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Analysis of habitat selection by wild rabbits in intensive agricultural areas

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Autor: Alba María Cobos García

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GENERAL INDEX

FIGURES INDEX

TABLES INDEX

ABSTRACT

The wild rabbit (*Oryctolagus cuniculus*) is a key species for the proper functioning of the ecosystem and one of the most valued small game preys. In the 1950s and 1980s, rabbit populations suffered a major decline due to the appearance of two viral diseases: myxomatosis and hemorrhagic fever. This fall in populations endangered the species itself and other species for which it is the main food source, such as the emblematic Iberian lynx (*Lynx pardinus*). However, even though in many regions the rabbit is still a scarce species, a rebound in populations is being observed in areas of intensive agriculture in the semi-arid Mediterranean climate in the south of the Iberian Peninsula. In these areas, rabbits can proliferate rapidly due to the availability of water, food, shelter and low hunting or predator pressure, causing significant damage to agricultural crops, which translates into economic losses, making the rabbit a pest species. The aim of this study is to analyse, within a study area where intensive agricultural practices are carried out, which are the habitats most selected by this species and the mechanisms and motivations involved in the process. To this end, we selected one rabbits´ population and fitted it with radio-collars that allowed tracking them to gather information on the use of the different habitats available and the roosting area per individual. The results show an overall tendency towards olive groves, being the most abundant crop, but we found significant differences at the individual level that indicate selection towards other habitat types such as vineyards.

Keywords: European wild rabbit; *Oryctolagus cuniculus*; Habitat preference; agriculture damage.

RESUMEN

El conejo de monte (*Oryctolagus cuniculus*) es una especie clave para el correcto funcionamiento del ecosistema y una de las principales presas de caza menor más valoradas en la península ibérica. Entre los años 1950 y 1980 las poblaciones de conejos sufrieron un gran declive por la aparición de dos enfermedades víricas: la mixomatosis y la enfermedad hemorrágica del conejo. Esta caída de poblaciones puso en peligro de extinción a la propia especie y a otras para las que supone el alimento principal como el emblemático lince ibérico (*Lynx pardinus*). Sin embargo, a pesar de que en muchas regiones el conejo sigue siendo una especie escasa, se está observando un repunte de poblaciones en zonas de agricultura intensiva de clima semi-árido Mediterráneo, al sur de la península ibérica. En estas zonas el conejo es capaz de proliferar rápidamente debido a la disponibilidad de agua, alimento, refugio y a la baja presión cinegética o de depredadores, causando importantes daños en los cultivos agrícolas que se traducen en pérdidas económicas, considerándose así el conejo una especie plaga. En este estudio se pretende analizar, dentro de un área de agricultura intensiva, cuáles son los hábitats más seleccionados por esta especie y los mecanismos y motivaciones implicados en el proceso. Para ello seleccionamos una población de conejos a los que colocamos radio-collares para poder localizarlos y así recopilar información del uso de los distintos hábitats disponibles y el área de campeo por individuo. Los resultados nos muestran una tendencia global hacia las zonas de olivar, siendo además el cultivo más abundante, pero encontrando diferencias significativas a nivel individual que indican selección hacia los demás tipos de hábitats como el viñedo.

Palabras clave: Conejo de monte; *Oryctolagus cuniculus*; preferencia de hábitat; daño en la agricultura.

INTRODUCTION

The European rabbit (*Oryctolagus cuniculus*) is a keystone species in Mediterranean ecosystems. First, they are prey to around 30 predators, providing the food base of some very important species such as the Iberian lynx (*Lynx pardinus*) and they also play a role as ecosystem engineers. For instance, some of their activities such as herbivory, seed dispersal, digging (warren building and scratching), and depositing faeces, mainly at latrines have a major benefit on the ecosystem (Delibes-Mateos et al., 2008, 2014a). Furthermore, rabbits represent one of the most valuable small game species (Delibes-Mateos et al., 2011) and, therefore, also has cultural and economic importance and impact in the two Iberian countries (Delibes-Mateos et al., 2014a, 2018).

In the last decades, most Iberian rabbit populations have declined drastically mainly due to habitat loss and the arrival of two viral diseases: myxomatosis in the 1950s and rabbit haemorrhagic disease (RHD) at the end of the 1980s (Delibes-Mateos et al., 2009; Moreno et al., 2007) being one of the causes that brought the Iberian lynx to the brink of extinction. Recently, the outbreak of a new variant of RHD which spread rapidly worldwide (Rouco et al., 2019c) has reduced rabbit populations in the two Iberian countries to levels that are affecting ecosystem functioning (Delibes-Mateos et al., 2014b; Monterroso et al., 2016). By contrary, even though most rabbit populations are still declining in the Iberian Peninsula recovery of some of them has been observed in some areas of southern Spain (Carpio et al., 2017a; Delibes-Mateos et al., 2018). This recovery is mostly associated with non-fragmented landscapes, interspersed patches of Mediterranean scrubland, good pastures and/or crops, soft soils that are suitable for warren construction and a Mediterranean climate with relatively high rainfall. Furthermore, low hunting pressure, habitat management and predator control are some management practices which favour the presence and increase of rabbit populations in certain areas, particularly in farmland (Delibes-Mateos et al., 2009, 2014a). However, although it would be seen as a benefit to the ecosystem it is causing damage to crops, through grazing or browsing, prompting complaints from farmers (Delibes-Mateos et al., 2018). It causes agricultural production damage (Lees & Bell, 2008). Pest species are those that, at least locally, exhibit too high densities and cause economic or ecological harm to humans (Stenseth & Hansson, 1981) therefore, wild rabbits are considered as a pest (Barrio et al., 2010, 2012; Delibes-Mateos et al., 2014a, 2018), like one of the most damaging (Smith et al., 2007). Moreover, another characteristic that make rabbits an even more dangerous pest, is its plasticity to adapt to a wide variety of environmental conditions, so it has been successfully introduced around the world (Barrio et al., 2011).

