2 wide area located 20 km east of Milan (northern Italy) (Fig. 1). Climate is sub-continental; the

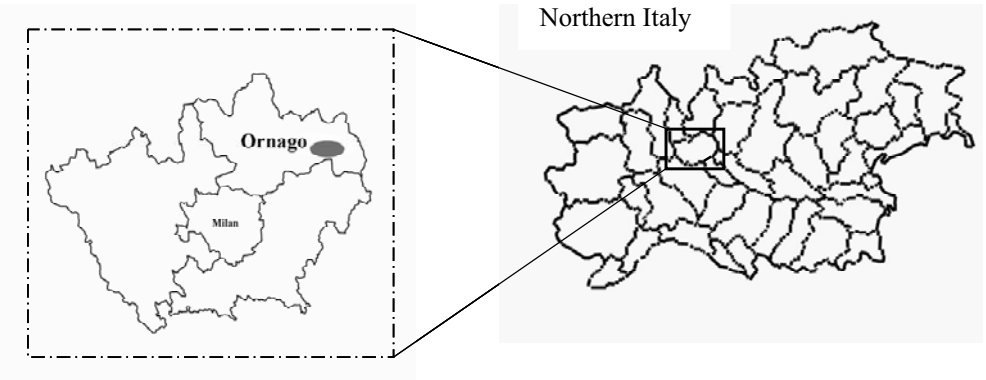

Figure 1 - Study area.

annual mean temperature is 13.9 ºC with a maximum of 25.2 ºC in July and a minimum of 2.2 ºC in January. Monthly rainfall ranges between 195 mm in winter and 315 mm in spring. The area is characterized by crops, mainly winter wheat (*Triticum aestivum*; 27.8% of the total area), barley (*Hordeum vulgare*) and maize (*Zea mays*; 13.1%) and hay-fields (*Lolium perenne, Phleum pratense, Alopecurus pratense*; 17.7%). The uncultivated zones covered a small part of the study area. Small wooded patches (20.1%) are formed by *Robinia pseudoacacia* and *Prunus serotina* and, secondarily, *Quercus robur, Q. petrea*, *Carpinus betulus* and *Ulmus campestris.* The undergrowth includes *Rubus spp*., *Phytolacca decandra, Corylus avellana*, *Crataegus monogyna, Cornus mas, C. sanguinea* and *Hedera helix*. There are also a few fallow fields (0.4%), with a spontaneous vegetation of *Rumex spp., Conyza canadensis, Chenopodium album* and *Solanum nigrum*. Hedgerows (0.4%), field edges (0.4%), dirt roads (0.4%), ploughed fields (0.4%) and buildings (18.9%) complete the study area.

METHODS

1. Rabbit abundance

From December 2005 to March 2008, we carried out spotlight censuses to assess pre- and post-breeding densities of wild rabbit population in the study area. Censuses were carried out from a moving car (maximum speed 5 km/h) covering the dirt roads of the study area and lighting on both sides of the route by a 100 watt hand-handled spotlight. We recorded the perpendicular distance of each independent observation from the transect by a telemeter Leica Rangemaster (range 10-900 m). Density estimates were obtained by the line transect method and the software DISTANCE 5.0 (Burnham *et al*., 1980; Meriggi, 1989; Buckland *et al*., 1993; Thomas *et al*., 2005).

Moreover, in July and August 2007 we covered the dirt roads of the study area between 7.00 and 9.00 am to observe the rabbits during their feeding activity and to calculate an index of kilometric abundance (IKA).

2. Habitat selection

To assess habitat availability, we produced a detailed land use map of the study area. By ArcView 3.2 (ESRI, Inc., Redlands, CA, USA) we digitised on aerial photographs all the polygons of spontaneous and cultivated vegetation; then we attributed each polygon to a vegetation type or habitat type by direct surveys in July and August 2007. The habitat types considered were: winter cereals, maize, hay fields, woods, fallow fields, field edges and buildings.

