Uso do Habitat e da Paisagem pelo Rato de Cabrera (*Microtus cabrerae* Thomas, 1906) em Ecossistemas Agrícolas: Implicações para a sua Conservação

Habitat and Landscape use by the Cabrera Vole (Microtus cabrerae Thomas, 1906) in Agricultural Ecosystems: Implications for its Conservation

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Dissertação para a obtenção do Grau de Mestre em
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Trabalho orientado por:

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Habitat and landscape use by the Cabrera vole (*Microtus cabrerae* Thomas, 1906) in agricultural ecosystems: implications for its conservation

ABSTRACT

Towards the increased threats to biodiversity resultant from human management practices, we need to outline specific conservation plans for species that often persist in marginal habitats. In the present study we aimed to provide basic information for the conservation of the Cabrera vole, particularly concerning its space use. For this, we considered two different scale-perspectives: at the microhabitat level and at the landscape level. Results indicate that the Cabrera vole is very selective in relation to habitat requirements, being associated to wet dense and tall herbs. Concerning the landscape structure, this small mammal appears to be very sensitive in relation to habitat-patch isolation and to the pasture regimes to which these habitats and adjacent areas are often submitted. Based on results a set of management practices are proposed in order to contribute for the conservation of this species.

Uso do habitat e da paisagem pelo rato de Cabrera (*Microtus cabrerae* Thomas, 1906) em ecossistemas agrícolas: implicações para a sua conservação

RESUMO

Face aos problemas da intensificação agrícola na conservação da biodiversidade, torna-se fundamental a elaboração de planos específicos de conservação para espécies que ocorrem em habitats marginais. Com o presente estudo pretendeu-se disponibilizar informação base para a conservação do rato de Cabrera, particularmente no que respeita ao uso do espaço. Foram adoptadas duas prespectivas de estudo: ao nível do microhabitat e ao nível da paisagem. Os resultados indicam que esta espécie é altamente selectiva quanto ao tipo de habitats onde ocorrre, estando associada a zonas húmidas ocupadas por gramínias densas e altas. Relativamente à estrutura da paisagem, o rato de Cabrera parece ser sensível quanto á forma como os habitats favoráveis se distribuem no espaço, particularmente em relação ao seu grau de isolamento e aos regimes de pastoreio a que frequentemente estão sujeitos. Com base nos resultados obtidos é proposto um conjunto de medidas de gestão em paisagens agrícolas com vista à conservação desta espécie.

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General Introduction

Research questions and aims of the present thesis

The expansion of agricultural landscapes is widely recognised as one of the most significant human alterations to the global environment (Matson et. al. 1997). Over the 5000 years of agricultural history in central Europe, the patterns of land-use have changed dramatically. Indeed, along a gradient of increasing land-use intensification, there has been a generalised switch from intermittent to continuous cultivation of the same area of land (Giller et. al., 1997). This anthropogenic transformation of natural, old-growth woodlands into mosaic landscapes, has produced considerable effects on biodiversity (e.g. Freemark, 1995; Smedinga & Joenjeb, 1999; Benton et. al., 2003; Waldhardt et. al., 2003).

In the Mediterranean basin, many wildlife species have adapted themselves to landscapes shaped by human activity (Naveh, & Dan, 1973; Santos & Cabral, 2003). Indeed, studies on intraspecific variation within plants and animals species show that organisms may evolve life-history traits as a response to human-induced habitat changes (Blondel & Aronson, 1999). By this way, human intervention upon the Mediterranean basin has strongly contributed to the biological diversification of this region. This fact, combined with the particular features of the geology, climate and natural vegetation of the Mediterranean basin, explain why this region has been considered a 'hotspot' of diversity with high conservation priority (Aschmann, 1973; Preiss et al., 1997; Myers et al., 2000). Nevertheless, the expansion of monocultures in agriculture during the last decades is thought to present serious problems for the conservation of many specialist species (Pignatti, 1983; Blondel & Aronson, 1999; Stoate et al., 2001). Activities like irrigation, shepherding, clearance of forests or woodlands and burnings, all involve the more or less complete replacement of the natural vegetation over limited or extensive areas. These practices, largely supported by pesticides, synthetic fertilisers and by specialisation either in crop or livestock species (Blondel & Aronson, 1999), are referred to reduce or eliminate native species, or to create new ecological systems (Aschmann, 1973; Stoate et al., 2001).

In the face of the diverse ecological problems connected to agricultural intensification in Mediterranean agricultural landscapes, we need to look forward to find proper solutions based on suitable farming practices. Indeed, although the effects of agricultural intensification upon Mediterranean's native biota have been globally identified, specific effects at a local level are still poorly assessed, especially concerning threatened species (Blondel and Aronson, 1999).

The Cabrera vole, *Microtus cabrerae* Thomas, 1906 (fig. 1), is a robust and large size arvicoline endemic to the Iberian Peninsula. It is included in Anexes II and IV of *Habitats* Directive and in Anexe II of Bern Convention, and is considered a threatened species both in Portugal (SNPRCN 1990) and in Spain (Palomo & Gisbert, 2002). This small mammal is considered a habitat specialist, occurring preferentially in open fields with high soil moisture able to support an evergreen herbaceous stratum (Fernandez-Salvador 1998). The features of these types of habitats appear to gather the requirements of good agricultural lands, and human pressure upon such areas, through their conversion into farmlands or pastures, seems to represent important threats for the Cabrera vole. Indeed, new agriculture techniques that promote the extension of cultivated fields with subsequent fragmentation of habitats, together with the constant stubble burnings to create pastures and cattle overgrazing, are often appointed as main factors affecting the Cabrera vole (e.g. Fernández-Salvador et al, 1998; Landete-Castillejos et. al., 2000). For these reasons, the distribution of this small mammal is patchy and there is evidence that many sites where it was present in the past are now out of its present distribution range (e.g. Ayarzaguena & Lopez-Martinez, 1976; Mathias et. al. 1998; Fernández-Salvador 1997).

Given the present threats for the Cabrera vole, detailed investigations about the ecology of this small mammal should be a priority towards the definition of suitable conservation measures for the species. This notion, together with the fact that the Cabrera vole is one of the less known rodents in Europe, makes this species a very interesting and promising research model to address several theoretical and practical questions about how to manage landscapes for conservation purposes.

In the present study it was aimed to get information about fundamental aspects on the ecology of the Cabrera vole in order to contribute to draw up a management plan for the species. The main goals were:

1 - To relate the level of activity of the Cabrera vole with several microhabitat descriptors in a previous selected agro-ecosystem.

2 - To evaluate the spatio-temporal dynamics of patch utilisation in relation to several local and landscape features of the same agro-ecosystem.

By doing that we expected to identify several important microhabitat descriptors that control space use by the Cabrera vole. This scale-perspective seems to be a very important study approach because, for the majority of threatened species, the protection and maintenance of the critical habitat provide the first key steps in order to increase long-term survival possibilities. On the other hand, we also expected to understand the relation between the patterns of patch occupancy and turn-over rates with landscape descriptors. This scale perspective may provide important information about the factors that determine the regional persistence of the Cabrera vole in fragmented agricultural landscapes.

The two research-lines (microhabitat use and spatio-temporal population dynamics) followed in this thesis are thus expected to provide important clues to sketch conservation priorities for the Cabrera vole. Furthermore, the outcomes from the present study are expected to outstretch the discussion about how intensive agricultural Mediterranean landscapes should be management in order to preserve their multi-functionality.

The Experimental model system

The Cabrera vole - background

The Cabrera vole (figure 1) belongs to *Iberomys* sub-genus, with origin in the median Plistocenic (Ayarzaguena & Lopez-Martinez, 1976). It is considered a relic-species (Ayanz, 1994), with a much reduced distribution area in the present days comparing with the original one. Indeed, fossils findings were already found the south of France (e.g. Montpellier) (Ayarzaguena & Lopez-Martinez, 1976), and within the Iberian Peninsula many areas where the species is now absent, were formerly occupied

(Mathias et. al. 1998; Fernández-Salvador 1998). The current fragmented distribution of the Cabrera vole includes several areas of the supra and meso-Mediterranean bioclimatic zones of south-west, centre and north-east Portugal, and south-east Spain and Iberian pre-Pyrinees (Ventura et al., 1998). The reduced distribution of the Cabrera vole can be explained by the decrease of favourable habitats during the last 300 years, mainly due to the dryness increase, which results from the destruction and transformation of formerly occupied areas (Ventura et al., 1998).

Concerning the habitat use by this small mammal in agricultural landscapes, and its relation to management inputs, known studies were so far largely descriptive. In part, the problem seems to be related with the difficulty to capture this species (Fernández-Salvador et al., 2001), which compels researchers to use alternative approaches in ecological studies, often supported on the employment of indirect methods for populations' monitoring.

The habitats often associated with the Cabrera vole include rush beds and dense evergreen perennial grasslands or small herbaceous areas associated with different oak trees or with shrubby vegetation near small and temporary stream banks (San Miguel, 1992; Fernandéz-Salvador, 1998; Ventura et al., 1998; Palomo & Gisbert, 2002; Mathias, 2003). Occasionally, this vole may be present near-by the borders of permanent streams, where usually the southern water vole, *Arvicola sapidus* is also present (Fernández-Salvador, 1998; Landete-Castillejos et al., 2000; pers. observ.). Therefore, the Cabrera vole can be considered a high geoclimatic demanding species and the presence of high soil moisture able to support an evergreen herbaceous stratum seems to be one of the main limiting factors for the distribution of this vole (Fernandez-Salvador 1998).

Fig. 1 – Cabrera vole

The study area

In order to attain the purposes of this research we needed to select an agro-ecosystem consisting in a mosaic of different types of habitats. Thus, within the distribution range of this small mammal, the south-west Portugal seemed a good choice, since in this region, agricultural landscapes are highly heterogeneous and dynamic in space and time. Furthermore, there is evidenced that in this region, the agricultural intensification interferes significantly with the quantity and quality of habitats for many species (e.g. Beja and Alcazar, 2003). In south-west of Portugal the Cabrera vole was considered a prior species for conservation (Palmeirim et. al. 1992; Mathias, 1995).

This region is included in the thermo-Mediterranean bioclimatic zone (Rivas-Martinez *et. al.* 1990) and, from a climatologic point of view, holds a rainfall regime with a greater influence in the climatic rhythm than temperature oscillations (Ribeiro et al., 1987). Average annual rainfall ranges from 400 and 700 mm (Neves, 1995), and average temperatures range between 6°C (during the coldest season) and 29°C (during the hottest season) (Neves, 1995).

A considerable area of the south-west Portugal is classified as a Natural Park: Natural Park of South-west Alentejo and Vicentina Coast (NPSAVC). From the conservationist point of view and in the European context, this area presents high interest, and is classified as a Site of Communitarian Importance. Indeed, the NPSAVC is annexed to international conservation nets, including the CORINE Program. Furthermore, this protected area was recently proposed to integrate the Natura 2000 network.

One of the most important characteristics of the south-west coast of Portugal is related with the amount of water presented in the soil in many areas (Coelho, 1997 in Neves, 1995). These saturated areas are mainly dependent on small streams (permanent or intermittent), and in some places may form temporary ponds, were particular flora and fauna might occur (e.g. Beja and Alcazar, 2003). Presently, these type of habitats are highly endangered, suffering widespread degradation and loss due to increases in the area of land under intensive cultivation, shepherding and urban use (Coelho, 1997 in Neves, 1995; Beja and Alcazar, 2003).