Due to its status and importance as a keystone species and main small game prey, the wild rabbit is a dangerous and difficult pest species to manage. It needs to be treated in a manner that does not lead to its uncontrolled decline or extinction as this could cause devastating damage to the ecosystem (Delibes-Mateos et al., 2018). For instance, if the presence of rabbits decline, consequently, the populations of predators that prey upon rabbits may decline as well. In this way, opportunistic mesopredator species could proliferate without a top predator to limit them, causing an imbalance in the ecosystem.

The presence of rabbits not only has consequences for crops and damage to infrastructures such as railways or roads but can also have direct consequences for humans as transmitters of diseases. The European rabbit can weaken or even destroy crops by scratching and burrowing which encourage the presence of weeds (Delibes-Mateos et al., 2018). Pest explosions may be related to a combination of specific environmental conditions. It has been studied that rabbit damage is more common in crops of the central-southern region, most semi-arid ones, of Spain where farming dominates, natural vegetation is scarce (Delibes-Mateos et al., 2018) and where crops provide food and the remnants of natural vegetation and the margins of fields offer shelter and breeding sites (Calvete et al., 2004). In this sense, rabbits are considered a generalist agricultural pest harming a variety of different crops. There is a positive relationship between rabbits' densities and the presence of woody crops (Delibes-Mateos et al., 2010) like olive groves or vineyards which account for most of the cultivated land in the country. It has been reported notable reduction in woody crop yields in some agricultural regions (Real et al., 2009) which in some cases like Montilla-Moriles (Córdoba) wine-growing region in southern Spain where the 98% of the area is devoted to this type of crops (Barrio et al., 2013).

Why rabbits have moved and proliferated in these anthropogenic areas instead of remaining in wild territories is mainly related to two factors: changes in human land use and climatic factors which are also interrelated. Certain human activities cause the degradation of natural communities and ecosystems, favouring the expansion and high densities of generalist species (Goodrich & Buskirk, 1995), and intensively managed ecosystems can provide gaps for opportunistic species (Vitousek et al., 1997) such as the wild rabbit. Rabbits damaged have been directly related with intensive agriculture practices (Delibes-Mateos et al., 2018; Barrio et al., 2013) like the removal of natural vegetation cover and weeds. The intensification of agriculture not only leads to a huge increase in food production, but also has serious environmental consequences (Matson et al., 1997). Therefore, in intensive agricultural areas (Barrio et al., 2010) practices are carried out that result in the extreme simplification of agricultural landscapes (Barrio et al., 2013), leading to the loss of biodiversity in the area (McLaughlin & Mineau, 1995). By eliminating the rabbits' alternative food, which is precisely these weeds, by abusing the use of herbicides, the rabbits come to the crops causing more damage.

Landscape and habitat characteristics are known to significantly affect the distribution of rabbits (Rogers, 1981). For example, the presence of rabbits´ warrens has been related to the proximity or the existence to motorways or railways. near to these places the environment conditions are appropriate for rabbits to succeed (Delibes-Mateos et al., 2018). are used as ecological corridors that facilitate its dispersion (e.g., Harrison et al., 2002; Hansen & Clevenger, 2005; Brown et al., 2006; Ascensão & Capinha, 2017; Hägerling & Ebersole, 2017) allowing their movement across physical and environmental barriers (Rouco et al., 2019b). Moreover, these infrastructures usually pass through or are close to crop areas from which the rabbits also obtain food (Barrio et al., 2013) where they will proliferate and cause serious problems.

On another hand, a consequence of geo-ecological factors (e.g., lithology, topography, and climatology) and changes in land use and vegetation cover is the soil erosion, one of the most serious and widespread environmental threats in the Mediterranean Basin (García-Ruiz, 2010). These changes in land use are characterized by the intensification and mechanization of ploughing and the use of herbicides in the last decades (Carpio et al., 2020). This has resulted in an increasing area of bare soils, which has provoked and accelerated the soil loss and degradation in agricultural land and finally leads in economic and environmental impacts (Symeonakis et al., 2007; Panagos et al., 2018). One of these economics and environmental impacts are visible in the olive-growing areas of Andalusia (southern Spain) (Milgroom et al., 2007; Gómez et al., 2014) where these types of crops dominate the landscape (18% of the total regional surface) (CAGPDS (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible)). Facing this problem, it has been observed that the use of cover crops in the lanes of olive groves are beneficial by reducing soil erosion (Gómez et al., 2009a, 2009b) and increasing the biodiversity (Carpio et al.,2017b; Gómez et al., 2018). However, in highly degraded soils (owing to compaction, poor soil fertility and the loss of seed banks) together with overgrazing due to the high abundance of European rabbits make it very difficult to establish an herbaceous cover with a significant effect on reducing water erosion in these olive crops (Guerrero-Casado et al., 2015). Thus, climate changes and soil management are key factors to determined rabbits´ populations densities and localization and therefore also determine the intensity and extent of their impact on the ecosystem, society, and the economy.

Habitat selection informs how organisms evolve and use the environment around them. Analysing and understanding the mechanisms and motivations that lead a population to select a particular area is a powerful tool (Montgomery & Roloff, 2013, 2017). Habitat selection research often compares the habitat that an organism selects to habitat that is available, the presence of an organism is assumed to be an act of selection for that habitat (Montgomery & Roloff, 2017). Therefore, effective management of vertebrate pests in agricultural systems should incorporate knowledge of temporal and spatial dynamics of such pest species (Van Vuren & Smallwood, 1996). In this sense, understanding space use of rabbits in these areas may contribute to the design of effective management aimed at mitigating their impacts.

However, most rabbit habitat preferences studies were conducted in areas where the species has been introduced (Hulbert et al., 1996; Stott, 2003; White et al., 2003; Moseby et al., 2005; Devillard et al., 2008) or in semi-natural habitats within its native range (Villafuerte, 1994; Lombardi et al., 2007). Yet, knowledge from agricultural areas within its native range where they cause damage to crops is neglected. Habitat selection is a function of habitat productivity, resource distribution, the area used during migration or dispersal periods, or individual energy requirements (McLoughlin & Ferguson, 2000; Mitchell & Powell, 2004). Thus, it is an incredibly powerful area of research that has the potential to inform ecologist through analysis of organism–habitat associations (Montgomery & Roloff, 2017).

