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Research Article

Effect of habitat structure and type of farming on European hare (*Lepus europaeus*) abundance

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Abstract

European hare (*Lepus europaeus*) is a typical species of farmland habitat that has been negatively affected by agricultural intensification and, for this reason, may be considered a good indicator of farmland habitat quality. We carried out an exploratory analysis of hare abundance in 26 lowland farms in Tuscany, Central-Italy, with similar basic features (large estates with the same game management) but that differ for crops, landscape structure and farming options (organic vs. conventional farming). We used multiple regression analysis with theoretic information approach and multi-model inference to evaluate the effect of habitat variables and type of farming on hare abundance. Habitat structure (variety of crops) was the most important factor positively affecting hare abundance. We did not find a benefit of organic farming on this species; on the contrary, the highest hare densities were registered in conventional farms. Our findings suggest that organic farming regulations may fail to provide a sufficient habitat heterogeneity and, consequently, do not enhance wildlife abundance in farmland habitat.

Introduction

The changes in agricultural practices, caused by intensification and mechanization, that occurred in recent decades in Europe have caused a strong reduction of animal biodiversity in agricultural landscapes (Chamberlain et al., 2000; Donald et al., 2001). In particular, these alterations include the increase of field size and mono-cultures, a reduction of grassy field margins, hedgerows and tree-rows, a large employment of herbicides and pesticides and a general reduction of permanent cover (Stoate et al., 2001; Robinson and Sutherland, 2002; Butler et al., 2010). As a result, wildlife on farmland has declined all over Europe (Green et al., 2005; Butler et al., 2007, 2010; Wretenberg et al., 2010).

European hare (*Lepus europaeus*) is a typical species of farmland habitat that has been affected negatively by the changes caused by agricultural intensification and therefore may be considered a good indicator of habitat quality (Edwards et al., 2000; Smith et al., 2005; Santilli and Galardi, 2006; Zellweger-Fischer et al., 2011). Abundance of European hares is related to abundance of other farmland species as grey partridge (*Perdix perdix*) (Báldi and Faragó, 2007) which can be considered one of the leading icons of the countryside. Understanding factors influencing the abundance of this species in agricultural habitat can provide useful information to set up an agricultural policy aiming to improve biodiversity. For this reason, we monitored hare abundance on 26 lowland farms and analysed to which extend variation in crop diversity, landscape structure, size of the estate and farming option (organic versus conventional farming) affected variation in hare abundance.

Material and methods

The study was carried out in 2011 on 26 farms localized in lowland farmland areas of Tuscany region (elevation between 0 and 250 m a.s.l.). In these farms arable lands (cereal and other crops) represented 37–99% of the surface (mean±SD = 79.1±18.5%), olive tree grooves 0-28% (6.6±7.3%), vineyards 0–36% (8.7±12.4%). Average farm dimension was 6.13 km^2 (±2.27, min 3.85 km^2, max 12.13 km^2). Half of the farms (13) were certified for organic production (register of certified organic farms of the Tuscany Region) and 13 were conventional farms. We considered organic farms those estates that comply with EU requirements of organic farming and that are checked and certified by a Inspection and Certification Body at least once a year. All farms were hunting estates established for small game management, for which the Italian law prescribes that hare density must be maintained at >10 hares/km^2. In these estates, hunting is mainly on pheasants, while hares are neither hunted nor captured for translocations.

In each study site, hare density was estimated using spot-light counts carried out from a moving car (maximum speed: 5 km/h) along selected transects whose length was proportional to estate size (average length 10.4±2.5 km, range 5.2–12.7 km), lighting up both sides of the transects by a handle lamp (1 million candle power) (Frylestam, 1981; Barnes and Tapper, 1985). The transects route was selected from the existing fields-road networks to survey each habitat type in proportion to its relative extension (Langbein et al., 1999). Monitoring was done in early March, starting at least two hours after sunset. At least two counts where done in each study site, and a third count was carried out when the number of hares counted in the second trial differed more than 25% from that in first one. A team comprised one driver and two observers. The car was stopped when shining eyes were seen. The observer located the initial position of the animal and kept track of that position before trying to identify the animal using binoculars. During these surveys we also counted foxes (*Vulpes vulpes*) and their abundance was determined with the same method.

