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Original paper

Density estimates and habitat preferences of the European hare (*Lepus europaeus*) on mountainous areas in Italy

Naldi Lorenzo[1,*], Greco Ilaria[1,*], Ferretti Marco[2] and Zaccaroni Marco[1,]**

[1] *Department of Biology, University of Florence, Florence, Italy*
[2] *Regione Toscana, Corso Gramsci 110, IT-51100 Pistoia, Italy*

Abstract. The European hare (*Lepus europaeus*) populations are declining throughout Europe due to intensive agriculture and hunting pressure. In Italy, information on this species is biased and focused on plain terrains, while data over mountains are scant. The study aimed to fill such a research gap, providing estimates on the population density and habitat preferences on a suboptimal mountainous environment in Italy, using the standardised pellet-count method. One protected area and two hunting areas were surveyed between June and August 2017, with 117 plots randomly checked for faecal pellets. The estimated density on mountainous territories ranged from 16 to 23 individuals/km^2, which resulted high for a non-favourable environment. Land cover was the most important predictor in the model, with arable lands and areas with sparse vegetation as the preferred land use. Habitat selection drove the altitudinal distribution of the hare, with high elevations preferred over lower altitude. Steepest slope and NE, SW, and West-faced plots were displaying less probability to find pellets. The density in the protected and hunting areas was similar, with the hunting ban being the least significant predictor. Despite the climate and altitude, the environmental heterogeneity of the Italian Apennine might offer a good-quality habitat for the European hare.

Key words: habitat heterogeneity, lagomorphs, land use, pellet-count, suboptimal environment.

The European hare (*Lepus europaeus*) is one of the most widespread small mammal species worldwide, as well as a valuable game species (Santilli 2007). Its distribution initially goes from Spain to the Southernmost part of Scandinavia, from the Northern Middle East to some portions of Siberia, but it has been extensively reintroduced in several countries across the globe (Chapman and Flux 1990). In Italy, the European hare was originally distributed in the Central and Northern regions, also presenting an autochthonous subspecies, the *L. e. meridiei* (Mengoni et al. 2015). However, its distribution has also been shaped by deliberate restocking for recreational hunting with the introduction of farm-reared individuals (Riga et al. 2001). As a consequence, already in the early 1990s, the species was distributed to the whole Italian peninsula.

Since the 1960s, European hare populations underwent a gradual decline throughout Europe (Smith et al. 2005a; Smith et al. 2005b; Santilli 2007; Smith and Johnston 2008). Such crisis was triggered by the agricultural intensification of farmlands, which resulted in a widespread loss of habitat heterogeneity (Mayer et al. 2018) and a reduction of important palatable grasses (Schai-Braun et al. 2015). The decline was also exacerbated by the emergence of highly virulent lagoviruses (Wibbelt and Frölich 2005) and by the overexploitation of hare populations for recreational hunting (Olesen and Asferg 2006). This decline was so severe and quick that the species was included in Appendix III of the Bern Convention on the European Wildlife and Natural Habitat (Mitchell-Jones et al. 1999) and some countries, like Germany and Norway, listed it as "near threatened" or "threatened" species (Reichlin et al. 2006) adopting special regulations for their conservation.

Given the pivotal role of habitat quality in the numerical decline of hares at the European scale, and the role played by the species as a game and in the trophic chains, many studies addressed the relationship between habitat quality and population parameters of the European hares,

*Naldi Lorenzo and Greco Ilaria contributed equally to this work.
**To whom correspondence should be addressed. E-mail: marco.zaccaroni@unifi.it

in the attempt to enforce effective conservation measures (Vaughan et al. 2003; Smith et al. 2005a).

Overall, the abundance and the presence of European hares, as well as their distribution and density, are generally connected with areas with open vegetation and with the presence and fertility of extensive arable fields (Schröpfer and Nyenhuis 1982). Conversely, the hare tends to avoid dense and extended woodlands, cold and humid terrains, shaded slopes and high altitude, which constitute suboptimal habitats (Spagnesi and Trocchi 1993; Vaughan et al. 2003; Trocchi and Riga 2005). Hence, mountainous territories might represent less favourable environments since the soil become progressively dry and nutrient-poor, woods and forests become the main land use, and these characteristics might not maximise the hares' fitness.