OBJETIVES

The aim of the present study is to analyse how a wild rabbit population select among a variety of habitats withing an agricultural intensive-managed area. The main objective is to obtain information on which crops are most selected in order to identify the areas most vulnerable to rabbit damage.

This work can serve as a basis for future research into the management and control of this and other pests. In addition, measures to reduce the damage caused by this pest are discussed.

MATERIALS Y METHODS

Study area

The study was carried out in an intensive agricultural area located in the province of Cordoba, southern Spain (37º 33´N, 4º 37´W). This area is characterised by dry Mediterranean climate, with moderate temperatures in winter and very strong temperatures in summer reaching over 40°C, and with low annual rainfall, on average 500 mm. The predominant crops in these intensive agricultural areas are olive groves, vineyards, and cereals crops.

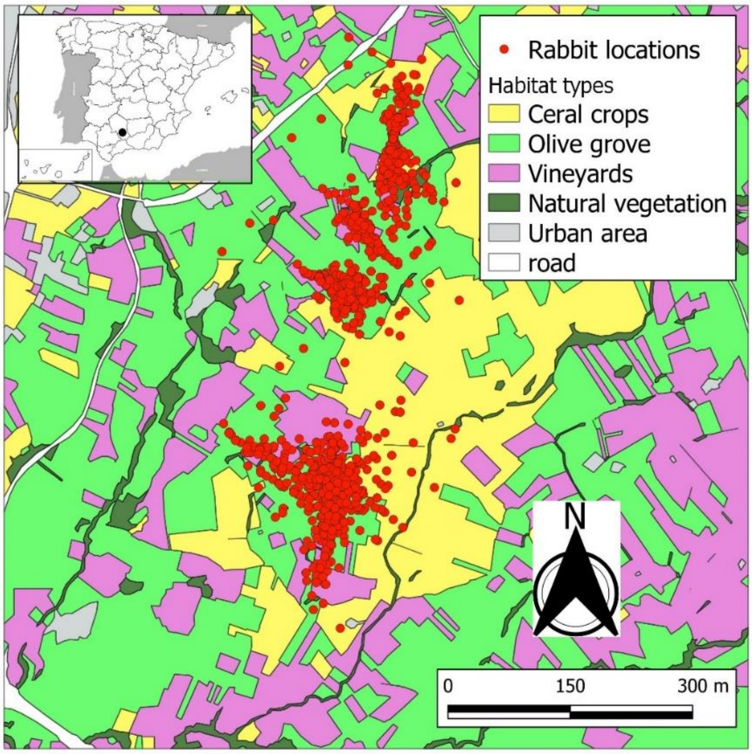

Figure 1. Location of the study area in the Iberian Peninsula in an intensive agriculture area in the province of Cordoba, southern Spain (37º 33'N, 4º 37'W). The location of each rabbit is marked with a red dot and the different types of habitats are represented by different colours: cereal crops (yellow), olive grove (green), vineyards (pink), natural vegetation (dark green), urban area (grey) and road (white).

Rabbit monitoring

We captured rabbits through ferreting; this technique consisted of introducing a ferret (*Mustela furo*) in one rabbit warrens hole and place nets on the remaining holes, to trap the rabbits when they try to scape due to the presence of the ferret (Cowan, 1984). Once captured, we weighed and sexed all the rabbits, and we fitted with a radio collar (AVM Instrument Company, Ltd., USA) 30 adults of them. For tracking the animals, we used a portable receiver (R-1000 Communications Specialists, Inc., California, U.S.A.) and a handheld three-element Yagi antenna (BIOTRACK, Wareham, UK) with transmitters' frequencies within the 150–152 MHz range. Every day, we located each rabbit from at least two mapped receiving points by using standard triangulation techniques for mobile triangulation systems (White & Garrot, 1990). For location error of triangulation measurements see Rouco et al., (2019a). Due to collar failure, we manage to collect location data from 20 animals out of the 30 animals originally tagged. Three months after the experiment ended, we removed the radio collars (excepted for the missing ones).

Data analysis

Home range size estimation

We estimated home range sizes areas for each rabbit using the 95% Minimum Convex Polygon method (MCP) (Devillard et al.,2008). Although the MCP has been criticized because it includes areas rarely visited and thus may overestimate home range (Laver & Kelly, 2008), but other methods, like kernels or the k-nearest neighbours convex hull, are sensitive to aggregated data, with potential lack of convergence in the smoothing parameters (Devillard et al., 2008). Since we only used locations collected during the day, data was expected to be highly aggregated. We used the adehabitatHR package (Calenge, 2006).

To calculate the appropriate number of locations needed to correctly estimate home range size we followed the incremental area analysis (Kenward, 2001), which assumes that home range estimates reach an asymptote with an adequate sample size. For each rabbit, we drew the relationship between the estimated 95% MCP home range size and the number of locations used in the estimation, with a bootstrapping approach (500 random samples of *k* locations, varying *k* from 5 to the total number of locations for each rabbit). For each value of *k* we estimated the mean 95% MCP over the 500 bootstrap samples. The appropriate number of locations k_{opt} to estimate home range size for each rabbit was the value of *k* for which the estimated home range size was at least equal to 95% of the home range size estimated with the full set of locations (i.e., when the asymptote is reached, Devillard et al., 2008). The median value of k_{opt} was 18.5 locations.

Habitat preference

We used five habitat classes in the analysis: cereal crops (crop), olive groves (oli), vineyards (vin), natural vegetation (nat) and roads outcrops (rd) according to the distribution areas of the rabbits within study area, except the road which was available but not used for the animals. We identified the five habitat types by digitising habitat types from orthorestricted aerial photographs and converting them to a rasterised habitat map (5m resolution) using QGis Desktop 3.22.7 (Quantum GIS Development Team, 2022). We based habitat preference analyses on two approaches depending on the data source. *Design II* was applied to tracking data for each individual, assuming that all habitat types available within study area, were equally available to all the monitored rabbits, specifying individual variations in the selection of each type of habitat available. And *Design III* was applied to the home ranges of each animal, considering that each animal has a different availability weight according to their home ranges (Calenge & Dufour, 2006).