We analysed habitat selection by wild rabbits at two levels: a) comparing the proportion of each habitat in the species range to its availability in the whole study area and b) comparing habitat use to habitat availability within the range itself (Johnson, 1980). For the first level we randomly located 150 1-m radius plots in the study area and then determined the species presence/absence based on faecal pellets (Swihart and Yahner, 1984; Litvaitis *et al.* 1985; Vidus Rosin *et al.,* 2008). The range of the species in the study area was defined by Kernel Analyses (KA) using 99% and 50% of the total plots with rabbit presence as fixes to describe, respectively, the maximum ranging area of rabbits and their area of concentrated activity (core area); Kernel contours were defined by using Ranges 6 V.1 (Kenward *et al*., 2003). We then compared the proportions of habitat types in the species range (use) and those in the study area (availability) by Jacobs' index of selection (Jacobs, 1974):

$$JI_i = (o_i - p_i)/(o_i + p_i)$$

where o_i is the proportion of use for the habitat i and p_i its proportion of availability.

Jacobs' index ranges between -1 to +1. A habitat type is selected if Jacobs' index is positive and avoided if negative.

For the second level we compared the proportions of presence plots in the different habitat types and the proportions of habitat types within the species range using the Chi-squared log-likelihood test. For this analysis we used the *w* index of selection (Krebs, 1999):

$$w_i = o_i/p_i$$

where o_i is the proportion of the presence plots in the habitat *i*, and p_i is the proportion of the habitat *i* in the species range defined by the 99% Kernel contour. Values of the index equal to 1 indicate no preference; $w < 1$ indicates relative avoidance, whilst $w > 1$ indicates relative preference. To test for significant differences between the use and availability of the habitat types we calculated the Confidence Interval at 95% of the selection index and verified if $w = 1$ fell in or out of the interval (Krebs, 1999).

Moreover we calculated Manly's index of preference α to rank the habitat types in order of preference (Krebs, 1999; Manly *et al.*, 2003):

$$\alpha_i = (r_i/p_i)*1/\Sigma(r_j/p_j)$$

where r_i and r_j are the proportions of positive plots in habitat types *i* and *j*, and p_i and p_j the proportions of the same habitat types in the rabbit range delineated by the 99% Kernel contour.

To highlight the habitat requirements of wild rabbits, we compared the macro and micro-habitat characteristics of plots with (presence plots) and without pellets (absence plots). For this analysis we measured 10 macro-habitat and 10 micro-habitat variables (listed in Tab. 2) (as percentage of habitat types; brightness was measured as the ratio of the Lux measured on the point over the Lux measured in open space), respectively within 1-m and 100-m buffers from the plot center (Manly *et al.*, 2003; Vidus Rosin *et al.*, 2008). We employed one-way ANOVA and the Discriminant Function Analysis (DFA, Wilk's lambda minimization method) to test for differences between positive and negative plots. For the latter method, we used only the variables that differed ($P<0.1$) between presence plots and absence ones (Green, 1974; Noon, 1981; Meriggi *et al.*, 1992, Vidus Rosin *et al.*, 2008). Cover type analyses were performed by ArcView 3.2 and statistical ones by SPSS/PC+ Version 14.0.

RESULTS

1. Wild rabbit abundance

From December 2005 to March 2008 wild rabbit density in the study area averaged 113.4 individuals per km^2 (SD = 19.88); pre-breeding density averaged 100.9 (SD = 12.21), whereas post-breeding density averaged 125.8 (SD = 19.30). No significant variations among years and between pre and post-reproductive periods were found (Fig. 2). In summer 2007, a total transect length of 16.3 km was covered, counting 52 rabbits; the global IKA was 3.2 rabbits/km.

2. Habitat selection

Thirty-nine out of the 150 random plots fell in buildings and were not considered for subsequent analysis. Thirty-three points out of 111 (29.7%) showed signs of wild rabbits presence. At the first level of habitat selection, considering the 99% Kernel range, only woods were selected, whereas the other habitat types were avoided (maize, fallow fields, edges, buildings) or used accord-

