Rabbits, weeds and crops: can agricultural intensification promote wildlife conflicts in semiarid agro-ecosystems?

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ABSTRACT

Agricultural intensification has led to the extreme simplification of agricultural landscapes. The subsequent impoverishment of farmland plant communities can drive dramatic changes in the associated food webs of agricultural systems, with potential implications on vertebrate pest management. Weeds may provide alternative food sources for damaging species and thus contribute to reducing their damage, which is particularly desirable if the species is a valuable resource in its own right. For example, wild rabbits are a game species of great conservation value in the Iberian Peninsula that causes frequent damage to crops. Here we describe the dynamics of non-crop plant communities over an annual cycle in a semiarid Mediterranean agro-ecosystem, and discuss the potential linkages and implications for rabbit damage management. Overall, the availability for rabbits of foods different from crops was very low, especially in the dominant habitat types, i.e. olive groves and vineyards. The seasonal pattern in plant productivity, which coincides with rabbits' phenology in Mediterranean areas, was only detectable in the less intensively managed habitat types. The scarce natural vegetation remnants retained the highest richness, diversity and plant cover, potentially acting as a refuge for both, plants and rabbits. Our results indicate that intensive management practices, through reducing alternative food sources for rabbits, are likely to promote the conflict between hunters, farmers and conservationists in semiarid agroecosystems of Southern Spain.

Keywords: arable flora, *Oryctolagus cuniculus,* management, Mediterranean ecosystems, vertebrate pest, wildlife damage

1. INTRODUCTION

Intensification of agriculture leads to tremendous increases in food production, but also to serious environmental consequences (Matson et al., 1997). The simplification and homogenisation of the landscape driven by agricultural intensification has led to a general decline in farmland biodiversity (McLaughlin and Mineau, 1995). For example, since the early 20th century, the diversity and abundance of the weed flora across Europe has sharply declined (Baessler and Klotz, 2006). This loss of plant species in agro-ecosystems can drive significant changes in the associated biotic communities via habitat and food-chain relationships (Albrecht, 2003), so weeds are increasingly seen as an important source of biological diversity (Marshall et al., 2003).

The depletion of plant communities in agricultural systems can be particularly worrisome in areas where weeds represent an alternative feeding resource for species that cause damage to crops. This can be further complicated if the damaging species has a great hunting value itself, which is the case of wild rabbits (*Oryctolagus cuniculus*) in Mediterranean ecosystems within the Iberian Peninsula. Rabbits are native to the Iberian Peninsula and represent one of the most valuable small game species, but at the same time they can cause extensive damages to crops (Delibes-Mateos et al., 2011). In some areas within their native range rabbits are considered an agricultural pest (Barrio et al., 2010b). Pest species are those that, at least locally, exhibit too high densities and cause economic or ecological harm to human interests (Stenseth and Hansson, 1981). In the case of rabbits few attempts have tried to assess their pest status within some areas of their native range, but in some cases damages to crops have been reported (circa 20% of annual yield in vineyards; Barrio et al., 2010b), coupled to moderate to high rabbit densities (Barrio et al., 2010a) and increased claims from farmers asking for rabbit control (Ríos Saldaña, 2010). Food availability is one of the main factors regulating rabbit densities (Villafuerte et al., 1997), especially in Mediterranean environments that are characterized by marked oscillations in annual primary production (Moreno and Villafuerte, 1995). Rabbits are selective grazers that prefer low-fibre herbaceous plants, but might be forced to consume less nutritious but abundant foods during food shortage (Mátrai et al., 1998). For example, rabbits do not damage woody seedlings if enough herbage is available (Auld, 1995), and rabbit damage to vineyards has been related to lower herbaceous plant diversity (Barrio et al., 2010b). Together with the fact that rabbits use alternative foods when available (Barrio et al., 2012), this suggests that weed management can have an impact on the management of rabbit damage. Therefore, the characterization of plant communities of agricultural lands can be relevant to the management of this vertebrate species. Weed communities have been described for particular crops, i.e. vineyards, with highly variable results, and the need for specific studies has been suggested for each particular area and crop type (Gago et al., 2007).

The aim of this study was to characterize non-crop plant communities of a semi-arid intensive agricultural landscape in Southern Spain, where rabbits are considered both a pest and a valuable game species, and discuss the implications of current agricultural practices to wildlife management. We describe species richness, diversity and plant cover of herbaceous plant communities to determine if alternative food availability for rabbits varies 1) across the main habitat types and 2) over the annual cycle of plants. We expect the current agricultural practices to have a negative impact on the availability of alternative foods for rabbits, and thus, to have implications to the management of rabbit damages to crops.