For surveys proposes, an area of about 4x4 km^2 was chosen (Figure 2). In this area the presence of the Cabrera voles was already confirmed on the basis of presence signs, captures and barn owl (*Tyto alba*) pellets. The selected study area corresponds to an open farmed arable land, mainly devoted to extensive dry-cereals cultivation, irrigated annual crops, wood production and shepherding. In this agricultural landscape, extensive and low input management practices represent the most frequent form of soil occupation. However, during the last decade there has been a decrease in fallows and dry cereal cultivation, accompanied by increases in irrigated cereals, vegetables, sunflowers and permanent pastures for cattle breeding production (Beja & Alcazar, 2003).

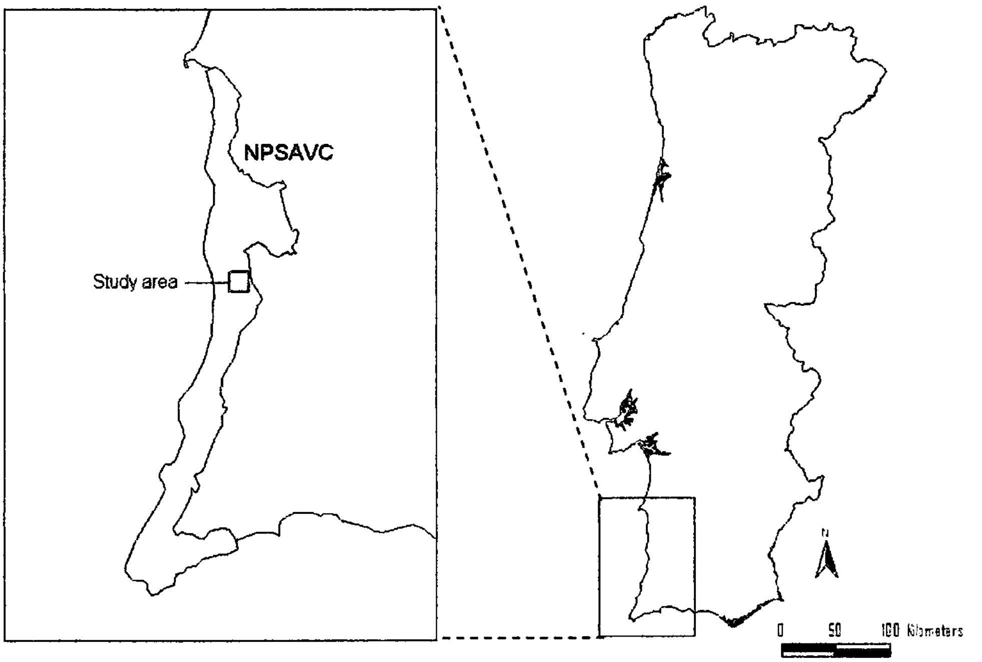

Figure 4 - South-west Portugal, limits of the Natural Park of South-west Alentejo and Vicentina Coast (NPSAVC) (grey shading), and study area location (red square)

Thesis structure and organisation

This thesis consists of two papers dealing with the habitat use by the Cabrera vole considering two different spatial scales, according the two specific objectives earlier defined. The first paper concerns the microhabitat scale-perspective (first objective), whereas in the second, the landscape perspective is considered (second objective). The papers are:

1- Critical habitats for the Cabrera vole (*Microtus cabrerae* Thomas, 1906): conservation in intensive Mediterranean farmland.

2- Patch use by the Cabrera vole in a Mediterranean agro-ecosystem: the role of fragmentation and landscape context.

The two papers were submitted for publication in two different peer-referee international scientific journals. In the final section of this thesis (*General discussion*), we make a shortly overview of the research. Here we briefly review the main results that came out from these two papers, and discuss the overall outcomes in the context of the Mediterranean basin, the agricultural intensification and the implications upon the biodiversity.

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Critical habitats for the Cabrera vole (*Microtus cabrerae* Thomas, 1906): conservation in intensive Mediterranean farmland

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Abstract

Conservation of biodiversity is a critical concern in agro-ecosystems under agricultural intensification. In these landscapes, marginal habitats such as meadows and grassy field margins support most of local biodiversity, so their management needs to be targeted to meet the habitat requirements of species of conservation concern. This is the case of small mammals, for which the management of herbaceous habitats may serve (either for pest control or species restoration), requiring information on microhabitat use by target species to achieve specific management purposes. In this study, we assessed habitat and microhabitat use by the threatened Cabrera vole, *Microtus cabrerae*, in an agricultural landscape of SW Portugal, in order to evaluate agricultural management practices that might favour its populations. Results confirmed that this species appears to be very selective towards wet grass meadows and sedge rush communities. Despite the patchy distribution and the sensitivity in relation to human management, colonies were relatively large (mean=1928m^2) and mean nearest neighbour distance was 363m. Within the selected habitats, the Cabrera vole activity was concentrated in sites with dense and tall herbs, though appearing to avoid areas where water voles, *Arvicola sapidus*, were present. Activity of Cabrera voles was higher during the winter, confirming the adverse effect of the dry periods for this species. Conservation of the Cabrera vole in agricultural landscapes would require the maintenance of a network of tall and dense herbaceous patches, which could eventually be established along field margins, road verges and ditches, and supported by agri-environment subsidy schemes.

Key-words: Microhabitat use, Cabrera vole, Agricultural landscapes, Agricultural management, Field margins

1. Introduction

Since the 1950s, there has been a pervasive trend for the intensification of agricultural practices, with the growing use of high-yielding crop varieties, agro-chemicals, mechanization, and irrigation of dry lands (Vos and Meekes, 1999; Benton et al., 2003; Waldhardt et al., 2003.). This has resulted in increasingly large managed fields and the loss of marginal semi-natural habitats such as ponds, woodlots, hedges, and herbaceous field margins, thus leading to the simplification and homogenization of agricultural mosaics (e.g. Vos and Meekes, 1999; Benton et al., 2003; Hietala-Koivu et al., 2004). As a consequence, major declines in farmland biodiversity have occurred over the past few decades, with dramatic reductions even in the abundance of once very common species (e.g. Battershill and Gilg, 1996; Paillat and Butet, 1997; Stoate et al., 2001, Crane and Bateson, 2003; Burel et al., 2004). Therefore, marginal habitats are widely recognised as fundamental elements supporting biodiversity in agricultural landscapes (Strachan et al, 2003; Hietala-Koivu et al., 2004). In this context, grassy areas in the form of set-asides, field margins or road verges, may provide habitats for wildlife, acting as biodiversity reservoirs (e.g. Moonen and Marshall, 2001; Perkins et al., 2002; Vickery et al., 2002; Buskirk and Willi, 2004) or stepping-stones for dispersal and/or migration pathways (e.g. Merriam and Lanoue, 1990; Haddad et al., 2003). This guiding idea has increased the interest on agri-environmental schemes as part of rural development strategies in Europe (e.g. Keller and Kollman, 1999; Lane et al., 2001; Stoate, 2001; Johnson and Baker, 2003). The declines in European biodiversity due to agricultural intensification have started early in northern and central countries, where they are very well documented (e.g. Battershill and Gilg, 1996; Stoate et al., 2001), but they are far more recent and less understood along the Mediterranean basin and in the East. Concerning the Mediterranean basin, although the effects of intensification of agricultural practices upon native biota have been globally identified (e.g. Pignatti, 1983), specific effects at a local level are still poorly assessed, especially concerning threatened species (Blondel and Aronson, 1999). This is partially due to the lack of information on the distribution, abundance and habitat use by most species (Blondel and Aronson, 1999), situation that may be preventing the establishment of a larger number of suitable and multi-agreeable agri-environmental schemes.

Small mammals are common in agricultural landscapes worldwide (e.g. Jacob, 2003; Tattersall and Macdonald, 2003) and the decline of species due to agriculture intensification is well documented (e.g. Paillat and Butet, 1997; Sullivan et al., 1998; Gorman and Reynolfs, 2003; Macdonald and Rushton, 2003, Tabena and Ojeda, 2003). In agricultural landscapes, marginal grasslands have a major role in maintaining many small mammal species (e.g. Batzli et al., 1999). Concerning rodent species, this group is often associated to agricultural damage (e.g. Cowan and Quy, 2003). This fact has raised the question of how to manage low-impact farming and set-aside land in central European agriculture, thus helping to protect threatened species, without creating conditions favouring pests (Jacob, 2003). Because different species show different ranges on habitat requirements (habitat specialists vs. generalists) it is expected that the knowledge of how species use habitat patches, may provide important clues for different management aims. In this context, since species distribution and abundance are primarily a cumulative result of individuals choices at the microhabitat level (Boyce and Macdonald, 1999), microhabitat use by species is expected to be one of the main previous processes affecting population dynamics in space and time and, in this context, small mammals have often been used as models (e.g. Delattre et al., 1996; Jacob and Brown, 2000). In fact, the evaluation of those factors that affect microhabitat use by small mammals, might be viewed as one first key-step to assess species-specific requirements in relation to habitat features and its implications on landscape use and management. Therefore, management can aim either to control potential pests (e.g. Jacob, 2003) or to favour ecological requirements of species facing strong populations declines (e.g. Tattersall et al., 2000).

The Cabrera vole, *Microtus cabrerae* (Thomas, 1906), is an endemic microtine restricted to the Iberian Peninsula, occurring typically in meso-mediterranean bioclimatic zones (Rivaz-Martinez, 1981). It is a threatened species both in Portugal (SNPRCN 1990) and Spain (Palomo and Gisbert, 2002), and listed as a species of European conservation concern in the Habitats Directive (92/43/EEC). Although the studies on habitat use by the Cabrera vole have been so far largely descriptive, there is strong evidence that this species is a habitat specialist with very demanding ecological requirements (e.g. Ayanz, 1994; Fernández-Salvador, 1998; Mathias et al., 1998; Santos et al., in press). Most important features concern humidity and temperature conditions afforded by grass meadows with seasonal springs, or small herbaceous areas with brushwood located near small riverine sedge or rush areas (e.g. Ayanz, 1994; Fernández-Salvador, 1998; Mathias et al., 1998; Ventura et al., 1998). As it lives in moist areas that are highly productive when converted to agricultural land, agricultural development and overgrazing are pointed out as the main human activities related with this species habitat degradation (Fernández-Salvador et al., 1997, Fernández-Salvador, 1998; Mathias, 1999; Landete-Castillejos et al., 2000). For this reason, in agricultural landscapes the Cabrera vole is patchily distributed in small colonies (e.g. Ayans, 1994; Fernández-Salvador, 1998), and fossil findings show that this vole has disappeared from many localities where it was present in the past (Ayarzaguena and Lópes-Martínez 1976; Mathias et al., 1998; Fernández-Salvador 1998). The long-term persistence of the Cabrera vole in agricultural landscapes may thus depend on certain agricultural practices compatible with the maintenance of suitable habitat patches. In this sense, the management of suitable grassland areas is certainly a key-factor determining Cabrera vole occurrence. Therefore, detailed research on habitat use by this species at fine spatial scales is needed. In fact, the major habitat features pointed-out as being determinants on this species success were not yet target of an analytical research. Furthermore, field observations suggest a differential use of space within the limits of colonies, which may have implications in highly managed agricultural landscapes, where extensive homogenisation of fields prevail over former traditional management practices.