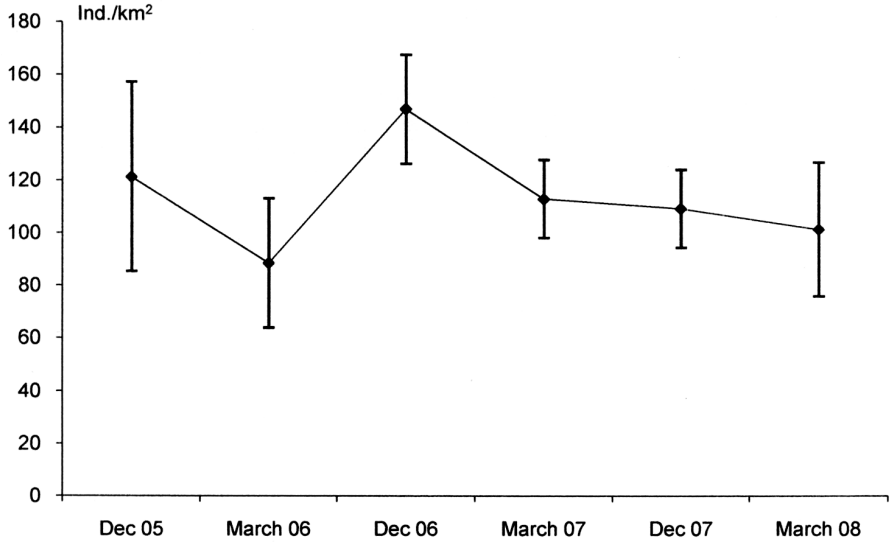

Figure 2 - Variation of wild rabbit density (±SD) from December 2005 to March 2008.

ding to their availability (winter cereals, hay fields) (Fig. 3). Considering the core area, edges, woods, maize, and winter cereals, in order of importance, were selected, whereas hay fields, ploughed fields, fallow fields, and buildings were avoided (Fig. 3). At the second level of habitat selection, we found a significant difference between observed and expected proportion of usa-

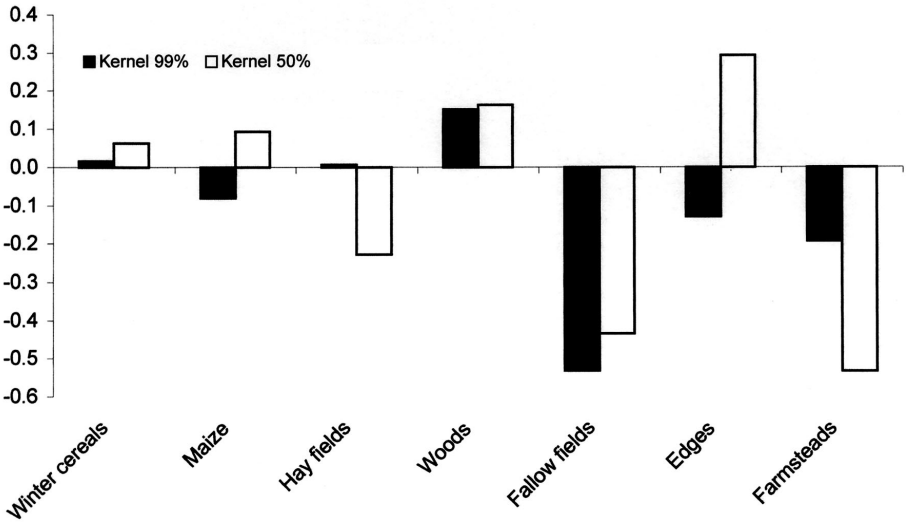

Figure 3 - Jacobs' Index of selection for the habitat types in wild rabbit range (99% Kernel contour) and core area (50%).

Table 1 - Habitat selection and preference by wild rabbits in the study area (range use vs. availability; SE = Standard Error) * Significant differences from the value $w = 1$ indicating no selection.

Habitat types	Availability proportions	Use proportions	*w* index of selection (SE)	Manly's α index of preference
Winter cereals	0.228	0.242	1.06 (0.33)	0.11
Maize	0.221	0.212	0.96 (0.32)	0.10
Hay fields	0.083	0.212	2.55 (0.86)	0.27
Woods	0.200	0.273	1.37 (0.39)	0.14
Fallow fields	0.097	0.001	0.00 (0.00)*	0.00
Edges	0.009	0.030	3.43 (3.38)	0.35
Buildings	0.162	0.030	0.19 (0.12)*	0.02

ge of the habitat types (Chi-squared log-likelihood = 18.27; d.f. = 6; P = 0.0057). Confidence intervals of the *w* index indicated significant avoidance of fallow fields and buildings, whereas the other habitat types were used in proportion to their availability. Ranking the habitats on the basis of their selection by wild rabbits, edges were the most used, followed by hay fields and woods (Tab. 1).