2. METHODS

2.1 Study area

The study was conducted in a semiarid agricultural landscape in Córdoba province (Montilla-Moriles Winegrowing Region), Southern Spain (37º33'N, 4º37'W). The area is characterized by a semiarid Mediterranean climate with hot dry summers and mild winters, with mean monthly temperatures ranging between 8 and 26ºC, and mean annual rainfall of 500 mm, with precipitations mainly concentrated in autumn. Soils are calcareous, and devoted in the most part to intensive agricultural practices, mainly olive groves, vineyards and cereal crops, with small remains of natural vegetation. Rabbits are found in the study area at medium-high densities (circa 7 rabbits/km; Barrio et al., 2010a) and cause significant damage to winegrowing (circa 20% yield loss; Barrio et al., 2010b).

2.2 Vegetation sampling

The sampling design was based on six study sites (for more details see Barrio et al., 2010b). Vegetation was sampled following a random stratified design, within a 500m-radius circumference centred on each of these sites. The main habitat types were mapped in each site and only those likely to be used by rabbits were surveyed. Consequently, two types were excluded (aquatic and urban habitats), and four habitat types were further considered: vineyards, olive groves, fallow lands, and remnants of natural vegetation. We included as fallow lands those crops that are sown annually in winter with alternate herbaceous crops (sunflower, legumes and cereals in subsequent years), and represent a very small proportion of the study area (2.2%). Natural vegetation remnants are those unploughed patches and field edges where some native vegetation still persists, and represented up to 16% of the study sites. On average, olive groves and vineyards represented 56.4 and 42.6% of the study sites respectively. When enough represented (>0.5% of total area), three transects were randomly set in each habitat type and study site, resulting in 60 transects. Each transect was 50 meters long and point intersections each 20 cm were recorded (N=15060 vegetation contact points, 251 points per transect). For each transect we calculated species richness (number of herbaceous plant species per transect), Shannon Diversity Index and plant cover (percentage of point intercepts in which plants occurred). Transects were surveyed in Feb, May, and Oct 2008. These sampling times were selected to broadly represent the annual cycle of plants and rabbit phenology in Mediterranean environments (**Figure 1**).

2.3 Statistical analyses

To compare the relative effect of habitat type and time of year on each of the indices calculated, i.e. species richness, diversity and plant cover, we built Linear Mixed Models (LMM), in which each one of the indices was the response variable. Species richness and plant cover were log-transformed to achieve normality. Transect identity within site was included in all models as the random component to account for data structure, and residual spread was allowed to differ across habitat types by including habitat as a variance covariate (Zuur et al., 2009). As explanatory variable we included the interaction between habitat type and time of year. Model selection followed a backward stepwise procedure based on

Akaike's Information Criterion (AIC). All modelling assumptions were checked. All statistical analyses were performed in R 2.10.1 (R Development Core Team, 2009).

3. RESULTS

In all cases the interaction between habitat type and time of year had a significant effect on the response variable, indicating that variations in the indices across year times depended on the habitat type considered. In the case of plant cover the interaction term was highly significant (**Table 1a**). Fallow lands and natural vegetation remnants showed similar trends with highest values in February and May and sharply declining through the summer period. On the contrary, plant cover in olive groves and vineyards remained constant and at low values (~15%) throughout the year (**Figure 2a**). Species richness ranged between 0 and 40 species (median=4, median absolute deviation= 4.45), and was highest for natural vegetation remnants throughout the year cycle (for a complete list of plant species found see **Supplementary Material**). Olive groves and vineyards showed a similar decreasing pattern in species richness along the growing season, while for fallow lands and natural vegetation remnants a peak was reached in May followed by a sharp decrease through the summer period (**Figure 2b**). In this case, the interaction term between habitat type and time of year was also significant (**Table 1b**), as was for Shannon diversity index (**Table 1c**). Mean diversity (±SD) was 0.93 (±0.74), ranging from 0 to 2.94. Patterns in diversity closely paralleled those in species richness, with olive groves and vineyards showing a decreasing trend in diversity along the growing season and fallow lands and natural patches peaking in May (**Figure 2c**).