The aims of this study were: (1) to survey the Cabrera vole colonies inhabiting an agricultural landscape in south-west Portugal and characterise occurrence areas concerning habitat features and spatial arrangement within the landscape; (2) to investigate the quantitative relationship between the Cabrera voles activity and several microhabitat descriptors at each surveyed colony; and (3) to assess the seasonal variation in the Cabrera vole activity and in microhabitat variables. This information was then used to discuss how current land uses may affect the Cabrera vole, and to help designing conservation prescriptions favouring the persistence of this species in agricultural landscapes, which might be enforced under adequate agri-environmental schemes.

2. Material and Methods

2.1. Study area

The study was carried out in a 4x4km^2 agricultural area on the coastal plateau of south-west Portugal, within the Natural Park of South-West Alentejo and Vicentina Coast (NPSAVC) (Fig. 1). This is a region of major conservation relevance that was recently proposed to integrate the Natura 2000 network. It is included in the thermo-Mediterranean bioclimatic zone (Rivas-Martinez, 1981), with a mean annual temperature of about 16.5°C and a mean annual rainfall of about 630mm, of which about 80% falls between October and March. Landscape is typically agricultural, with management practices, such as farming and pasturing facing at present a strong intensification, with significant detrimental impacts on biodiversity (Beja and Alcazar, 2003). Most important land uses include natural and semi-natural pastures, extensive cultures of winter cereals in a fallow-cereal rotation basis, and irrigated corn-fields, associated to frequently pesticides and fertilisers inputs. Land fragments devoted to wood production are also common. Fields are often separated by arboreal, shrubby and sometimes grassy strips.

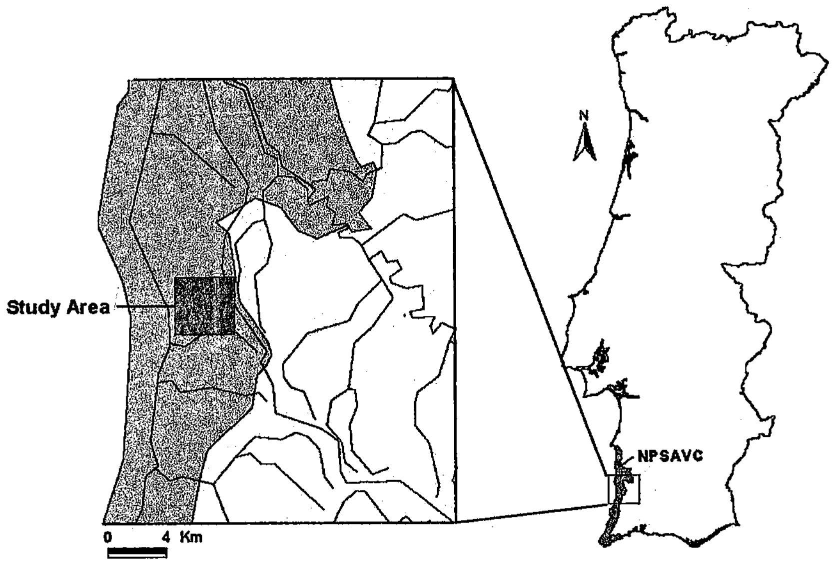

Fig. 1 - Study area location (dark-grey square) and limits of the Natural Park of South-West Alentejo and Vicentina Coast, NPSAVC (grey stain).

2.2. Vole survey

A systematic survey of Cabrera vole colonies was carried out within the study area in the hot and dry season (August-September 2001) and in the cold and rainy season (January 2002), to account for eventual seasonal variation in microhabitat use. Detection of colonies was based on the presence of species-specific signs, particularly the conspicuous tunnels or pathways on the ground grasses, on which the voles leave small dark-green droppings. Colony is here referred to any single aggregation or any circumscribed assemblage of aggregations of voles' tunnels and droppings within a discrete habitat patch. Droppings can be found isolated along the pathways or grouped in latrines placed usually at crossings or endings. There is no possibility of confusing Cabrera voles signs with that of other species, even with sympatric southern water vole, *Arvicola sapidus*, the droppings of which are about twice as large (Pita et al., unpublished data). Four outer limits of each colony were mapped (corresponding to the maximum width and the maximum length) and its area was estimated approaching the elliptical shape.

2.3. Microhabitat sampling

Data on Cabrera vole presence and activity levels for microhabitat analysis were measured at 50x50cm^2 sampling plots. Eight plots were located in each vole area, with two plots per cardinal direction at 10m and 30m from the centre of each colony. This design was used to encompass both discontinuities in vole distribution within the colonies and the periphery of the colonies, allowing the evaluation of small scale gradients at microhabitat attributes. In each plot we counted the total number of droppings and measured the total length of pathways in the vegetation. These measures were assumed to provide indirect indices of Cabrera voles activity or relative abundance, as referred to other *Microtus* species (e.g. Delattre et al., 1996; Petty et al. 2000; Sherratt et al. 2000). Comparable activity indices were estimated for the southern water vole, using its droppings and length of pathways, because this species is thought to have influence on habitat use by Cabrera vole (Ayans, 1994; Fernández-Salvador, 1998). Vegetation characteristics were measured in the plot and its vicinity using the point-intercept technique, with one point at the centre of the plot and another six located along the plot's cardinal orientation, at 2, 4 and 6 m from the central point. A metallic rod was placed vertically at each sampling point, and the eventual intercepts with the tallest shrub and herb were registered, noting also the height and vegetative stage (green versus dry) of the plants. These data were then used to derive six microhabitat variables describing the herbaceous and shrubby vegetation (Table 1).

2.4. Data analysis

Prior to analysis, variables were transformed to approach normality, using the angular transformation for proportional data and the logarithmic transformation for other skewed continuous variables (Table 1). Spearman rank correlations (R_s; Siegel and Castellan, 1988) were computed between all pairs of microhabitat variables averaged per colony, to investigate for the presence of collinearities that might confound the interpretation of statistical results. From each pair of highly inter-correlated variables ($R_s \geq 0.7$; Tabachnik and Fidell, 1996), we retained the one potentially most relevant for the Cabrera vole, as judged from previous published studies (e.g. Ayanz, 1994; Fernández-Salvador, 1998). Differences in the mean values of microhabitat descriptors between plots used (with droppings or pathways in vegetation) and unused by the Cabrera vole were assessed for each season using mixed-effects one-way ANOVA models (Pinheiro and Bates 2000). The use of mixed-effects models was necessary, because sampling plots were grouped by colony, and so there might be potential sources of pseudo-replication. Colony was thus used as the random effect in the model, with the fixed-effect corresponding to the dummy variable coding the presence of the Cabrera vole. A similar approach was taken to evaluate the variation between seasons (winter vs. summer) in activity levels and microhabitat descriptors in used plots. Variation in vole activity among used plots was examined likewise using mixed-effects linear models (Pinheiro and Bates 2000). In these models, the activity level in a season (measured by the length of pathways in the vegetation) was the dependent variable, the microhabitat variables were the fixed-effects, and the colony was the random effect. Multivariate linear models were built for each season, using stepwise deletion from the full model with all main effects, and retaining the model with the lowest value of the Aikake Information Criteria (AIC) and for which all covariates were statistically significant (p<0.05). Analyses were carried out with S-PLUS 2000 (Mathsoft, 1999; Pinheiro and Bates 2000).

Table 1

Description of variables used to assess microhabitat use by the Cabrera vole in Southwest Portugal.

Variables	Units	Transformation
Voles		
Cabrera voles occurrence	absence/presence (0/1)	
Number of Cabrera vole droppings	counts	$\log_{10}$ [x+1]
Length of Cabrera vole tracks in ground vegetation	cm	$\log_{10}$ [x+1]
Southern water vole occurrence	absence/presence (0/1)	
Number of water vole droppings	counts	$\log_{10}$ [x+1]
Length of water vole tracks	cm	$\log_{10}$ [x+1]
Vegetation		
Shrub cover	%	arc-sin [$\sqrt{}$(x/100)]
Green shrub cover	%	arc-sin [$\sqrt{}$(x/100)]
Average height of shrubs	Cm	$\log_{10}$ [x+1]
Herb cover	%	arc-sin [$\sqrt{}$(x/100)]
Green herb cover	%	arc-sin [$\sqrt{}$(x/100)]
Average height of herbs	cm	$\log_{10}$ [x+1]

3. Results

3.1. Habitat typing of colonies

Altogether, we recorded 23 colonies of Cabrera voles, one of which was only present in summer and another one only in winter (Fig. 2). Colonies tended to be spatially aggregated in small clusters, always occurring in habitat conditions characterised by hight superficial groundwater table, supporting relatively humid tall-her communities with or without scattered shrubs. Most colonies were associated to small intermittent streams (52.2%) and temporarily flooded soil depressions (18.2%) with sedge and rush communities, which in many cases (68.8%) were grazed by cattle. A further 30.4% of the colonies were found in nitrophile plant communities of agricultural field margins or road verges. Altogether, about 78.3% of the colonies had some kind of agricultural interference.

Colonies size averaged 1928.3m^2±21.2m^2 (standard error), ranging between 134.3 and 3401.6m^2. The number of distinct cores within each colony, i.e. areas where pathways go deeper in the soil towards subterranean galleries and burrows, was variable. Most of the colonies were composed by 1 core (69.6%), but in some cases, we identified 2 (21.7%) and 3 (8.7%) distinct cores. Mean distance (± standard error) to the nearest colony was 363.3±54.3m, ranging from 184 to 976m.

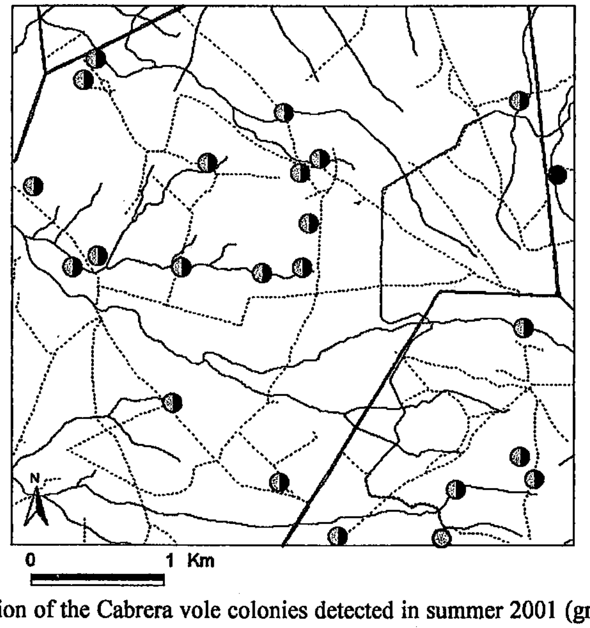

Figure 2 - Location of the Cabrera vole colonies detected in summer 2001 (grey and half grey circles) and winter 2002 (black and half black circles) in a 16km^2 area in south-west Portugal. Black thick lines are paved roads, dashed lines are dirt roads and full thin lines are streams.