For both designs, we used QGis software to calculate habitat used we overlaid triangulation locations from collared rabbits on the habitat map and calculated the proportion of locations in each habitat type. To calculate the habitat available for *Design II* we plotted 1000 random points across the study site and calculated the proportion of plotted points in each habitat type (at 5m resolution). To calculate the habitat available for *Design III* we plotted an average of 36 random points within the home range of each animal and calculated the proportion of points in each habitat type (at 5m resolution).

We compared, for both designs, the habitat types used and available using Manly selection ratios (Manly et al., 2002). For the selection ratios for *Design II*, we tested of identical habitat use for all animals (Chi-square L1 test), and of overall habitat selection (Chi-square L2 test). For the selection ratios for *Design III*, habitat selection was tested using a Chi-square for each animal (Chi-square Lj test) (see Manly et al., 2002 for further details). All these methods rely on the assumptions of independence between animals, and that all animals are selecting habitat in the same way, including that no territoriality exists, and the fact that all animals having equal access to all available resource units (see Manly et al., 2002 for further details).

If preferences differed between individuals after running Manly selection ratios tests, we carried out a factorial analysis using an eigenanalysis (Calenge & Dufour 2006). Eigenanalysis is an extension of principal component analysis and displays habitat preference graphically. This is a useful tool for investigating variability in habitat preference between individuals, and for identifying groups of individuals that choose the same habitat. The analysis assigns scores that maximise the squared deviation between individuals. It also assigns scores to the habitat types that maximise the squared distance between the habitats that are used in proportion to their availability. (Calenge & Dufour, 2006) The analysis produces plots that are explained by two factors or axes (factorial axis 1 – the x-axis, and factorial axis 2 – the y-axis). The first factorial axis is for habitat types that are selected the most. We carried out all analyses using the adehabitatHS package (Calenge, 2006). We carried out all statistical analysis in the R statistical computing environment (v.4.0.2, 2020; R Core Team).

RESULTS

The study area selected for this work contained four major habitat types (olive groves, vineyards, cereal crops and natural vegetation) representative of the typical intensive agricultural landscape in southern Spain. The presence of crops stands out, with olive groves representing 48.84%, cereal crops 30.75% and vineyards 17.57% of the total study area. Areas of natural vegetation and roads were represented to a lesser extent, with 2.33% and 0.52% respectively (Figure 2.).

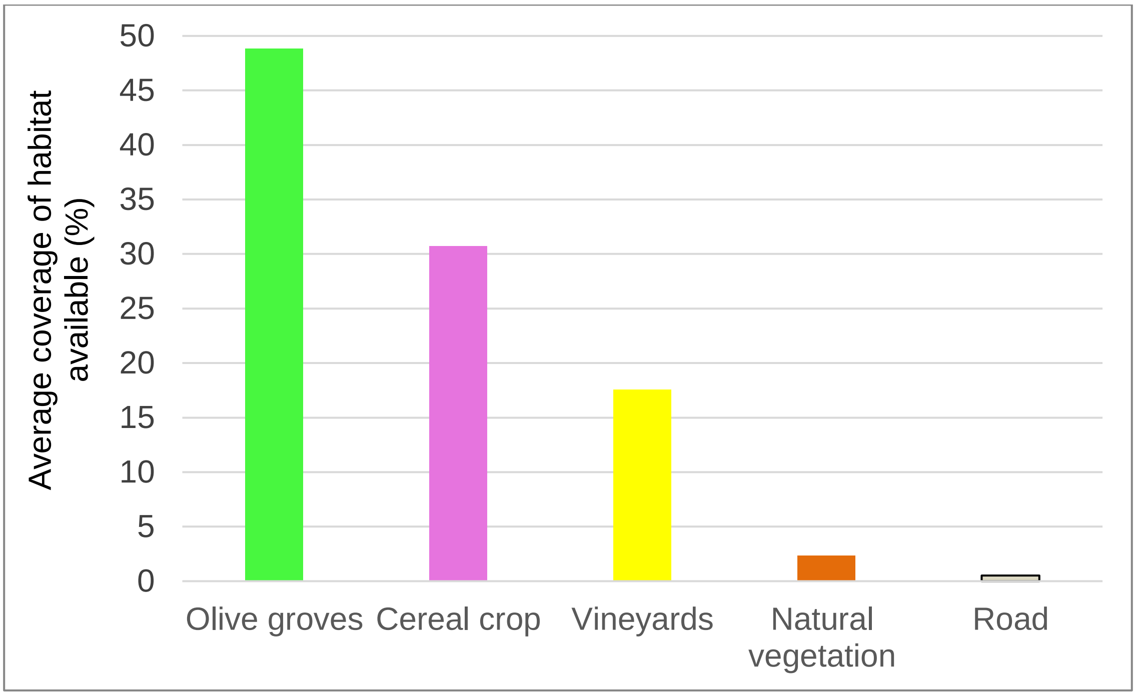

Figure 2. Habitats available within study area. There are 5 different types of habitats shown which are equally available to all individuals: olive groves (oli: 48.84%), cereal crop (crop: 30.75%), vineyards (vin: 17.57%), natural vegetation (nat: 2.33%) and road (rd: 0.52%) that make up 100% of the study area.

Our results showed an overall preference for olive groves habitats by rabbits and an avoidance to the rest of the available habitats (Figure 3). However, for both designs we found individual variability.