4. DISCUSSION

Agricultural practices in semi-arid environments can have an impact on vertebrate pest management through reducing alternative food sources for the damaging species. In an intensively managed agroecosystem in Southern Spain food availability for rabbits, as determined by the description of the non-crop plant communities, was dramatically low throughout the year. The main crops in the study area are olive groves and vineyards, which occupy on average 56% and 42% of the arable lands respectively, while fallow lands and natural vegetation remnants are only marginal land uses. Interestingly, the trends observed in the non-crop plant communities both for species richness and diversity were consistent for the two dominant crops, showing a slight decrease along the growing season. Plant cover was low in these habitats throughout the year. These trends may reflect the intensive management of these crops, which are traditionally left without plant cover through frequent ploughing and the use of herbicides (Arnaez et al., 2007). On the contrary, natural vegetation remnants and fallow lands showed a distinct seasonal pattern; with the highest richness and diversity in May, and plant cover remaining high through spring and decreasing sharply in summer, as is expectable in Mediterranean environments. Fallow lands had lower diversity and richness than natural remnants, but paralleled closely the seasonal pattern of the later. These results suggest the occurrence of a gradient of agricultural intensification, from olive groves and vineyards being the most intensively managed to natural vegetation remnants being the least, and fallow lands representing an intermediate position.

Intensive management of vineyards and olive groves includes annual weed control with pre-emergence herbicides at different times of the year and contact herbicides in the case of already developed plants (Monteiro and Moreira, 2004). It has been shown that plant communities of agro-ecosystems are strongly affected by agricultural practices (Gago et al., 2007; José-María et al., 2010), and our study is no exception; weed flora within vineyards and olive groves was severely impoverished when compared to that in nearby vegetation remnants. Although the application of herbicides to these patches is not infrequent, these natural remnants held the highest species richness and diversity, and were probably acting as a refuge for characteristic plant species, as has been described in other studies in Mediterranean areas (José-María et al., 2010). As well, natural vegetation remnants have been shown to be beneficial to the preservation of farmland biodiversity, with positive effects on different groups of organisms (Benton et al., 2003; McLaughlin and Mineau, 1995).

The scarcity of alternative foods in the dominant habitat types due to the current agricultural practices, may promote rabbit damage to crops. For instance, most damage to vineyards occurs in the early growing season (Mar-Apr; Barrio et al., 2010b), when rabbits have greater energetic demands due to their breeding period (Villafuerte et al., 1997) and when most herbicides are applied (**Figure 1**). During this time, rabbits may actively select highly nutritious vine buds over other foods (Barrio et al., 2012), but rabbit damage to vineyards has been negatively correlated to the diversity of herbaceous plant communities (Barrio et al., 2010b). Coupled to the attractiveness of young vine tissues, the severe depletion of alternative feeding sources may render woody crops more susceptible to foraging rabbits. In addition, other land uses can impact the dynamics of rabbit populations in agricultural lands and the interests of rabbit management in these areas. Rabbit hunting has the potential to control rabbit populations, but if conducted at certain times of year like the current hunting periods (**Figure 1**), its effects on rabbit populations can be minimal (Angulo and Villafuerte, 2003); besides, some hunting-related practices, such as predator control, can even promote rabbit populations. Clearly, interests of hunters and farmers diverge and the rabbit conflict has no easy solution. However, adopting appropriate agronomic measures could potentially reduce rabbit damage to crops in the future. For example, a sensible approach could be to restrict and delay weed control as much as possible when rabbit damage is highest. Using mechanical instead of chemical mowing to control weeds could be as efficient but would not reduce alternative foods for rabbits as dramatically. Alternatively, some areas of the farm could be judiciously allowed to develop a natural weed cover over those recommended only from agronomic reasons to prevent competition with the crop. In this sense, 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). Such less intensive agricultural practices are thus likely to have a positive impact on vertebrate pest management in Southern Spain, but need to be coupled to other measures to prevent excessive increases in rabbit numbers, like rabbit hunting before the period of damages to crops. This integral management of Mediterranean agro-ecosystems could then reduce the conflict between hunters, farmers and conservationists in semiarid agricultural landscapes of Southern Spain.

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FIGURES AND TABLES

Figure 1. Simplified calendar of the main agricultural practices carried out in vineyards and olive groves in the study area along the year cycle, together with rabbit biology and the main events in the rabbit hunting season.