3.2. Microhabitat use

In both seasons, some microhabitat variables were strongly intercorrelated, and so they were not used in further analysis. This was the case for the cover by green shrubs and shrub height, which showed high rank correlations (R_s>0.95) with overall shrub cover, and the number of southern water vole droppings, which was highly rank correlated (R_s>0.80) with the length tracks made by the species. The analyses for the remaining variables indicated that sites used by Cabrera voles in summer had a significantly higher herbaceous cover and those herbs were taller than in unused sites (Table 2). The same pattern was apparent in winter, when there was also evidence for reduced shrub cover in used sites (Table 3). Southern water vole tracks were always absent from sites used by Cabrera voles, though they were present nearby four colonies during the summer (in five sampling plots) and three colonies during the winter (in four sampling plots). Sites where the southern water vole occurred, presented relatively high mean (±standard error) herbaceous cover (100±0%) and height (69.21±3.18cm), and low shrub cover (1.59±0.59%).

Activity levels of the Cabrera vole, measured by the length of pathways in the vegetation, were positively related with the height of the herbaceous layer in sites used during the summer (Table 4). In winter, there was a positive relationship with herbaceous cover and herbs height.

Table 2

Comparison of microhabitat variables between sites used and unused by Cabrera voles during the summer 2001, in southwest Portugal. Statistics were based on mixed-effects ANOVA.

	Used sites (n = 115)			Unused sites (n=61)				
Variables	average ± sd error	min.	max.	average ± sd error	min.	max.	*F*	*p*
Shrub cover	6.7±1.2	0.0	57.1	9.1±2.3	0.0	71.4	1.41	0.236
Herb cover	98.6±0.4	71.4	100.0	83.8±3.3	0.0	100.0	34.51	<0.0001
Green herb cover	43.4±12.4	0.0	100.0	37.2±4.2	0.0	100.0	1.67	0.197
Herb height	39.7±1.4	4.3	94.0	22.1±2.1	0.0	70.1	57.22	<0.0001
Water vole tracks	0.0	0.0	0.0	12.5±5.7	0.0	211.0	-	-

Table 3

Comparison of microhabitat variables between sites used and unused by Cabrera voles during the winter 2002, in southwest Portugal. Statistics were based on mixed-effects ANOVA.

	Used sites (n = 109)			Unused sites (n = 67)				
Variables	average ± sd error	min.	max.	average ± sd error	min.	max.	*F*	*p*
Shrub cover	5.0±1.4	0.0	85.7	9.0±2.3	0.0	71.4	3.99	0.047
Herb cover	99.1±0.4	71.4	100.0	80.6±3.6	0.0	100.0	35.49	<0.0001
Green herb cover	36.5±2.8	0.0	100.0	43.1±4.0	0.0	100.0	0.99	0.322
Herb height	34.0±1.5	6.4	76.6	26.7±3.0	0.0	114.0	15.39	0.0001
Water vole tracks	0.0	0.0	0.0	8.2±4.0	0.0	162.0	-	-

Table 4

Linear regression analysis for the effects of microhabitat variables on the activity levels of Cabrera voles, as measured by the length of its tracks. Statistics are based on mixed-effects linear models.

	Variables	Coefficients of the model	Sd errors of coefficients	*t*-value	*p*-value
Summer	*Herb height*	0.35	0.10	3.31	0.0013
Winter	*Herb cover*	0.34	0.17	1.97	0.049
	Herb height	0.37	0.09	4.35	0.0001

3.3. Seasonal variations

Although we found slightly more used sites in summer than in winter (Tables 2 and 3), the mean (± standard error) activity level of the Cabrera vole, measured by the length of its tracks, was significantly higher (F=5.11; p=0.029) in winter (118.2±0.83cm per plot) than in summer (96.9±3.34cm per plot). The corresponding difference regarding vole droppings (46±0.4 versus 60±0.6 droppings per plot) was not significant (F=2.08; p=0.15). Microhabitat features did not vary in used sites between summer and winter (Tables 2 and 3) in the case of shrub cover (F=0.58, p=0.45), herb cover (F=0.77, p=0.38) and green herb cover (F=0.28, p=0.59). For herb height, however, there was a tendency F=3.43, p=0.07) for higher values in summer than in winter.

4. Discussion

4.1. Microhabitat use in space and time

The occurrence of Cabrera vole colonies in the studied agricultural landscape was restricted to specific areas sharing a set of particular local conditions. Favourable habitats were associated mainly to sedge rush and grassy areas along streams, soil depressions, ditches and agricultural field margins consisting of tall-herb vegetation in fence-lines, and road or track verges. These habitats were patchily distributed and embedded in an inhospitable matrix of human managed lands. Furthermore, the availability of these habitat patches through time seemed to be dynamic, as they may be destroyed due to agricultural and pastoral activities. Despite this, comparing with observations made by San Miguel (1992) in Spanish populations, colonies surveyed here were relatively large. Although probably overestimated, due to the applied estimation approach, these dimensions may still suggest reasonable availability of habitat-patches in the studied landscape. Particularly, the large dimensions of habitat-patches allowed the occurrence of large colonies, some of which encompassing two or three distinct cores. Within favourable habitat-patches the microhabitat use by the Cabrera vole occurred at fine spatial scales. Vegetation characteristics at sites where voles were present differed from the unused sites, suggesting that this species responds to specific microhabitat features. Indeed, the presence of Cabrera voles was associated with small micro-patches of grasses covering about 100% of the surface and reaching mean heights around 35-40cm both during the summer and winter, tending to be absent if herbs were sparse and shorter than about 30 cm. Furthermore, vole activity levels increased with herb coverage (on winter) and height (on both seasons). Such low variation among the type of microhabitat underlies a refined microhabitat specialisation, which is thought to reflect specific demands concerning both the refuge conditions against predators and the suitability of food resources available. These observations agree with earlier descriptive statements on the favourable habitats for the Cabrera vole (e.g. Ayanz, 1994; Fernández-Salvador, 1998; Mathias et al., 1998), and seem to conform to the general view that most *Microtus* voles have evolved in grasslands that provide considerable cover (Wolf, 1999). Contrary to the predictions of other authors (Ayans, 1994; Fernández-Salvador, 1998), however, the dominance of green herbs, showed no effect on voles presence and activity level, which may underlie a higher tolerance by the Cabrera vole to dryer conditions than previously thought. In winter the shrub cover was smaller in used sites, which may reflect the avoidance of potential refuges for mammalian predators, as suggested for other grassland voles (e.g. Gliwicz and Jancewicz, 2003). In alternative, this result may simply reflect the competition between the shrub and herbaceous strata for space, light and nutrients, resulting in a smaller quantity and quality of herbs upon which the Cabrera vole seems to be more dependent.

Results from this study also support the possibility of competition between the Cabrera vole and the southern water vole, since in sites where one species was present, the other was always absent. Although, few sites were occupied by the water vole, this species used largely similar microhabitats, with very dense cover by tall herbs, suggesting that habitat requirements of both species might overlap in some extend. Indeed, although the water vole is considered a more strictly water dependent species (Madureira and Ramalhinho, 1987), it may persist in the face seasonal droughts typical of some Mediterranean areas (Fedriani at al. 2002). This fact narrows the ecological similarities between species, and in sympatric areas, spatial overlapping may be reduced by a higher competitive ability of the water vole over the Cabrera vole, due to the larger size of the former, as suggested by Ayanz (1994) and Fernandez-Salvador (1998).

More Cabrera vole signs were found in winter than in summer, suggesting that hot and dry periods may be less favourable for this species than cold and moist periods. This was also suggested by other authors, who observed a decrease of activity signs in the field in summer (e.g. Ayanz, 1994; Ventura et al., 1998). According to Ayans (1994), during this season, at least the above ground activity reduces in such a way that it can even stop completely. Also Ventura et al. (1998) refer that the dryness conditions on summer, reduces not only the spatial activity but also the reproductive one. No significant changes between summer and winter were recorded in the selected microhabitat descriptors in used sites. Nevertheless, the apparent tendency for higher herbs during the summer might underlie either an attempt of the Cabrera vole to reduce the dryness effect, or a more slippery behaviour from predators and thus a decrease in above ground activity. Yet, other factors not treated in this study must be considered in future research aiming to identify the causes of the seasonal variations in Cabrera voles' activity. These should include other microhabitat characteristics (e.g. soil humidity and temperature, microclimate conditions and plant composition), population parameters (e.g. density, survival and reproduction) and interspecific interactions (competition, predation and parasitism).

4.2. Conservation Implications

Humid, seasonally-flooded or waterlogged grassy habitats are globally less common in Europe than they were in the past, as a result of land use changes (Stoate, 2001; Gliwicz and Jancewicz, 2003). In the Mediterranean these habitats are very attractive for cultivation and pasturing and so they tend to be quickly lost in intensively farmed landscapes (e.g. Stoate et al., 2001; Beja and Alcazar, 2003; Ortega et al., 2004). For the Cabrera vole, intensification is thus likely to interfere with critical habitats and thereby with local ability of persistence., Indeed the conversion of humid grasslands into arable lands and permanent pastures is thought to be one of the main reason for declines in Cabrera vole populations (Fernández-Salvador, 1998; Ventura et al., 1998; Landete-Castillejos et al, 2000). Indeed, as a specialist living in a landscape consisting of critical habitat-patches embedded in an inhospitable matrix, the Cabrera vole is expected to be highly susceptible to habitat changes either due to natural instability or to human agricultural activities (Andreassen and Ims, 1998; Batzli et al., 1999; Millan de la Peña et al., 2003). On the other hand total abandonment of agriculture is also expected to bring negative effects on certain vole populations, since it would result in a rapid development of shrub cover and loss of the herb diversity typical of traditional arable rotations and extensive grazing.

In the studied landscape the main changes on habitat-patches for the Cabrera vole are associated with a growing area under permanent cultivation and increased livestock density, with the consequent reduction in lightly grazed fallows, field margins and other herbaceous habitats. Therefore, the patches of tall herbs required by the Cabrera vole are becoming too small and too ephemeral, as they are frequently destroyed due to agricultural activities and livestock grazing. Conservation of Cabrera voles in the farmed landscape may thus require some kind of agri-environmental scheme supporting extensive practices, whereby farmers could be compensated for maintaining patches of favourable habitat. Given the results of the present study, these should be grassy patches, preferentially larger than 2000 m^2, composed by a dense (about 100%) stratum of tall herbs (> 30 cm). These patches could be located along field margins and along road verges, drainage ditches and small streams, increasing connectivity across the landscape. Patches could be established through natural regeneration, but afterwards it might be necessary to manage these extensively in order to assure favourable local conditions for the species. In particular, management should include extensive grazing or mechanical cutting in order to prevent scrub encroachment. The optimal spatial arrangement of habitat patches should also be considered in the future, requiring that further information is collected on the ideal distance between habitat patches and matrix conditions favouring successful dispersal and migratory movements of animals.