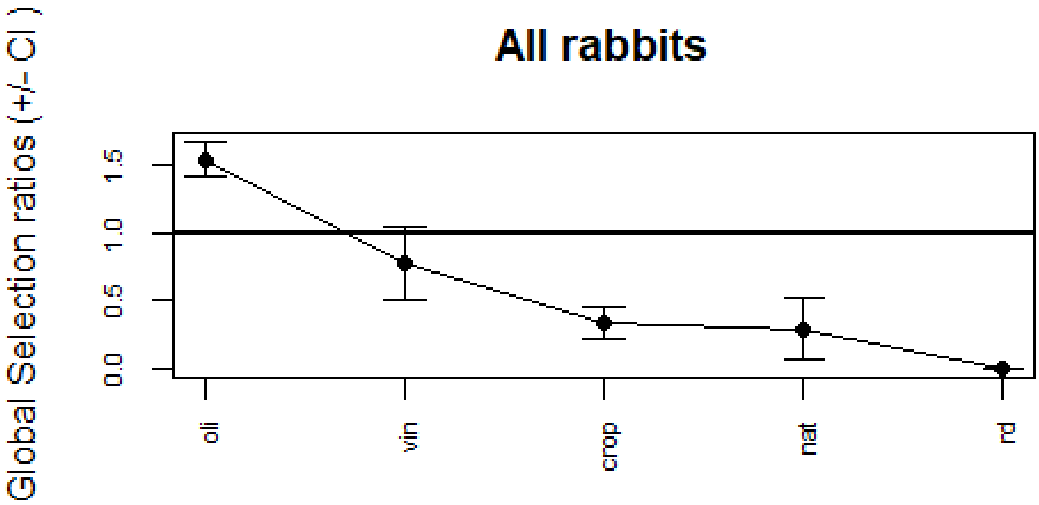

Figure 3. Manly´s global selection ratios of the wild rabbit population for the five habitat types; olive grove (oli), vineyards (vin), cereal crops (crop), natural

vegetation (nat), and road (rd). Habitat type is on x-axis and selectivity measure is on y-axis for all rabbits. The mean selection values for each habitat and their standard deviations are shown. Mean values shown above the dividing line indicate selection or preference, while values below indicate avoidance.

Habitat preferences analysis based on same availability for all animals, but use measured for each one (*Design II*) showed that test of identical habitat use for all animals was highly significant (*Chi-square* L1=312.41, d.f.=76, P<0.0001). Furthermore, the selection was not identical for all animals (*Chi-square* L2=1001.54, d.f.=80, P<0.0001). Similarly, for *Design III*, when the use and the availability measured for each animal, Chi-square for each animal (*Chi-square* Lj test) was highly significant for all the animals (Table 1) that significant.

Table 1. Results of test of habitat selection for each rabbit using Manly´s selection ratios for the 20 rabbits for *Design III* indicating Chi-square Lj test, degrees of freedom d.f. and P values.

Individual	Chi-Square Lj	d.f.	P-value
1	18.7	2	8.65×10^{-5}
2	Inf.*	3	>0.00001
3	11.63	2	2.98×10^{-3}
4	13.44	2	1.2×10^{-3}
5	0.00	2	1.00
6	Inf.*	2	>0.00001
7	61.62	3	2.63×10^{-13}
8	1.51	3	6.79×10^{-1}
9	13.61	1	2.24×10^{-4}
10	16.85	2	2.18×10^{-4}
11	13.91	2	9.49×10^{-4}
12	0.36	3	9.41×10^{-1}
13	52.95	2	3.17×10^{-12}
14	74.11	1	>0.00001

15	46.06	2	9.92 x10^{-11}
16	7.87	1	5.00 x10^{-3}
17	1.10	3	7.75 x10^{-1}
18	8.91	2	1.15 x10^{-2}
19	2.30	3	5.10 x10^{-1}
20	55.61	3	5.08 x10^{-12}

*Inf. Stands for infinitive value

These results showed that rabbits individuals selected habitats in different ways. Thus, we graphically explored the habitats selected by individual rabbits using the eigenanalysis (Calenge & Dufour, 2006).

The eigenanalysis for *Design II* (same availability for all animals, but use measured for each one) showed the tendency of each individual for each type of habitat. In this case there is an overall tendency towards olive crops, however, not all individuals select this type of habitat with the same intensity, revealed by the different slopes and lengths of the arrow's vectors (Figure 4).