For each area we determined the land use intersecting an on-line land use map (http://www502.regione.toscana.it/geoscopio/servizi/wms/USO_E_COPERTURA_DEL_SUOLO.htm) with the boundaries of the farms using a GIS software (Qgis 2.4). With the same software we determined the average dimension of fields, interpreting an aerial photograph taken in 2010 and the Crop Diversity Index using the Shannon Wiener Index of the different crops. The different colouring and the texture of

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Table 1 – List of variables considered for the analysis.

Variables	Description
TYPE (categorical)	Farms were classified as "organic" when they were registered in the list of certified organic farms of Tuscany by at least 5 years; farms were classified as "conventional" when they did not deal with any organic farming program
SIZE	Estates area in hectares
Average Fields Dimension (AFD)	AFD were calculated for every farm measuring fields dimension on an aerial photograph of 2010 using a GIS software
Crop Diversity Index (CDI)	CDI was calculated as Shannon-Wiener Index of different type of crops interpreting an aerial photograph of 2010 using a GIS software
Perimeter Area Ratio (PAR)	It is the ratio between the sum of the fields perimeters and the total surface of the farm calculated using a GIS software
Arable lands (ARA)	% of arable lands obtained by a land use map
Fallow lands (FAL)	% of uncultivated lands obtained by a land use map
Vineyards (VIN)	% of vineyards obtained by a land use map
Olive tree groves (OTG)	% of olive tree grooves obtained by a land use map
Mixed arable lands (MAL)	% of arable field bordered by olive tree rows obtained by a land use map
Fox abundance index (FAI)	Density (per Km^2) of fox sighted during the night counts

the fields was used to determine the different crops. In this way it was possible to determine the crop-diversity, but not to identify the type of crops (complete crop maps were not available for all the farms). The aerial photograph (AP) was taken about six month before the survey. Farms have a cultivation plan that depend on crops rotation. Annual crops can be moved from one field to another, but generally variety and kind of crops change little as we verified overlaying the AP of 2010 with the AP of 2013. Finally, we calculated the ratio between the sum of the fields perimeters and the total surface of the farm. The variables considered for the analysis are reported in Tab. 1. Farms data are reported in Supplemental material (Tab. S1).

In order to evaluate the effect of environmental variables on European hare density we constructed 12 Generalized Linear Models (GLMs) of hare density registered in each study area versus the environmental variables. Models were bound to include one categorical variable and only three independent continuous variables chosen among the less correlates ones so to avoid over-parametrization and Freedman's paradox (Anderson and Burnham, 2002). For these analyses, a correlation matrix among independent variables was calculated beforehand, with the aim to identify the subset of independent non-correlated variables. Inference from models was made according to the Information-theoretic approach (Anderson and Burnham, 2002). Akaike's Information Criterion (AIC), differences with the minimum AIC (Δ_i) and Akaike weight (w_i) for each i-model were computed to rank and scale the models. AIC is: AIC = 2k-2ln(L) where "k" is the number of parameters in the statistical model, "L" is the maximized value of the likelihood function for the estimated model and "n" denotes the sample size. We used AIC correction for finite sample size (AICc). According to Burnham and Anderson (2002) models with Δ_i>10 have essentially no support and they were omitted from further considerations The relative importance of predictor variables were measured, as resulted from the best models, by the sum of the models Akaike's weight were each variable appeared (Burnham and Anderson, 2002). The kind of relationship between the variables selected by multi model inference was investigated by regression analyses. In addition we compared the mean hare density between organic and conventional farm and mixed and no-mixed farm. All analyses were carried out by using JMP 5.0.1 for Windows.

Results and Discussion

Hare density (Tab. 2) resulted higher in conventional farm (23.9±12.8 hares/km^2) compared to organic farms (13.59±9.7 hares/km^2, t=2.34; df=24; p<0.05).