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Patch use by the Cabrera vole in a Mediterranean agro-ecosystem: the role of local attributes and landscape context

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Abstract

In intensive agro-ecosystems, species of conservation concern are often known to persist in small habitat-patches amid an inhospitable matrix, though the abundance and spatial arrangement of favourable patches required for species persistence is generally unknown. This is the case of the Cabrera vole, which is threatened by the loss and fragmentation of humid tall-herb communities due to agricultural intensification. We analysed the population spatial structure of this species and the relationship between patch use and variables describing patch and landscape attributes. This was based on a three-year data set (2002-2004) of quarterly surveys made in an agricultural landscape of south-west Portugal. Patch isolation, but not patch size, had an important effect in determining presences. At the landscape level, areas used for intensive pasturing showed a negative effect on occupancy status of patches, whereas extensive pastures seemed to favour vole's occurrences. Scrubland cover nearby habitat patches appeared to have a negative effect on patch occupancy, eventually due to increased predation risk by small carnivores. The patch size and its distance to the nearest stream were, respectively, positively and negatively correlated with the degree by which each patch was used. These results point out the importance of spatial processes in determining patch occupancy patterns by the Cabrera vole, suggesting that key metapopulation processes might be at play. The conservation of this species in agricultural landscapes may thus require the maintenance of high connectivity between habitat patches, thereby decreasing the probability of local extinctions and increasing the likelihood of colonization of empty patches.

Key-words: Spatial structured populations, Cabrera vole, Agricultural landscapes, Agricultural management

1. Introduction

Land use patterns are widely recognised as major factors determining species distribution and abundance (Zebisch et al., 2004). In agricultural landscapes, habitat loss and fragmentation due to intensification of human management practices, have dictated rapid decreases in biodiversity world-wide (e.g. Stoate, 2001). In particular, cumulative habitat loss and fragmentation are believed to result in serious problems for the persistence of many threatened species (Danielson and Anderson, 1999), through the increase of local extinction risk (Alonso and McKane, 2002). Analysing and modelling the dynamics of threatened species that often persist in highly fragmented agricultural landscapes, are critical steps to the modern practice of species conservation and suitable habitat management in human dominated landscapes (MacCullough, 1996).

Conservation planning often relies on the knowledge of where, and in what numbers, species are to be found, and how their distributions will be affected by human interventions (Macdonald and Rushton, 2003). Most studies aiming to describe species responses to fragmentation are highly embedded on the metapopulation thinking and analysis, and have emphasised the under-utilisation by many species of available high quality resources (e.g. Hokit et al., 2001). This is thought to result from species' inability to find those resources or to fully exploit them (Danielson and Anderson, 1999), as a response to fragmentation and landscape context. Many studies on species' patch-occupancy patterns using presence/absence data at one point in time ("snapshoting"), have lead to the developed of useful predictive models able to describe local colonisation-extinction processes (e.g. Gotelli and Kelley, 1993; Hanski, 1994; Moilanen, 1999: Ovaskeinen and Hansky, 2001; Ovaskeinen and Hansky, 2004) and to address suitable conservation strategies (e.g. Lindenmayer and Poosinghan, 1996; Hanski, 2000; Hokit et al., 2001; Lopez and Pfister, 2001; Sauchik et al., 2002; Anthes et al., 2003). These models are often based on the incidence of species and usually consider some particular set of discrete and permanent habitat-patches such as islands (e.g. York at al., 1996; Crone et al, 2001; Banks et al., 2004), ponds (e.g. Sjogren-Gulve and Ray, 1996), or forest fragments (e.g. Lawes et al., 2000; Hames, et. al., 2001; Virgós and García, 2002). Main outcomes of such kind of models emphasise the importance of size and isolation of habitat patches on the rates of extinction and colonisation processes. Despite their utility and their ability to incorporate information on habitat quality of patches (e.g. Moillanen, 2002; Hanski and Ovaskainen, 2003), incidence-based models still present certain limitations in describing species space use in temporally dynamic landscapes where patches arise and disappear on a regular basis over certain periods of time (e.g., see Danielson and Anderson, 1999; Telfer et al., 2001; Wahlberg at al., 2002; Snall et al., 2005). A further problem is that incidence-based models assume that populations are at equilibrium and each patch is thought to have particular probabilities of extinction and (re)colonisation (Hanski, 1994; Hanski 1997; Moillanen, 2000). Furthermore, turn-over rates are expected to result from stochastic processes, rather than from deterministic causes (e.g. habitat changes) (e.g. Marsh and Trenham, 2001). These assumptions are difficult to accept for species of conservation concern existing in dynamic landscapes, where patch availability is continually changing due either to natural disturbance or to frequent management interference (e.g. Telfer et al., 2001). For such a system, the traditional metapopulation modelling approaches might be hardly practicable, since past and current human changes in land uses are expected to be main influences in species ability to use particular habitat patches and hence to persist both at the local and the regional level (Snall et al., 2005). Therefore, a good approach to study spatially structured populations might rely on spatial analyses that emphasise the importance of local and landscape features upon species persistence ability, keeping in mind the basic predictions of metapopulation models. This is probably most relevant for specialist species, particularly for those threatened by intensification of human management practices, and for which little is known on their basic biological and ecological traits.

The Cabrera vole *Microtus cabrerae* (Thomas, 1909) is a threatened arvicoline (SNPRCN, 1990 and Palomo and Gisbert, 2002) endemic to the Iberian Peninsula and restricted to the meso-Mediterranean bioclimatic zones (Rivas-Martinez, 1981). This species forms discrete and easily recognise breeding colonies and is considered a habitat specialist, largely dependent on Mediterranean dense and tall humid grasslands (San Miguel, 1992; Fernåndez-Salvador, 1998; Landette-Castillejos et al., 2003; Santos et al. in press; Pita et al., 2005). In agricultural landscapes the intensification of land and water management are pointed out as main threats for this small mammal, due to habitat loss and fragmentation through the conversion of suitable habitat-patches into farmed or grazed land (Fernandéz-Salvador et al., 1997; Landette-Castillos et al., 2003). For this reason, the present distribution of the Cabrera vole is patchy and populations seem to be decreasing rapidly (Ventura et al., 1998; Landette-Castillos et al., 2003). The temporary nature of suitable habitats for the Cabrera vole in agro-ecosystems suggests that this species may be submitted to extinctions/(re)colonisations dynamics, which might be affected by temporary appearance/disappearance of favourable patches (Pita et al. 2005). Thus, despite the deviations from the classical concept of metapopulation, which implies the presence of a static and clearly defined set of habitat-patches (Hanski, 1996; Baguette, 2004), a broader application of this concept (Telfer et al., 2001) may point out the Cabrera vole as a good candidate for the metapopulation approach.

In this study we evaluated the responses of the Cabrera vole to the highly dynamic mosaic landscapes typical of south-west Portuguese agro-ecosystems. In these areas, voles are typically associated to patches of dense/tall grasses and rushes embedded in an inhospitable matrix (Pita et al., 2005). The spatial distribution of patches tends to be highly dynamic, since they are frequently destroyed due to agricultural and pastoral activities, but may recover thereafter if these cease for a sufficiently long period. This suggests that the Cabrera vole might have a complex extinction-colonization dynamics in agricultural landscapes, which might have far-reaching consequences for its conservation. Therefore, in the present study, we aimed (i) to model the dynamics of patch-occupancy by the Cabrera vole in relation to patch spatio-temporal availability, size and isolation, as well as with the landscape features in the surrounding areas of the patch; (ii) to evaluate which of these features most determine the degree by which each patch is used. By knowing in advance the Cabrera vole's basic needs to persist in fragmented agricultural landscapes, we might advocate proper landscape designs that encompass the size, number, and spatial distribution and arrangement of suitable habitat patches.

2. Material and methods

2.1. Study area

The study was carried out in a 16 km^2 area of an agricultural landscape in south-west Portugal (fig. 1). Climate is typically Mediterranean with average annual rainfall ranging around 700 mm and average monthly temperatures between 6°C (during the coldest season) and 29°C (during the hottest season) (Neves, 1995). In this plain area, human settlements are sparse and activities are generally restricted to cattle production, wood production, and agriculture, which, though mainly extensive and traditional, is at present facing a rapid intensification (Beja and Alcazar, 2003). Remaining areas are kept as fallows and a few fragments are dominated by scrubland. Thus, six main land uses systems may be recognised: agricultural, pastures, forestry, fallows, scrubland, and urban (fig. 1). Agricultural category includes land units cultivated with cereals, irrigated crops, fodder, silage, or sunflowers. Pastures are characterised by natural, semi-natural and cultivated grasslands or other types of herbaceous communities, and are mainly devoted to cattle production. Forestry category comprises eucalyptus and pines plantations and strips. Fallows are open areas with relatively uniform vegetation that are inactive or abandoned and may or may not have been planted in the past to a cover crop. Scrubland encompasses bramble thickets of *Rubus* spp., acacias *Acacia* spp., or other types of brushy communities. Urban category includes both habitations and agricultural warehouses.

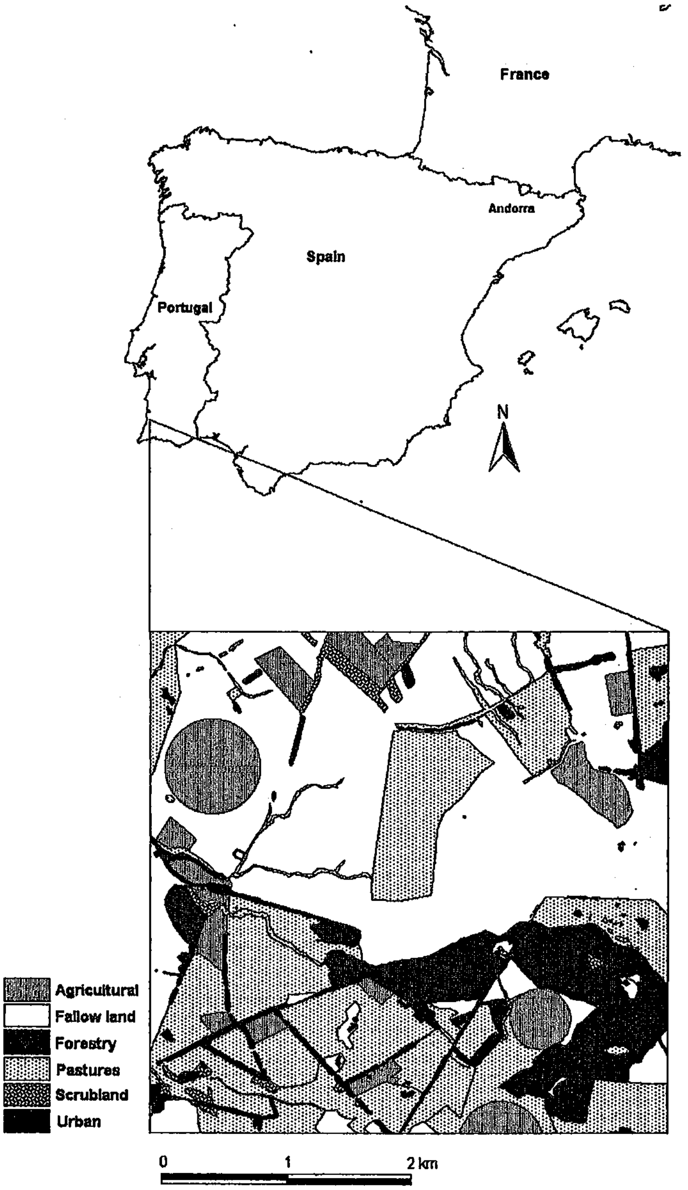

Fig. 1 - Study area location and most important land uses.