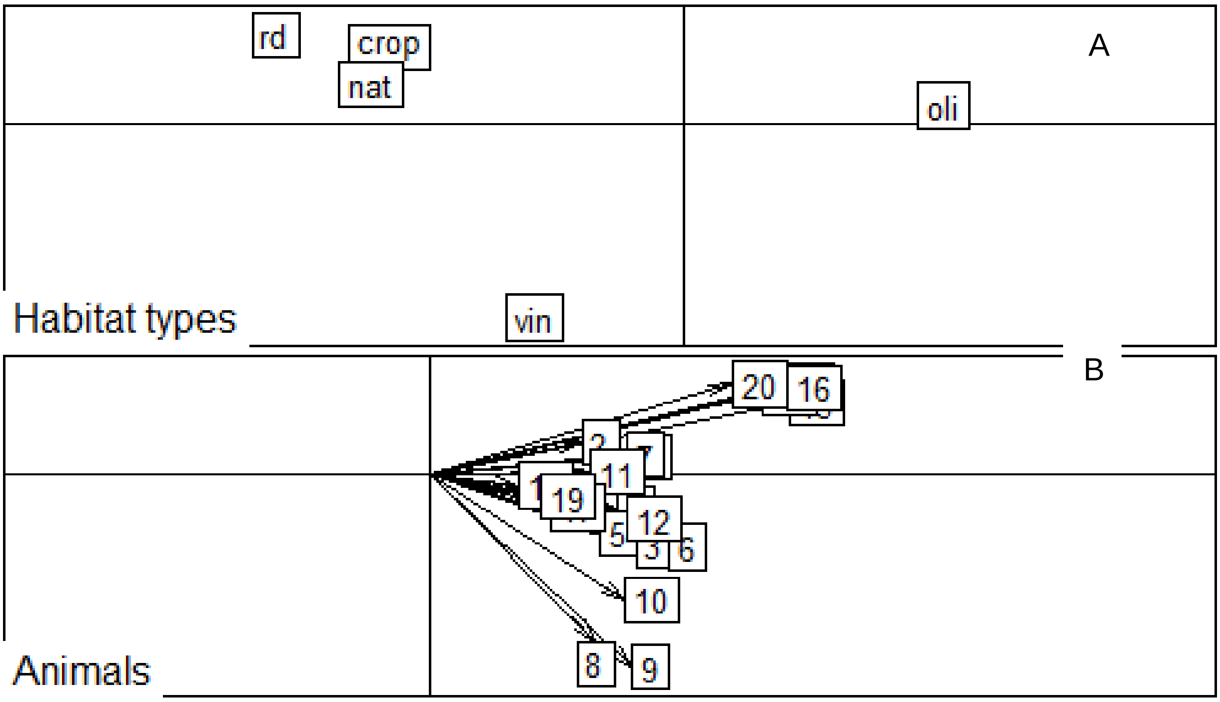

Figure 4. Results of eigenanalysis of preference ratios, showing habitat preference by individual GPS-collared rabbits using *Design II*. A) Habitat type on the first two factorial axes. The grey cross shows the position of a hypothetical habitat type

unused by all animals and divides the figure into four quadrants B) Animal scores on the factorial plane. Each arrow and number represent one different rabbit. The longer the arrow, the greater is the preference by individuals for the habitat type indicated and the steeper the slope, the greater the selection.

We also carry out an eigenanalysis for *Design III* (when the use and the availability are measured for each animal, within its Home Range). In this occasion there is a wide variety of habitats selected excluding roads, that were not represented within the home ranges of the individual monitored. Although, olive groves remained as the most strongly selected habitat. Althouigh, some animals showed preference for vineyards (Figure 5). Moreover, the remaining habitats were selected to a greater or lesser extent by part of the rabbits monitored.

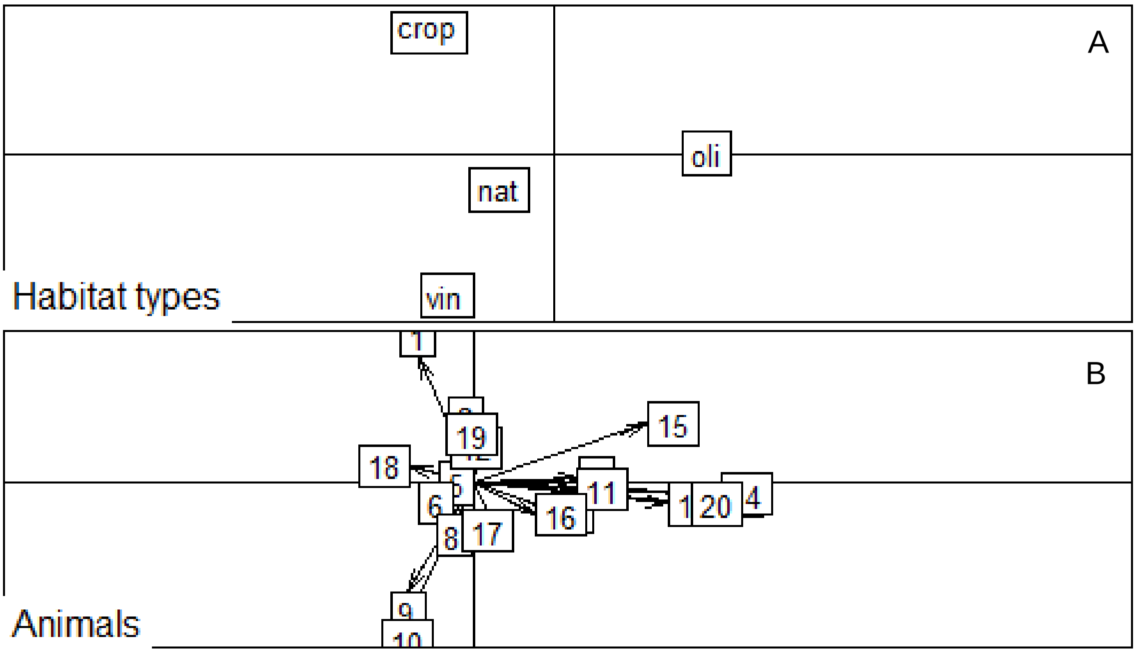

Figure 5. Results of eigenanalysis of preference ratios, showing habitat preference by individual GPS-collared rabbits using *Design III*. A) Habitat type on the first two factorial axes. The grey cross shows the position of a hypothetical habitat type unused by all animals and divides the figure into four quadrants B) Animal scores on the factorial plane. Each arrow and number represent one different rabbit. The longer the arrow, the greater is the preference by individuals for the habitat type indicated and the steeper the slope, the greater the selection.