Comparing plots with and without rabbits, we found significant differences between the average values of 4 variables of the micro-habitat and of 3 variables of the macro-habitat ($P<0.1$). The percentages of woods and hay fields, the height and percentage of canopy cover and the percentage of dead leaves were higher in plots of rabbit presence than in those of absence. On the contrary, the percentages of winter cereals and herbaceous cover were higher in plots of rabbit absence (Tab. 2).

The function derived from the Discriminant Function Analysis discriminated significantly between presence and absence plots. The percentages of woods and canopy cover were the main positive variables contributing to the discrimination, while the percentage of herbaceous cover was the main negative variable. The DFA correctly classified 75.7% of the original cases, 66.7% of the cases of presence and 79.5% of the absence ones (Tab. 3).

DISCUSSION

The densities recorded in our study area are hard to compare with other Italian situations because of the lack of published data and the use of different census methods. In northern Italy an average density of 20 individuals per ha (max. 100/ha) was found in the Ticino Regional Park (Meriggi, 2001). In Sicily, Caruso and Siracusa (2001) found, by the pellet count method, an average density of 9.2 rabbits per ha (min.=1.2 max= 38.4), whilst, in 2006 and 2007, Lo Valvo *et al.* (2008) by the same method recorded, respectively, 10.0 and 10.1 individuals per ha in protected areas and 6.0 and 1.6 rabbits

per ha in hunting areas. In Sardinia, O. Sacchi (unpublished data) found in 2007, by spotlight counts, an average spring density of 29.1 rabbits per km^2 (SD = 74.43; min. = 0 max.= 312.8). In neighbouring France, Marchandeau *et al.* (2004), between 1994 and 1996, estimated, by the Mark-Recapture method, from 0.7 to 23.4 rabbits per ha, with a decreasing density trend. In the Iberian Peninsula, which represents the main wild rabbit range in Europe, the species could reach quite high densities (40 ind. per ha), but the present ones are much lower (Angulo and Villafuerte, 2004; Ward, 2005).

If we consider the IKA calculated in July and August, the abundance of wild rabbits in our study area seems to agree with those recorded in some areas of the Iberian Peninsula; for example Beltran (1991) found from 2.6 to 9.1 rabbits per km in Doñana (SW Spain), and Ontiveros *et al.* (2005) calculated IKA ranging from 0 to 0.9 rabbits per km in 8 territories of Bonelli's eagle (*Hieraaetus fasciatus*). In contrast, in New Zealand higher values were

Table 2 - Habitat variation between plots with and without rabbits (one-way ANOVA).

Habitat variables	Presence (N=33)	Absence (N=78)	F	P
Winter cereals	31.7(5.20)	42.6(3.52)	3.12	0.080
Maize	20.1(3.90)	21.1(2.81)	0.006	0.798
Grasslands	12.7(2.83)	16.5(2.50)	0.88	0.353
Woods	28.1(4.16)	11.9(1.71)	18.10	<0.0001
Hay fields	1.2(0.81)	0.1(0.14)	3.54	0.063
Ploughed fields	0.1(0.07)	0.3(0.18)	0.73	0.396
Hedgerows	0.3(0.15)	0.2(0.10)	0.32	0.573
Field edges	0.1(0.13)	0.3(0.08)	2.147	0.146
Dirty roads	0.3(0.13)	0.3(0.09)	0.007	0.932
Buildings	5.4(2.11)	6.5(1.29)	0.26	0.608
Herbaceous cover	20.3(3.07)	31.23(2.70)	5.62	0.019
Height of herbaceous cover	40.1(8.78)	44.78(5.42)	0.21	0.645
Bushy cover	0.5(0.31)	3.72(1.33)	2.32	0.131
Height of bushy cover	0.1(0.05)	0.13(0.04)	0.22	0.638
Canopy cover	22.7(6.39)	8.21(2.39)	6.89	0.010
Height of canopy cover	3.4(1.01)	1.83(0.52)	3.48	0.055
Litter cover	11.9(4.19)	14.72(2.95)	0.30	0.587
Litter thickness	0.7(0.31)	0.62(0.14)	0.052	0.820
Dead leaves cover	12.9(4.22)	4.97(1.88)	3.98	0.048
Brightness	0.5(0.04)	0.47(0.02)	0.03	0.862

Table 3 - Results of the Discriminant Function Analysis between plots with and without rabbits.