2.2. Habitat survey

The study of patch use by the Cabrera vole was made in 12 sampling occasions carried out at 2,7±0.03 (mean±sd) months intervals from February/2002 till September/2004. At each sampling occasion potential habitats for the Cabrera vole were identified according former studies on the Cabrera vole habitat requirements (e.g. San Miguel, 1992; Fernández-Salvador, 1998; Landette-Castillos et al., 2003; Santos et al., in press; Pita et al., 2005). These studies suggest that the Cabrera vole seems to be restricted to areas with superficial groundwater table, supporting dense, tall and wet grasses (e.g. San Miguel, 1992; Fernández-Salvador, 1998; Landette-Castillejos et al., 2003; Santos et al., in press). This was also the case for the present study area (Pita et al., 2005), where these kinds of grassland patches occur as marginal habitats in the farmed landscape, and where its spatial distribution is highly dynamic due primarily to natural vegetation succession to the scrub stage and the frequent agricultural management. Identification of suitable habitats was thus made by interpreting the data on (i) the known habitat requirements of the species using information derived from detailed field studies, and (ii) the perceive of the temporal dynamics of the suitability of habitat for the Cabrera vole in response to disturbances. Thus, potential habitat-patches included all dense (about 100% of cover) and tall (mean height around 30-40 cm) grassy communities close to small streams and temporarily flooded or waterlogged soil depressions with sedge and rush communities, as well as nitrophile grasslands in agricultural field margins, ditches and road verges (Pita et al, 2005).

2.3. Cabrera vole survey

The patch use by the Cabrera vole was made using species-specific sign surveys, particularly searches of the typical surface indices such as droppings and tunnels made on grasses (e.g. San Miguel, 1992). In each sampling occasion, all potential habitat-patches were target of an intensive inspection of vole's signs, covering the whole surface of the fragments. For each occupied patch, the relative abundance or observational activity of voles was assessed, using an activity-index similar to that of San Miguel (1992). Resembling approaches have been successfully used to assess the relative abundance of other *Microtus* species (e.g. Delattre et al., 1996; Petty et al. 2000; Sherratt et al. 2000). The modified activity-index of San Miguel (1992) is similarly based on the conspicuousness and freshness of presence signs and ranged from 1 (low) to 4 (very high) (Table 1). In order to reduce the subjectivity inherent to this activity-scale, activity levels in each patch were always classified by the same observer. To classify an "absence", patches were surveyed unsuccessfully at least two times in each sampling occasion.

Table 1

Activity index used to classify the surface activity of Cabrera voles in an agricultural area in southwest Portugal. (modified from San Miguel, 1992).

Level of activity	Description	Score
Very high	*High abundance of pathways or tunnels on the ground and on grasses; high abundance of fresh droppings and traces of gnawed fresh vegetation.*	4
High	*Abundance of pathways or tunnels on the ground and on grasses; abundance of droppings, most of which are fresh; recent traces of gnawed fresh vegetation are rare.*	3
Medium	*Pathways or tunnels on the ground or grasses, as well as droppings are easily found; some of droppings are recent, although there are no signs of recent traces of gnawed fresh vegetation.*	2
Low	*Few observable pathways or tunnels on the ground or grasses; few droppings, most of which are old.*	1
Absent	*There are no defined pathways or tunnels on the ground or grasses, and droppings, if present, are residual and very old.*	0

2.4. Patch persistence, size and isolation measures

For each habitat patch, a set of variables related to its temporal availability (persistence), size and isolation were quantified. The persistence of each patch was evaluated because it might be expected that the ephemeral quality of suitable habitats will emphasise the degree to which the temporal heterogeneity of the landscape affects local occupancy. This variable was estimated as the proportion of sampling occasions in which the patch retained potentially favourable conditions for the Cabrera vole.

Patch size and isolation were assessed because these descriptors might give important clues for the evaluation of spatially structured populations, being key explanatory features determining metapopulational processes. The estimation of patch size was made using a size-class scale to account for potential small-scale fluctuations (Table 2), due to management interference (Fernandéz-Salvador et al., 1997; Landette-Castillos et al., 2003) or seasonal effects (San Miguel, 1992, Ventura et al., 1998). This means that size variations on each particular patch were ignored, even though such variations might be quite informative respecting the effects of demographic and environmental stochasticity on local populations (e.g. Moilanen, 2002). Isolation was measured as the linear distance (in meters) to the nearest fragment irrespective of its occupation status and the land use between fragments. For patches in the edges of the study area, for which the nearest patch is not known, isolation was set as the average distance estimated for all known cases.

Table 2

Patch size-class scale adopted to describe the size of each habitat-patch

Patch size-class	Measures	Score
Small	< 500 m^2	1
Medium	500 - 1000 m^2	2
Medium-large	1000 - 2000 m^2	3
Large	2000 - 3000 m^2	4
Very large	> 3000 m^2	5

2.5. Landscape survey

At a landscape-level, factors such as the type of habitat in close proximity can affect occurrence or persistence of species within a patch (e.g. Dellatre et al., 1996; Wolff et al., 2002; Weyrauch et al., 2004). Therefore, land uses are other relevant spatial structures were mapped in the study area and incorporated into a Geographical Information System. Distance to the nearest stream was measured (in meters), because previous studies referred that colonies are likely associated to the hydrographical networks (e.g. Fernandéz-Salvador, 1998). Land use information was accounted in buffers with 150 meters of radius around the centre of each habitat-patch, to allow the characterisation of neighbouring areas. The classification of land uses was made considering the general proposes of each landscape element and accounting for the degree of shifting/rotation regimes. Landscape elements were thus classified according

9 categories, which were chosen to reflect either the landscape structure or the degree of human intervention (Table 3).

Table 3

Classes of land uses used to characterised each 150 m-radius buffer around the centre of each patch

Land use	Description
Intensive farmland	*Fields intensively cultivated with cereals, irrigated crops, fodder, silage, or sunflowers, over short-time rotation processes*
Extensive farmland	*Fields used for the production of cereal, crop, fodder, silage, or sunflower on a fallow-cultivation seasonal rotation basis*
Permanent pasture	*Fields used as permanent cattle pastures*
Temporary pasture	*Fields used as extensive cattle pastures, on a fallow-pasture basis*
Scrubland	*Patches of brambles, acacias, or other types of brushy communities*
Pine	*Pinus* sp plantations
Eucalyptus	*Eucalyptus* spp. *plantations*
Fallow land	*Fields dominated by grasses, typical of early stages of succession, that were abandoned from any kind of human exploitation*
Urban	*Human buildings, either habitations or agricultural warehouses*

2.6. Statistical analysis

Descriptive statistics was used to characterise the study system in terms of patch-availability-occupancy dynamics over the three studied years, i.e. accounting for the number of habitat-patches, the fraction of occupied patches, and the turn-over dynamics.

Occupancy status was assessed for each patch by compiling overall data and classifying each fragment as occupied, if it showed presence of Cabrera voles in at least one occasion, and unoccupied if the voles were always absent. Because of the dichotomous nature of this response variable, logistic regression was used to model the Cabrera vole occurrence in the studied landscape as a function of patch and landscape context descriptors. The presence/absence of the Cabrera vole was used as the dependent variable and all patch and surrounding landscape descriptors were treated as independent variables. Identification of eventual collinearities between explanatory descriptors was assessed computing a

Spearman correlation matrix (R_s, Siegel and Castellan, 1988), and retaining only one variable from each highly inter-correlated pair of variables ($R_s \geq 0.7$, Tabachnik and Fidell, 1996). Moreover, only independent variables for which the Wald test (e.g. Cumming, 2000) of univariate regressions was significant at 0.25 significance level, were considered for subsequent multivariate logistic regression. Stepwise forward procedures were then computed for the selection of independent variables, starting with an empty model and adding descriptors one-at-a-time. The significance of each predictor was assessed using the Wald statistics, and setting a p-value<0.05 for the inclusion of variables and a p-value>0.10 for removal operations.

The fitness of the final model was assessed by the area under the ROC curve (AUC). The global significance of the models coefficients was evaluated through a chi-square test for the significance of the likelihood-ratio decrease. We also look at the rate of correct classifications considering the overall data, the presences (sensitivity) and the absences (specificity), using the frequency of presences (0.56) as the cut value (e.g. Fielding and Bell, 1997; Cumming, 2000). Association between observed and predicted responses was evaluated using Phi correlation coefficient (Siegel and Castellan, 1988). We also use Nagelkerke's R-Square as a measure of model performance. The final model was subjected to a cross-validating Jacknife procedure (e.g. Knapp and Preisler, 1999). In this procedure, data from one patch were deleted from the data set and the model was recalculated without information concerning that particular patch. Model-based predictions for each case were then compared with true presence/absence data. Phi correlation coefficient was computed to evaluate the similarity between observed and predicted values, which indicates how confident we can be that there is a relationship between both variables.

The linear association between patch use by the Cabrera vole and independent variables was analysed computing Spearman correlation coefficients (R_s), considering only occupied patches. As dependent variable, we estimated for each patch an utilisation index, which was assumed to reflect the local persistence ability and the degree of activity by the Cabrera vole in each fragment. This use index was estimated as the product of the frequency of patch occupancy and the mean score on observational activity recorded in each presence occasion. Independent variables were again all patch and surrounding landscape descriptors.

All analyses were carried out using SPSS for Windows (12.0) statistical package (SPSS, 2001).

3. Results

3.1. Overall patterns of patch occupancy

Considering the three years of study, the presence of the Cabrera vole was recorded in 62% of the habitat patches surveyed (n=57). Mean (± standard error) number of habitat patches surveyed by sampling occasion was 45.25±0.52 and about 54% of the monitored habitat patches persisted throughout the three years of study. The frequency of occupied patches ranged between 0.40 and 0.52, decreasing about 22% over the course of the three studied years (fig. 3). Extinction events determined the loss of 18 colonies, of which 10 were stochastic extinctions (disappearance from suitable habitat patches) and 8 were deterministic extinctions (disappearance due to habitat degradation through overgrazing or abandonment, or to habitat destruction through ditch clearance operations, burnings or ploughings). Colonisations totalled 13 events, of which 3 were re-colonisations.

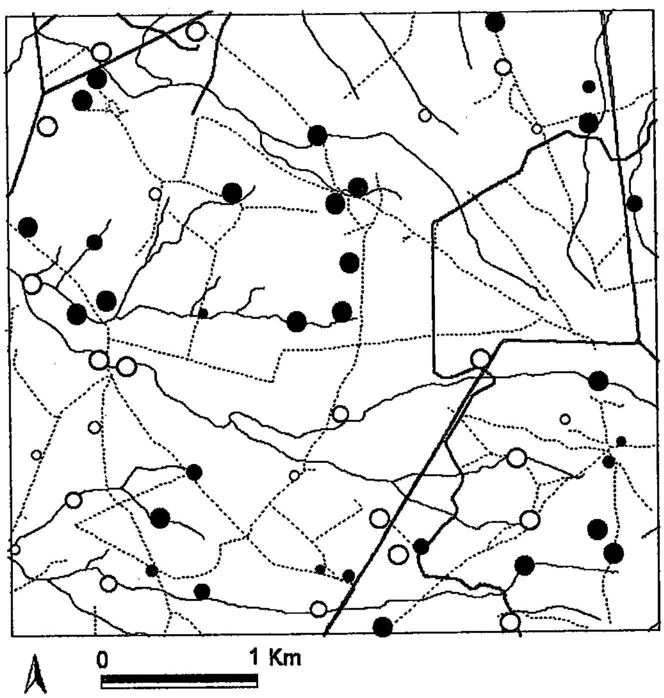

Fig. 2 – Sketch map of the study area with locations of the potential habitat patches monitored (circles). The size of each circle is proportional to the frequency of patch persistence throughout the three years of the study. From the 57 fragments surveyed, 32 (black circles) were occupied by the Cabrera vole during at least one sampling occasion, and 25 (grey circles) were always empty. Black thick lines are paved roads, dashed lines are dirt roads and full thin lines are streams.