Correlation analyses among habitat variables led to build 12 different models taking into account all the original 11 variables (Tab. 2). Comparison among models showed that only 2 models well predicted hare density (ΔAICc$\leqslant$ 2 and $w_i \geqslant$ 0.2). The two models that better explained the variance of hare density both included crop diversity index (CDI) (Tab. 2).

With regard to the habitat structure the results of the present research confirmed the actual knowledge on the ecology of the European hare in agricultural habitats. Diversity at landscape and farm scale are fundamental for hare numbers (Frylestam, 1980; Tapper and Barnes, 1986; Lewandowski and Nowakowski, 1993; Vaughan et al., 2003). Crop diversity is generally associated with hare abundance, whereas monoculture has a negative effect. Small fields and poly-culture enable hare to exploit the resource (food and cover) of the area more efficiently (Smith et al., 2005; Schai-Braun and Hackländer, 2013; Petrovan et al., 2013). We cannot exclude that smaller home ranges resulted in a reduction of spatial intra-specific competition allowing higher densities.

The higher densities registered in conventional farms compared to organic farms and the lack of effect of organic farming on hare abundance in the models may be surprising since this kind of farming is generally considered beneficial for many wildlife species (Bengtsson et al.,

Table 2 – Genelized Linear Models obtained to explain European hare abundance in the 26 hunting estates. In bold the variables selected by the models.

Variable	r^2	AICc	Delta AIC Δ_i	Relative likelihoods	Akaike weight wi
CDI*FAI*PAR	0.343	100.617	0.000	1.000	0.437
FAI***CDI***AFD	0.343	100.617	0.000	1.000	0.437
AFD*MAL*FAI	0.205	103.338	2.721	0.257	0.112
OTG*FAI*MAL	0.000	107.444	6.827	0.033	0.014
MAL***CDI***VIN	0.227	127.540	26.923	0.000	0.000
OTG*PAR***CDI**	0.227	128.080	27.463	0.000	0.000
PAR***TYPE***ARA	0.282	128.170	27.553	0.000	0.000
AFD*ARA*OTG	0.211	128.622	28.005	0.000	0.000
SIZE***AFD***ARA	0.211	128622	28.005	0.000	0.000
VIN***TYPE***FAL	0.186	129.415	28.798	0.000	0.000
TYPE*ARA*VINE	0.186	129.863	29.246	0.000	0.000
ARA***PAR***FAL	0.137	130.934	30.321	0.000	0.000

2005; Fuller et al., 2005; Hole et al., 2005; Garratt et al., 2011; Tuck et al., 2014). We cannot exclude a bias due to the small number of sample farms, however the effect of organic farming on European hare needs more detailed investigation. Application of the principle of organic farming may greatly vary between farm: studies have shown that some certified organic farms comply with the regulations, but not with the theoretical principles of organic farming (Darnhofer et al., 2010). Similarly there are many types of conventional farms: use of pesticides and farming practices can greatly vary between farms resulting in different levels of interaction with wildlife. In our study we observed some farms converted to organic, but which maintain the habitat structure typical of intensive agriculture, with very large fields and few crop species. Organic farming may have some disadvantages for some taxa in particularly when it is not paired with mixed farming (Topping, 2011). Weed control in organic farming system in fact is achieved through more intense and frequent soil tillage reducing temporal availability of food and cover for hares (Trewavas, 2001). Overwintered cereal stubbles, for example, are very beneficial for European hare (Tapper and Barnes, 1986; Santilli et al., 2014). Winter stubbles availability is generally more frequent in conventional farm (Norton et al., 2009) as organic farmers cannot afford the resulting weed burden.

We did not found any relationship between hare and fox abundance although fox predation is considered an important factor in the hare population dynamic (Goszczynski and Wasilewski, 1992; Reynolds and Tapper, 1995; Schmidt et al., 2004; Knauer et al., 2010; Reynolds et al., 2010). This result is probably due to the small differences found in fox abundance between study areas.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Hare density (animals/km^2), type of farming, estate size and landscape composition variables for the 26 study sites.