Habitat variables	Standardized coefficients	Correlation coefficients
Herbaceous cover	-0.372	-0.406
Canopy cover	0.565	0.449
Height of canopy cover	-0.220	0.319
Dead leaves cover	-0.104	-0.104
Winter cereals	0.093	-0.302
Woods	0.811	0.728
Hay fields	0.434	0.322
Eigenvalue	0.31	
Canonical correlation	0.489	
Chi-square	28.78	
df	7	
P	<0.0001	

recorded (up to 200 ind. per km; Caley and Morley, 2002). Possibly, either our census method underestimates wild rabbit density or other methods can generate overestimates. Our population does not seem to be affected by a serious incidence of the two main diseases that affect Iberian and French populations, but the time of censuses could have masked the high mortality that usually occurs in summer because of myxomatosis and viral haemorrhagic disease (Marchandeau *et al.,* 2000). In fact, the reproductive increase of the population was low with respect to those usually recorded in other studies (Angulo and Villafuerte, 2004; Ward, 2005). It is possible that diseases act as regulatory factors of the population together with predation by foxes (*Vulpes vulpes*).

Our results support the hypothesis that, in summer, habitat selection is determined by a compromise between food availability and the need for protection from predators (Moreno *et al*., 1996). At the range level, rabbits selected only woods, demonstrating that high canopy and undergrowth cover is the main habitat requirement of the species in northern Italy (Serrano *et al.* 2007). However, considering the most attended part of the range, also edges, maize and winter cereals were selected. Monzón *et al*. (2004) observed that rabbits prefer landscapes with heterogeneous and fragmented vegetation cover, while Beltran (1991) and Fernández (2005) reported that rabbit abundance was directly correlated with the density of scrub-pasture ecotones. Accordingly, our results suggest that areas with a mosaic of scrub and arable patches could provide a favourable combination of food and refuge for the species.

Foraging close to warrens or cover reduces predation risk (Rogers, 1974; Jaksic and Soriguer, 1981), the dense herbaceous cover of field-wood ecotones in summer also provides a variety of weeds, which allows rabbits to forage close to tree cover.

Moreover, in our study area rabbits foraged also during the day in areas with high canopy and shrub cover. This behaviour has been described in sheltered areas of Portugal (Martins *et al*., 2003), Spain (Rogers and Myers, 1979) and France (Rogers, 1981; Chapuis, 1990).

The proximity of warrens or shelter could play a major role in limiting the species dispersion (Chapuis, 1990).

Grasses and forbs make up the bulk of rabbit diet, although diet composition varies markedly during the year (Rogers *et al*., 1994). The consumption by rabbits of maize and winter cereals markedly decreases in summer. The leaves and stems of both crops are highly available and consumed by rabbits in spring and the first part of summer (Chapuis, 1990). In August, the lignification of the maize plants reduces digestibility and nutritional quality, while the availability of winter cereals is almost nullified by harvesting. The moderate selection for maize and winter cereals recorded by us in the core area of the range, could be due to the protection that maize fields offer against predators, and to the growth of fresh cereals and grasses within the stubbles.

Considering the second level of habitat selection, hay fields emerged as an important habitat type for the species; in fact this habitat, offering a great abundance and variety of grasses, clovers and other herbs of high nutritional value, was the second used after the edges and before the woods.

The analyses of micro- and macrohabitat variables mainly confirmed rabbit selection for woods, suggesting that rabbits prefer habitats with permanent cover. A high and dense tree cover reduces prey detectability and protects from raptors, while dense undergrowth provides refuge from terrestrial predators such as the red fox (Gibb, 1993; Ontiveros *et al.*, 2005). In Italy, the reputation of the European wild rabbit varies according to different parts of its range: on the islands (Sicily and Sardinia), the wild rabbit is considered as a very important small game species, whereas in northern and central Italy it is considered as a pest because of the damage caused to crops and arboriculture. The present study provides insights into resource availability and habitat use by the wild rabbit, providing useful data for the development of landscape management strategies for the recovery of rabbit populations and for the reduction of damage to crops. Based on our result, we suggest that habitat management should firstly aim to preserve remnant woody habitats. Secondly, crop-woods ecotones should be maintained and possibly enlarged, increasing the availability of foraging areas close to refuges and turning rabbit foraging activity to spontaneous vegetation rather than crops.

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