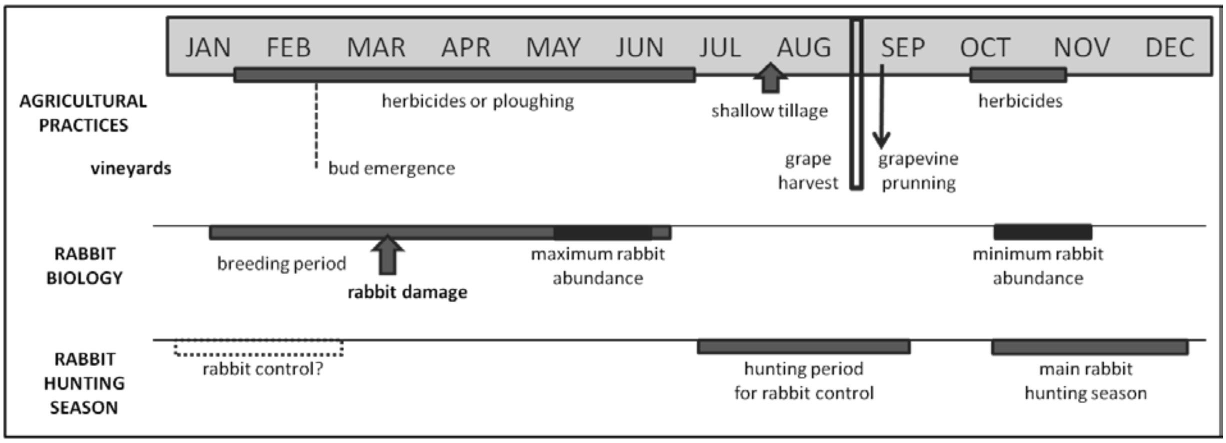

Figure 2. Characterization of arable plant communities across the year cycle and different habitat types, through a) percentage plant cover, b) species richness and c) diversity (Shannon's index). Mean values ± standard errors are shown.

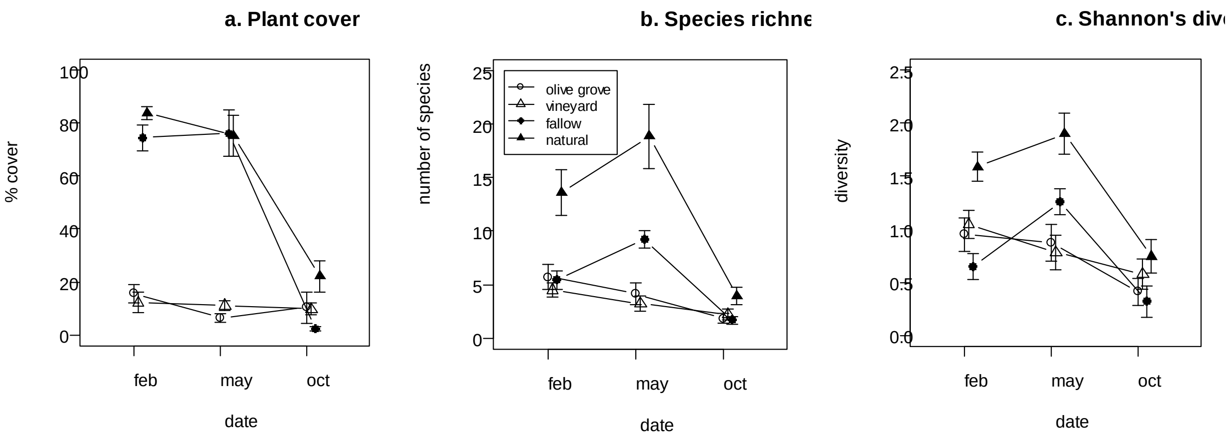

Table 1. Linear Mixed Models (LMM) for plant cover (a), species richness (b) and Shannon's diversity index (c). Results of likelihood ratio tests (LRT) are given.

a. Linear Mixed Model for plant cover
Random factor: transect identity within site
Variance covariate: habitat type

	LRT	Sig.
HABITAT*DATE	71.86	0.000

b. Linear Mixed Model for species richness
Random factor: transect identity within site
Variance covariate: habitat type

	LRT	Sig.
HABITAT*DATE	30.79	0.000

c. Linear Mixed Model for species richness
Random factor: transect identity within site
Variance covariate: habitat type

	LRT	Sig.
HABITAT*DATE	22.43	0.001