DISCUSSION

This study aimed to analyse habitat selection by wild rabbits in areas of intensive agriculture where they may cause damage (Barrio et al., 2010; Rouco et al., 2019a). Regarding the preferences for habitats found in the present study, wild rabbits' populations have basics requirements to choose an area to grow properly, starting with soft soils where it is easier to dig warrens (Calvete et al., 2004; Williams et al., 2007) that are used for reproduction, shelter from extreme weather conditions, and protect themselves from predators or hunters (Delibes-Mateos et al., 2008; Palomares, 2003; Parer, 1977). But these soils are not only necessary for protection, but also need to provide maximum food and water resources. If there is a scarcity or heterogeneity of resources in space or time rabbits will need to forage on larger areas (Ferguson et al., 1999; Johnson et al., 2002; Petrovan et al., 2017) to meet their needs. This is the main problem in intensively managed semi-arid Mediterranean environments, such as our study area, where the lack of precipitations, resources, and the abusive use of herbicides, are forcing rabbits to seek shelter and food in crops (Calvete et al., 2004), causing significant damage and economic losses. Our results revealed that there was a clear preference for olive groves, and, in a lesser extent, for vineyards, which also were the most abundant habitats within the study area (Figure 1). In the semi-arid Mediterranean agroecosystem, especially in Andalusia, a very high proportion of agricultural areas are devoted to olive groves (e.g., more than 1.5 million hectares, 15% of the territory, Farfán et al., 2008). It had been proved in a recent study that areas with these types of crops are the most favourable for occurring damage caused by rabbits (Delibes-Mateos et al., 2018). Olive groves offer important resources that encourage the presence of rabbits. First, burrows have been observed often under the trees, as their roots provide great protection (Barrio et al., 2011). This warren occurrence is directly related to the presence of natural vegetation remnants, (Barrio et al., 2011) which is more frequent in olive groves than in vineyard. On the other hand, rabbits do not usually select woody seedling to feed which is less nutritious, is the last resource when there is not enough herbage available (Auld, 1995; Ferreira & Alves, 2009). Olive groves and vineyards are intensive management with herbicides at different times of the year (Monteiro & Moreira, 2004) and traditionally left without plant cover (Arnaez et al., 2007). The shortage of alternative food resources due to these agricultural practices causes these crops to suffer greater damage (Barrio et al., 2013). In the case of vineyards, most damage occurs in the early growing season

(Mar-Apr; Barrio et al., 2010), coinciding with rabbits breeding period when they have more energetics demands (Villafuerte et al., 1997) and most herbicides are applied. In that period, rabbits may strongly select vine buds which are more nutritious than other foods (Barrio et al., 2012). However, some studies suggested that an area heavily ploughed affect negatively to the presence of warrens because these are destroyed in the process (Gea-Izquierdo et al., 2005; Gálvez et al., 2008). This must be the reason why vineyards, that needs to be ploughed at least twice a year (Barrio et al., 2010), or cereal crops are less selected or avoided. It is also worth considering that the presence of rabbits in vineyards areas may increase the edge effect. Rabbits are edge animals as a strategy to avoid predators. It has been observed a decrease in grapevine yield specially in the edges due to rabbits' damage. In the case of cereal crops it has been observed in the middle of the crop where the productivity is greater (Bell et al., 1998).

One of the available habitats in this study is the road. Some studies have investigated the relationship between the presence of rabbits and the nearby to roads and railways acting such as dispersal corridors across landscapes (Rouco et al., 2019b) or providing refuge (i.e., roadside vegetation) (Ruiz-Capillas et al., 2013). These infrastructures allow movement across environmental barriers and could supply suitable soil to build warrens for rabbits facilitating the spread of their populations and the lower predator and hunting pressure (Planillo et al., 2018). Rabbit grazing and browsing in these areas often result in a reduction in crop yield, particularly on woody crops. In southern Spain, where this study is based, motorways usually pass though farmlands which have mechanisms that repel rabbits by causing them to settle in areas closer to roads (Calvete et al., 2006; Gea-Izquierdo et al., 2005; Barrientos & Bolonio, 2009). Furthermore, the high traffic mortality of these individuals compensates and allows the high reproductive rates of rabbits facilitating their presence in these areas. However, our results showed that this is not the case of the populations that have been studied since none of these individuals selected this habitat within the study area.

Despite that our results revealed an overall preference for a particular habitat type (i.e., olive groves) by the rabbit population studied, we found a discrepancy between the two statistical approaches used (i.e., *Design II vs. Design III*). While *Design II* clearly showed an olive groves preference, *Design III*, showed a wide individual variability in habitat preference. The main difference between both approaches is the scale of the habitat considered available. These results suggest that not all the habitat on a study site scale was available for all the animals, instead, rabbits seemed to have available only those habitats within its home range. Therefore, in future studies, it may be worth it to applied only a *Design III* approach, which likely would reveal a more realistic behaviour of each animal.

Finally, it could be said that rabbits select olive groves and vineyards because they provide the best conditions for them to settle. And, in particular, olive groves, because of the composition of the soil and the roots of the trees that support and protect the rabbit burrows, because it maintains to a greater extent the natural vegetation surface that provides food and finally there is not so much continuous ploughing in these areas, so burrows are less at risk. In addition, intensive agricultures, and in particular monocultures seem to be favouring the presence of rabbit population, that may cause damage. However, this intense agricultural damage is also causing a biodiversity impact, since tends to reduce the natural vegetation patches. These natural remnants not only support the highest biodiversity, but also are used such as refugia for characteristic plants and animal species (José-María et al., 2010). This natural vegetation is beneficial to the preservation of farmland biodiversity (Benton et al., 2003; McLaughlin & Mineau, 1995) and as source of food for herbivores such as rabbits. Therefore, intensive agricultural practices are provoking the homogenization of the land (Albrecht, 2003) and consequently the biodiversity leakage and possibly favouring the occurrence of damage to crops cause by rabbits.

Some possible solutions

Considering the high damage and economic losses caused by rabbits, many scientists have tried to find a solution to eliminate or reduce this problem as much as possible. And here we stated some measures that could be applied in olive groves and vineyards in south Spain to mitigate the rabbit impact in such crops.

One of the main measures that have been proposed is to provide alternative food for rabbits by weed management (Barrio et al., 2013) in a couple of different ways. First, some studies promote cover crops (Barrio et al., 2012). This measure is based on avoid weed control in crops so that rabbits feed on these natural weeds and do not damage the crop. It also has others benefits to the agroecosystems like preventing soil erosion. However, there are lots of consequences of this practice that could be even worse. These naturals herbaceous cause water competition with the crops, which reduces crop yields. Therefore, it has been observed that this alternative food may act such an attractant for rabbits increasing the damage to this crop (Barrio et al., 2012). This practice is not recommended to vineyard in semi-arid regions.

A similar solution was proposed in the original study from which this paper is founded (Rouco et al., 2019a) that is based on the application of supplementary food to reduce home ranges of wild rabbits in an intensive agricultural landscape concluding that even if this strategy solve the problem in a short term reducing rabbits home range sizes, it has the potential to increase rabbit densities in the medium and long term which would provoke even worst damage to crops.