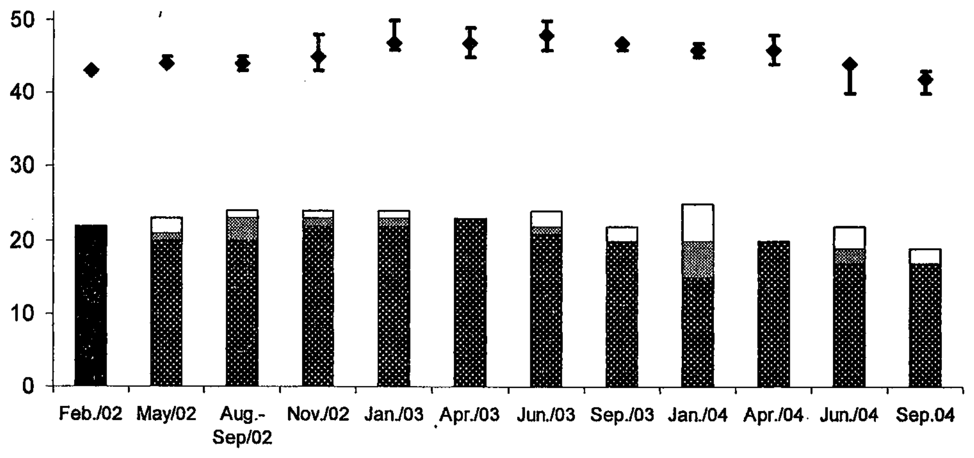

Fig. 3 – Life history of the study system: ■ Starting condition – number of occupied patches in the first survey; ▩ Number of current occupied patches, also occupied in the survey before; ▩ Number of colonisations; □ Number of extinctions; ◆ Number of available patches (bars indicate the turn-over; upper – number of new patches; lower – number of senescent patches

3.2. Determinants of patch occupancy

Table 4 summarises average values (± standard errors) of independent variables, according the presence/absence status of the surveyed habitat patches. Spearman coefficients showed no high correlations between any pair of independent variables (R_s<0.7 for all possible correlations). Results on univariate logistic regressions and on candidate variables for the multivariate model are also presented on Table 4. Forward stepwise analyses selected the following four variables: *isolation, permanent pasture, temporary pasture* and *scrubland* (Table 5). The AUROC, the chi-square test for the significance of the likelihood decrease, the Nagelkerke R square, and the proportion of correct classifications all indicate that the model is well fitted (Table 5). Phi correlation coefficient computed between observed and expected values, according the validating Jacknife procedure, suggest that the model has a good prediction power (Table 5).

Table 4

Mean (± standard errors) values of independent variables, for occupied and unoccupied patches. Landscape attributes concerning land uses refer to cover percentages. A summary of the results of univariate logistic regressions is also presented. Variables significant at $p<0.25$ (represented in bold) were retained for further analysis.

				Univariate regressions resume		
		Presence (n= 32)	Absence (n=25)	Coeficient	Wald	p-value
Patch attributes	***Persistence***	**0.84 (± 0.21)**	**0.74 (± 0.11)**	**0.81**	**1.41**	**0.236**
	Size	2.55 (± 1.92)	2.31 (± 0.20)	0.12	0.01	0.942
	Isolation	**290.74 (± 1.83)**	**377.15 (± 2.17)**	**-4.59**	**5.54**	**0.019**
Landscape attributes	*Distance to nearest stream*	95.16 (± 0.09)	86.00 (± 1.92)	-0.22	0.48	0.487
	Intensive farmland	**4.33 (± 0.59)**	**10.84 (± 0.77)**	**-2.31**	**3.95**	**0.047**
	Extensive farmland	**4.09 (± 0.67)**	**0.20 (± 0.20)**	**4.24**	**1.49**	**0.223**
	Permanent pasture	**9.62 (± 0.84)**	**35.02 (± 1.15)**	**-1.86**	**7.61**	**0.006**
	Temporary pasture	**32.07 (± 1.11)**	**5.02 (± 0.72)**	**2.97**	**7.28**	**0.007**
	Scrubland	**1.27 (± 0.36)**	**3.36 (± 0.51)**	**-4.31**	**3.51**	**0.061**
	Pine	**0.59 (± 0.27)**	**2.42 (± 0.45)**	**-6.26**	**3.74**	**0.053**
	Eucalyptus	14.96 (± 0.92)	13.32 (± 0.91)	0.14	0.04	0.850
	Fallow land	32.83 (± 1.04)	29.65 (± 1.15)	0.07	0.02	0.894
	Urban	0.38 (± 0.17)	0.16 (± 0.12)	3.65	0.40	0.529

Table 5

Summary statistics of the multivariate stepwise logistic regression model

	Coeficient	Wald	p-value
Constant	21.84	8.57	0.003
Isolation	-8.46	8.29	0.004
Permanent pasture	-2.51	6.41	0.011
Temporary pasture	4.72	6.58	0.010
Scrubland	-5.46	4.26	0.039

AUROC=0.833 (P<0.001); Qui-square =36.89 ($p<0.001$); Nagelkerke R-square=0.64; Correct classifications: overall=85.96%, presences=81.25%, absences=92.00%; Phi=0.72 (p<0.001).

3.3. Vole's activity

Positive moderate correlations ($0.5<R_s<0.7$, according e.g. Tabachnik and Fidell, 1996) were found between the USE indexes and the size of habitat patches (R_s=0.54; p=0.001). The distance of patches to streams was negatively, and also moderately, correlated with patch utilisation by the Cabrera vole (R_s=-0.52; p=0.002) (see figure 4). No other tested correlations proved to be significant.

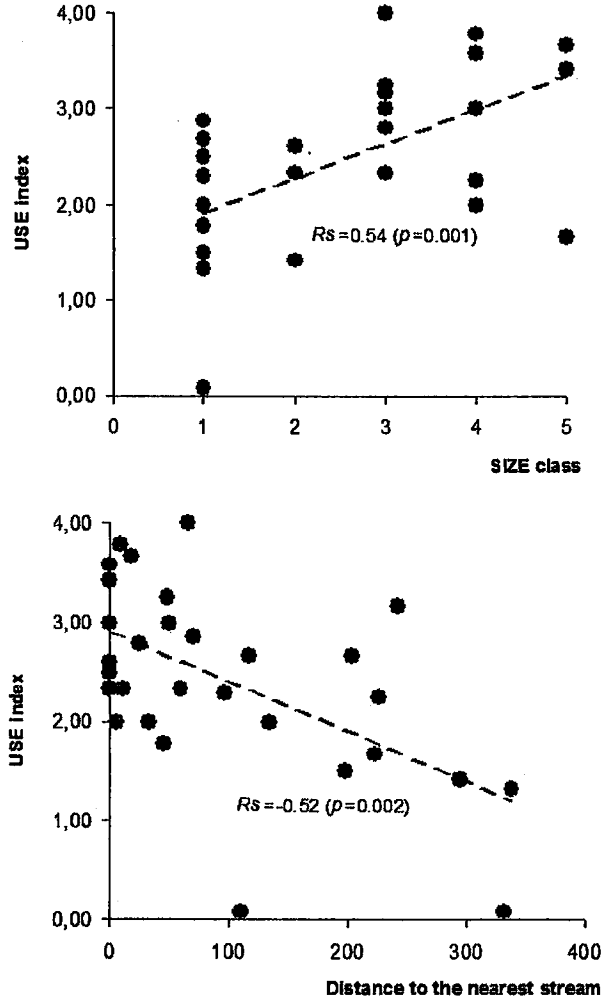

Fig. 4 – Scaterplots relating use indexes with size class of habitat-patches and with the distance to the nearest stream. Respective spearman correlations (R_s) are also presented.

4. Discussion

4.1. Population structure of the Cabrera vole

In the studied landscape of south-west Portugal, suitable dense and tall Mediterranean humid grasslands for the Cabrera vole occurred always in discrete and marginal patches within a matrix of inhospitable habitats. Moreover, the availability of these patches changed over time, reflecting the temporary nature of the habitat-systems associated to the Cabrera vole in highly managed landscapes (Pita et al, 2005). The overall observed spatio-temporal distribution of colonies suggested that the regional persistence of the studied population might be influenced by local processes of extinction, colonisation and migration, and that this spatially structured population approaches a metapopulation structure. Nevertheless, the low turn-over rates on patch occupancy patterns, prevented us to assess analytically the interplay between extinctions and colonisations, as successfully done in many studies inspired on the metapopulation concept (e.g. Crone et al, 2001; Andreassen and Ims, 2003). Indeed, occupied patches tended to remain occupied, whereas empty patches tended to remain empty. The low number of extinctions, of which a substantial fraction was thought to be deterministic, is for sure related with the expected higher probability of a patch to be occupied if occupied in the previous survey (e.g. Telfer et al., 2001). On the other hand, colonisation events might be more common in patches formerly occupied than in patches never or few times occupied. As suggested for other rodents (Rushton et al., 2000 and references therein) it is possible that the Cabrera vole might also mark their home ranges with scent-marked latrines, so olfaction, and hence past experience of the landscape, might play a major role in patch-occupancy pattern. Therefore, extinctions and colonisation events were not sufficiently common to accurately predict a trend on population parameters, although the balance observed between extinctions and colonisations, which seemed to favour extinction events, suggests that the population is not at equilibrium (e.g. Hansky, 1994; Moilanen, 2000). A prolongation of the study period will probably allow a clearest identification of the population stochastic turn-over patterns, and hence a better picture of the patch occupancy dynamics. In fact, the observed reduced colonisation and extinction events may be simply associated with time-scale constrains. Therefore, in order to properly assess the spatial dynamics of the Cabrera vole, we need more long-term studies based on more demographic parameters and preferentially coupled with individual based models (e.g. Kostova et al., 2003; Ovaskeinen and Hanski, 2004) supported on capture-recapture techniques and radiotraking technologies.

4.2. Determinants of patch occupancy and vole's activity

In the studied system, patch occupancy patterns, and hence regional population processes, were influenced either by patch or surrounding landscape attributes. According to the logistic model, population persistence seemed to be influenced by the degree of isolation between habitat patches and by the land use regimes around them. In particular, the pasturing regimes and the proportion of scrublands apparently affected the occupancy status of habitat patches.