Nowadays, quantitative information regarding the hare density on the Italian peninsula is heterogeneous and biased, as the main studies focus almost entirely on the Mediterranean farmlands or lowlands (Meriggi and Alieri 1989; Ferretti et al. 2010; Cardarelli et al. 2011; Bertolino et al. 2013). Information on which densities the European hare reach, and which habitat they select in Italian mountains, such as the Apennines, is lacking. Addressing this issue might be necessary for hare conservation in these environments, which are facing quick rewilding dynamics and significant landscape changes (Vitali et al. 2018). This study aims to fill such a gap, providing information on the density and macrohabitat selection of the European hare in Northern Apennines. This was done by using the pellet-count technique, eventually estimating if a suboptimal habitat, as the mountainous territories, might represent a good-quality habitat for hares. Hence, habitat preferences were estimated as the probability of finding hare's pellet on the different land use considered.

Materials and methods

Study areas

The survey of hare populations was performed from June to August 2017 over one protected area and two hunting areas: the Western zone and the Eastern zone, all of them are located in the province of Pistoia, Tuscany, Italy (Fig. 1). The three areas are characterized by deep valleys, pastures, open fields, and rocky terrains at high elevation, as well as cliffs, and ridge sections reaching 2000 m a.s.l. Mean temperatures are stationary at 25°C during June–August, whereas they range between –1°C and –3°C during December–February, with occasionally abundant snowfall that ranges between 5 and 100 cm, whereas mean annual precipitations are above 1000 mm. The protected area, Oasi Dynamo, is a hunting-free zone established in 2006 (www.dynamocamp.org), affiliated with the WWF (World Wide Fund for Nature) network of protected areas (Fig. 2). It was founded on the territories of a former hunting reserve, and the abandoned industrial buildings located downstream have been recovered to a camp for children suffering from diseases, to be subjected to recreational therapy. Additionally, the protected area is actively devoted to scientific research and conservation projects, also promoting environmental education. The protected area has a noteworthy fauna assemblage which includes ungulates, like red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), fallow deer (*Dama dama*), and muflon (*Ovis orientalis*). Hares constitute part of the diet for a variety of predators, like wolves (*Canis lupus*), foxes (*Vulpes vulpes*), least weasels (*Mustela nivalis*), beech martens (*Martes foina*), golden eagles (*Aquila chrysaetos*), and buzzards (*Buteo buteo*). It extends for 1000 ha, the altitude ranges between the 599 and 1204 m a.s.l., and the land use is mainly characterized by deciduous and coniferous forests, alternated by patches with open vegetation. The latter covers about 150 ha and includes arable fields, areas with sparse vegetation, meadows, grazing areas, and bare rocks. Such open areas are managed through traditional agroforestry management, including equine and cattle breeding, vegetable and fodder cultivations, and forest clearcuttings.

On the other hand, the hunting territories extend for a total of approximately 2967 ha, and mixed woods primarily constitute them and reach the maximum altitude of 1938 m a.s.l. Notably, the Western area has an extension of 1022 ha, with open areas and woods covering 352 ha and 620 ha, respectively (Fig. 3a). Thus, the Eastern area is larger with an extension of 1945 ha, where open areas occupy only 439 ha, whilst 1366 ha are covered by woods (Fig. 3b). The patches of open vegetation are managed by local farms and by the ski facilities, as well as by the action of climate on the ridge areas, which does not allow the arboreal vegetation to settle down.

Data collection

Indirect methods that link signs of animal presence to the overall number of individuals are more efficient in habitats where hares cannot be directly observed or in the presence of physical barriers that makes the observation cost-inefficient (e.g., snow, terrain roughness). The pellet-count method can be considered a good quality