Finally, a simple way to decrease rabbits´ population could be by increasing the synergetic pressure. When hunting is just restricted to hunting periods which coincide with the breeding season, the effect on rabbits´ populations is minimal (Angulo & Villafuerte, 2003) and other practices such as predator control could even increase it (Barrio et al., 2013) by eliminating intraspecific competition. But it has a lot of conflicts to increase the hunting period unless the problem in a given area was very serious.

However, the best solution to reduce rabbit damage to crops in the long term seems to be adopting appropriate agronomic measures (Barrio et al., 2013). Rabbits' populations are determined for the availability of food so a correct weed control in crops that enables natural vegetation to grow to some point that do not affect the crops may reduce rabbits´ damages. An example of these could be by reducing or delaying the herbicides use or by changing chemical remedies for physicals ones (Barrio et al., 2013) that reduces weeds in a less permanent way. European regulations are now promoting the maintenance of biodiversity in agricultural areas and the incoming reform of the Common Agricultural Policy will encourage and reinforce greening and compensation for carbon sequestration (European Commission, 2010; Barrio et al., 2013). Thus, less intensive agricultural practices combined with hunting to avoid an excessive increase in rabbit numbers would allow coexistence between this species and human interests to be achieved.

CONCLUSIONS

Our results show that, overall, despite individual differences, there is a strong selection towards olive groves and vineyards. The abundance of rabbits in these crops, apart from being the most abundant in the south of the Iberian Peninsula, is justified by changes in land use and agricultural intensification in these crops, which eliminate the natural vegetation cover, causing them to seek refuge and food in these areas where there are also favourable conditions for the settlement of the species.

CONCLUSIONES

Nuestros resultados muestran que, de manera global, a pesar de las diferencias individuales, existe una fuerte selección hacia el olivar, principalmente, y hacia el viñedo. La abundancia de conejos en estos cultivos, además de por ser los más abundantes al Sur de la Península Ibérica, está justificada por los cambios en el uso del suelo y la intensificación agraria que se da en estos cultivos que eliminan la cubierta vegetal natural haciendo que busquen refugio y alimento en estas zonas donde además se dan unas condiciones favorables para el asentamiento de la especie.

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ANNEXED 1

Table A.1. 1 Data set obtained from the study on the percentage of area selected per individual. Each individual (IND) is represented with a number and has specifics and different data for all the different habitats available: oli (olive groves), crop (cereal crops), vin (vineyards), nat (natural vegetation), rd (road).

IND	*oli*	*crop*	*vin*	*nat*	*rd*
1	75	14.29	10.71	0	0
2	68.75	18.75	10.42	2.08	0
3	72.97	8.11	18.92	0	0
4	71.59	12.5	15.91	0	0
5	68.75	12.5	18.75	0	0
6	77.27	4.55	18.18	0	0
7	74.36	12.82	10.26	2.56	0
8	65.71	2.86	28.57	2.86	0
9	69.57	0	30.43	0	0
10	70.27	5.41	24.32	0	0
11	68.89	17.78	13.33	0	0
12	72.73	9.09	16.36	1.82	0
13	95.95	2.7	1.35	0	0
14	95.24	4.76	0	0	0
15	92.68	6.1	1.22	0	0
16	96	4	0	0	0
17	63.19	17.36	17.36	2.08	0
18	59.4	24.06	16.54	0	0
19	62.11	20	16.84	1.05	0
20	89.22	8.82	0.98	0.98	0

ANNEXED 2

Table A.1. 2 Data set obtained from the study on the percentage of area available within home range per individual. Each individual (IND) is represented with a number and has specifics and different home ranges for all the different habitats available: oli (olive groves), crop (cereal crops), vin (vineyards), nat (natural vegetation), rd (road).

IND	*oli*	*crop*	*vin*	*nat*	*rd*
1	70.59	2.94	23.53	2.94	0
2	68.97	13.79	17.24	0	0
3	54.79	24.66	19.18	1.37	0
4	47.19	28.09	23.6	1.12	0
5	68.75	12.5	18.75	0	0
6	85.71	0	14.29	0	0
7	23.08	53.85	15.38	7.69	0
8	72.73	3.03	21.21	3.03	0
9	88.89	0	11.11	0	0
10	87.5	6.25	6.25	0	0
11	45.07	35.21	16.9	2.82	0
12	71.05	7.89	18.42	2.63	0
13	50	43.75	6.25	0	0
14	38.71	54.84	6.45	0	0
15	49.47	24.21	25.26	1.05	0
16	83.33	16.67	0	0	0
17	59.46	21.62	13.51	2.7	2.7
18	70.93	12.79	12.79	3.49	0
19	60	16	20	4	0
20	39.06	54.69	4.69	1.56	0

ANNEXED 3

Table A.1. 3. Data set obtained from the study on the percentage of area within Study area. Each individual (IND) is represented with a number and has the same availability of each habitat: oli (olive groves), crop (cereal crops), vin (vineyards), nat (natural vegetation), rd (road). The average of this results is represented in the Figure 1.

IND	*oli*	*crop*	*nat*	*rd*
1	48.84	30.75	2.33	0.52
2	48.84	30.75	2.33	0.52
3	48.84	30.75	2.33	0.52
4	48.84	30.75	2.33	0.52
5	48.84	30.75	2.33	0.52
6	48.84	30.75	2.33	0.52
7	48.84	30.75	2.33	0.52
8	48.84	30.75	2.33	0.52
9	48.84	30.75	2.33	0.52
10	48.84	30.75	2.33	0.52
11	48.84	30.75	2.33	0.52
12	48.84	30.75	2.33	0.52
13	48.84	30.75	2.33	0.52
14	48.84	30.75	2.33	0.52
15	48.84	30.75	2.33	0.52
16	48.84	30.75	2.33	0.52
17	48.84	30.75	2.33	0.52
18	48.84	30.75	2.33	0.52
19	48.84	30.75	2.33	0.52
20	48.84	30.75	2.33	0.52