As expected from the predictions of the metapopulation theory, voles were more likely to occupy less isolated areas, probably because more isolated fragments have a reduced chance of colonisation. This aspect is of major importance in the context of habitat fragmentation, since it will determine the capability of persistence and the distribution of the Cabrera vole at the regional scale. Thus patch isolation should be viewed as an important feature driving the Cabrera vole distribution, as demonstrated for other spatially structured rodent populations (e.g. Walker et al., 2003). In contrast to the predictions of the metapopulation theory, according our model, the size of habitat patches had no effect on occupancy of fragments and hence on the persistence of the Cabrera vole. Nevertheless it should be noted that the measure used to describe the patch utilisation by the Cabrera vole was positively correlated with the size of habitat patches. This indicates that size may not determine the presence and the distribution of the Cabrera vole, although small patches are likely to be less used or to have lower abundances than larger fragments. Also, in contrast to expectations, patch occupancy was not affected by the persistence of the habitat patch. This is probably due to the strong unpredictability of the type of habitat-systems to which the Cabrera vole is associated in agro-ecosystems. Indeed, habitat patches may appear and disappear quite rapidly, especially in landscapes where high management inputs interfere either directly or indirectly with potential suitable habitat. Thus, the Cabrera vole might be unlike to perceive dramatic changes in advance, or to predict the life-time of a particular habitat patch.

Concerning landscape attributes, the distance of habitat patches to the nearest water valley, i.e. to wetlands, had no effect on patch occupancy status. However, a negative correlation was observed with measurements of patch utilisation, suggesting that the proximity with permanent or temporary small streams might influence positively voles' abundance.

Intensive pasturing regimes within and around habitat patches appeared to influence negatively the local occupancy. This result reinforces the notion that livestock can alter the spatial behaviour in voles (e.g. Jacob and Hempel, 2002), and supports earlier predictions about the potential effects of overgrazing upon the Cabrera vole (e.g. Fernández-Salvador, 1998; Pita et al., 2005). These effects include the removal and/or destruction by consumption and/or treading of a great amount of grasses, on which voles are thought to be more dependent. Thus either within the patch or in adjacent areas, i.e. either directly or by increasing both the edge and the isolation effects, overgrazing appeared to affect negatively voles' persistence, through habitat degradation. On the contrary, the presence of low input pasturing regimes seemed to favour the persistence of the Cabrera vole at a regional scale. As appointed in Pita et al. (2005), extensive grazing of natural or semi-natural grasslands might favour the Cabrera vole, by preventing habitat degradation through natural succession of vegetation structure.

The amount of scrublands in the landscape also appeared to affect negatively the occupancy status of habitat patches. This might reflect not only the likely impoverishment in amount and diversity of herbaceous stratum, but also the avoidance of predators (anti-predatory response). Indeed, beyond birds and snakes, the Cabrera vole is predated by virtually all middle-sized carnivorous mammals, which are expected to use preferentially scrubland fragments (e.g. Fedriani et al., 1999).

Although in unoccupied patches larger amounts of intensive farmland and pine plantations were observed at adjacent areas, that difference was not sufficient to predict the occupancy status of habitat-patches according the final model of the logistic regression. However, as revealed by the results of univariate logistic regressions, intensification of farming practices and forestation with pines are expected to affect negatively the presence of the voles, by decreasing availability of food, cover, and sometimes nesting sites for voles (e.g. Sullivan et al., 1998; Jacob and Hempel, 2002; Jacob, 2003). These results are of major concern in face of the present national incitements to agriculture intensification and forestation of abandoned agricultural fields (RURIS, 2002), practices that, at present are widely spread out in south-west Portuguese landscapes.

Despite the good predictive power of the model developed here, it should be emphasised that other influences may contribute to how frequently a site is occupied. Further studies should include e.g. an exhaustive evaluation of the vegetation composition at habitat patch (e.g. Santos et al., in press), the food availability (e.g. Costa et al.,), and the presence/absence of predators or potential competitors, either conspecific or not.

4.3. Conservation

From the present study, several considerations concerning the conservation of the Cabrera vole populations might be added to the ones enumerated by Pita et al. (2005), which respected mainly within patch management practices. Indeed, the presented approach might serve to allocate suitable designs of land use and management within agro-ecosystems, in order to increase the chances of regional persistence of the Cabrera vole.

Considering that typically the effects of isolation are characteristic of species with lower dispersal capability (Virgós and García, 2002), we suspect that the spatial arrangement of suitable habitat patches might be crucial for the effectiveness of voles movements between fragments, and hence for the long-term survival of the Cabrera vole populations. In this study we found that, ideally, distances between habitat-patches above 300m should be view in advance as potentially critical, although we still want to reinforce the importance of individual based models to assess the extend of migratory movements by the Cabrera vole (e.g. applying radiotraking techniques). In order to increase connectivity between habitat-patches, grassy margins around arable fields or pastures, and along grassy waterways or roadside verges, should be retained as uncultivated edge vegetation.

Given the possible positive effects of nearby streams upon patch utilisation by voles, fragments associated with the landscape hydrographical network should be prioritised for the habitat restoration purposes referred in Pita et al. (2005), which basically pointed out the importance of low input management practices within or interfering with potential habitat-patches.

Conservation measures should also take into account the land use patterns, towards the reduction of intensive management regimes and the incentive of rotational schemes. This is probably most relevant concerning cattle pasturing, which if done extensively may favour the Cabrera vole populations. Concerning the extension of scrubland around habitat-patches, given its importance to a wide range of species, and hence to the increment of biodiversity at the regional level, these type of habitats should be keep untouched. Nevertheless, elimination of scrubland should be considered if formerly occupied areas are abandoned and kept indefinitely as fallows tending to progress to advanced stages of succession.

To conclude, it should be noted that target patches for habitat management purposes, either sedge rush or grassy areas along the water-valleys network, soil depressions, ditches or agricultural field margins, may be empty for long periods. In fact, the conciliation between human management practices and what are suitable habitats for the Cabrera vole does not necessarily mean that individuals will be capable of utilising all resources available. This situation is driven from the spatial population structure of the Cabrera vole showed in this study, which was based the metapopulation concept. From this approach, it can be stated that a conservation strategy for the Cabrera vole should not be focused on optimising patch habitat quality only, and should include also a network of connected habitat patches, whether or not currently occupied.

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General Discussion

During the last decades the problem of biodiversity declines on European farmlands has been generally identified and research has aimed to assess the magnitude of the overall problem. This has been done keeping in mind the possibility of modify specific aspects of agricultural management to provide benefits for wildlife (Benton et. al., 2003). In the Mediterranean, and particularly in the south part, one major risk to the biodiversity today derives from excessive intensification of land use systems (Blondel & Aronson, 1999). The understanding of who species respond to human land management and the recognition of the interplay with the conservation of the biodiversity is a central goal in ecological research. In the present research, we attempted to address the question of how conservation can take place on a regional scale in Mediterranean agro-ecosystems, treating the Cabrera vole as a focal species. The Cabrera vole was chosen not only for its current conservation status, and hence urgent need for basic information upon the species, but also because this small mammal might be a good ecological model to test the effects of agricultural intensification in the Mediterranean. The research aimed to get information concerning the spatial ecology of the Cabrera vole in an agriculture landscape of south-west Portugal, in order to outline a conservation plan for this small mammal. Two different spatial scales were considered in two distinct stages. Firstly we assessed the microhabitat features that determine the space use by the cabrera vole within suitable habitat patches. Secondly we evaluated the population structure of the Cabrera vole at the regional level and identified the landscape determinants of populations' persistence.

Towards the need for basic information about the spatial requirements of the Cabrera vole, these two perspectives seemed a good solution to approach this species' spatial needs.

The study was carried out in an agricultural landscape of south-west Portugal. In this region the development of agricultural activities during the last decades has contributed to the disappearance or circumscription of many water-saturated areas, since that the viable development of certain agricultural species implied the drainage of the soil, changing the original moisture conditions (Neves, 1995). Therefore, south-west Portugal landscapes seemed adequate to evaluate how the Cabrera vole might respond to habitat changes.

Concerning habitat and microhabitat use by the Cabrera vole, results confirmed that the Cabrera vole is very selective towards certain types of habitats, such as wet grass meadows, sedge rush communities and grassy agricultural field margins. Habitat patches were relatively large and hence colonies dimensions were also large comparing with other studies. Mixed effect linear modelling revealed that for both seasons the Cabrera vole activity uses preferentially sites with dense (near 100% of cover) and tall herbs (around 30cm on average) except when the southern water vole, *Arvicola sapidus* Miller 1908, was present. Voles were more active during the winter, in accordance with elsewhere findings (e.g. Fernández-Salvador, 1998).

Considering the landscape level, results provided evidence that in agricultural landscapes, land use patterns are important determinants of habitat-patch utilisation by the Cabrera vole. Furthermore, overall data indicated that the studied population might be viewed as an interesting variant of the typical assumptions of the metapopulation theory. Logistic regression revealed that patch isolation had an important affect in the occupancy status of habitat-patches. The context where habitat-patches occurred also affected the occurrence of voles. We found that permanent pastures and scrublands showed a negative effect on the presence of the Cabrera vole. The interference of intensive pasturing upon habitat patches and neighbouring areas was thought to result in the decrease of habitat quality through herb consumption and treading. The apparent avoidance of scrublands might be related with avoidance from middle-sized mammal predators. The extensive pasturing favoured the occurrence of the Cabrera vole, suggesting that low-input regimes may prevent certain types of suitable habitats to progress into advanced stages of vegetation succession. Results showed positive correlations between patch size and the degree by which it is used by the Cabrera vole. This last variable was also correlated, though negatively, with the distance to small streams suggesting that the proximity to water might influence positively this small mammal. We stated the importance of the metapopulation concepts to understand the dynamics of the Cabrera vole and the influence of the landscape context upon the ability of persistence of the species at a regional scale.

In the face of the results gathered in the presented research, and considering the increased human management inputs upon the typical habitats of the Cabrera vole, we recommend the establishment of a conservation plan for the species in agricultural landscapes. This conservation plan is recommended to have two different scale approaches. Firstly, potential suitable habitat-patches should be target of protection, restoration and management actions. Secondly, thought equally important, the spatial arrangement of habitat-patches and the landscape context in which they are embedded should considered both the increment of connectivity among fragments, and the adequacy of human management practices. Globally, recommendations for a conservation plan towards the Cabrera vole can be resumed in the fallowing guiding ideas:

(1) Suitable habitat patches should consist of ample grassy areas, composed by tall herbs covering 100% of the surface;

(2) High quality habitats providence should consider not only the protection of all natural and semi-natural wet grasslands holding sedge rush communities, but also the possibility of habitat restoration, specially grassy communities nearby small streams, agricultural field margins and road verges;

(3) Patches can be established through natural regeneration, but after the habitat-patch has been established, it might be necessary to managed it extensively through extensive grazing;

(4) Connectivity between habitat-patches might be achieved by retaining herbaceous vegetation around arable fields or pastures as uncultivated edge vegetation;

(5) Spatial arrangement of habitat-patches within agricultural landscapes should consider the distance between them, which is recommended in advance to be below 300m;

(6) Land use context of habitat-patches should account for low-input management practices, especially concerning pasture regimes.

Overall, the presented research reported that a conservation strategy for the Cabrera vole should be focused either on optimising within patch habitat quality, inter-patch distance or landscape context. Our approach strongly supported the idea that, in the context of agriculture intensification and biodiversity conservation in Mediterranean landscapes, the Cabrera vole might be considered a useful focal species for the conservation of Mediterranean damped grasslands.

To conclude, it should be noted that our results reinforced the idea that the patterns of land management in Mediterranean agro-ecosystems account to the occurrence, distribution and persistency of threatened species. Therefore, in the face of the present efforts towards the compatibility between biological conservation and the necessary increase in agricultural production (REF), researches aiming to assess the space use by species might be a critical step to minimise the effects of habitat loss and fragmentation. .

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