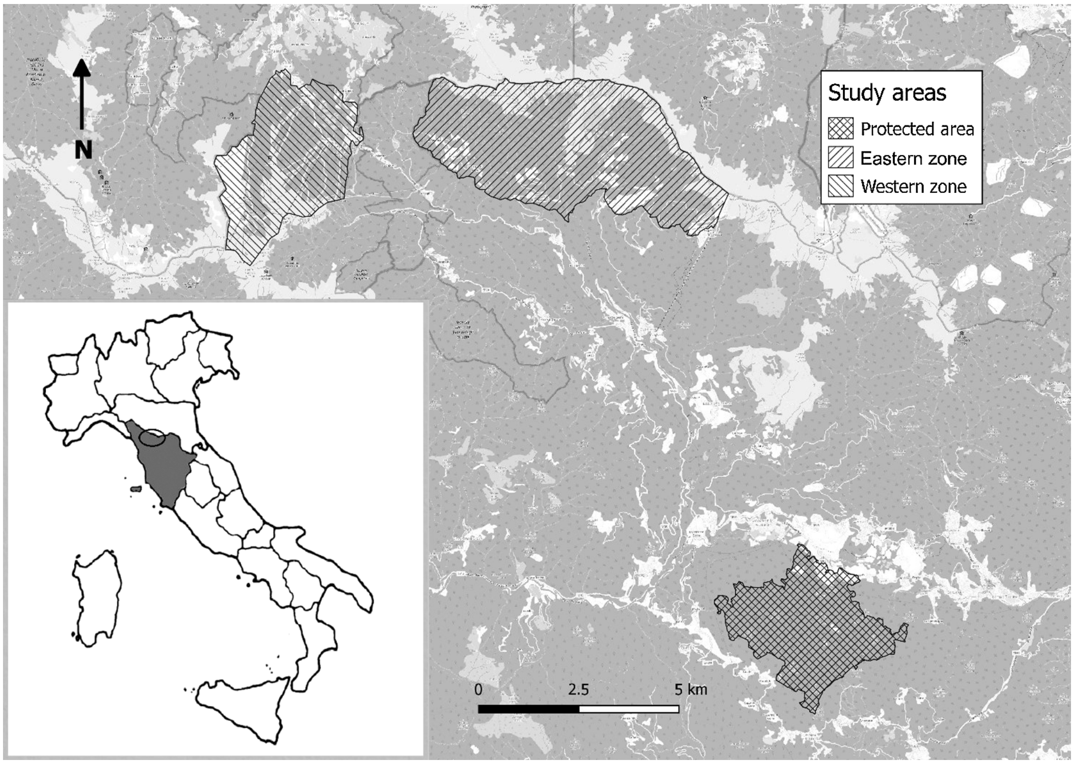

Fig. 1. Study areas on the Italian Apennine in Tuscany. In the lower section of the figure the protected area is located, whereas in the upper part the two hunting areas are located.

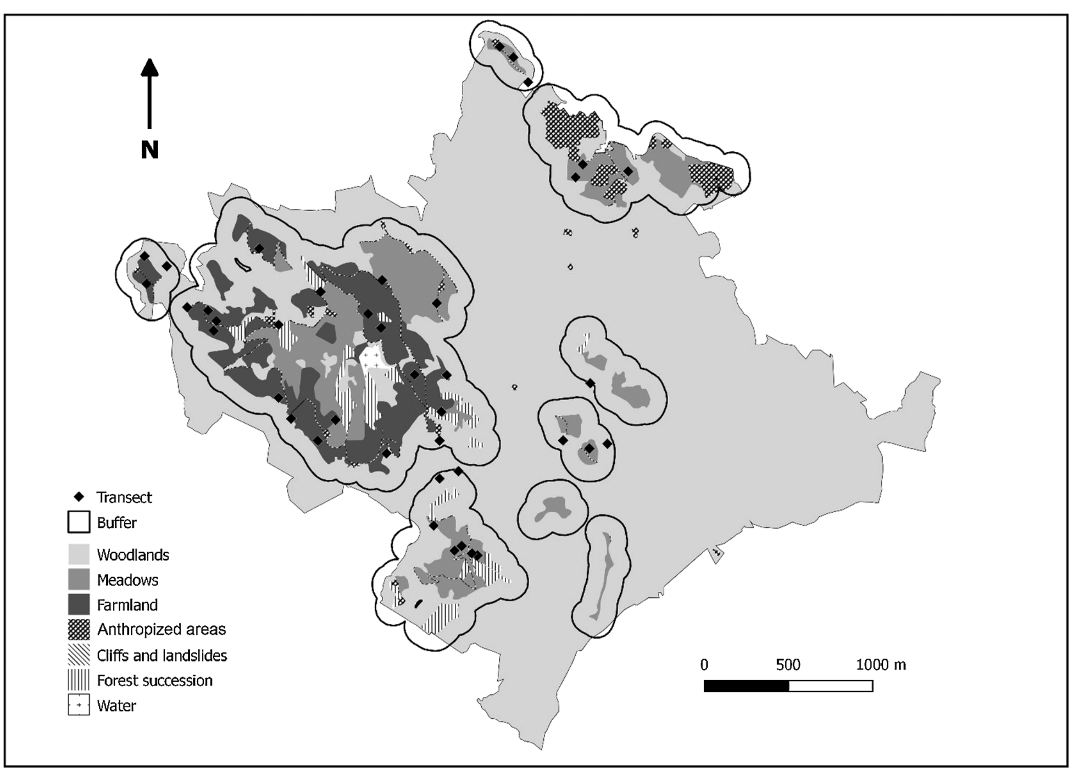

Fig. 2. Study area representing the protected and hunting-free area on the Tuscan Apennine, Italy. The figure shows the patches with open vegetation and adjacent wood patches. The figure shows the different land uses while the outline represents the 100 meters buffer around the open areas.

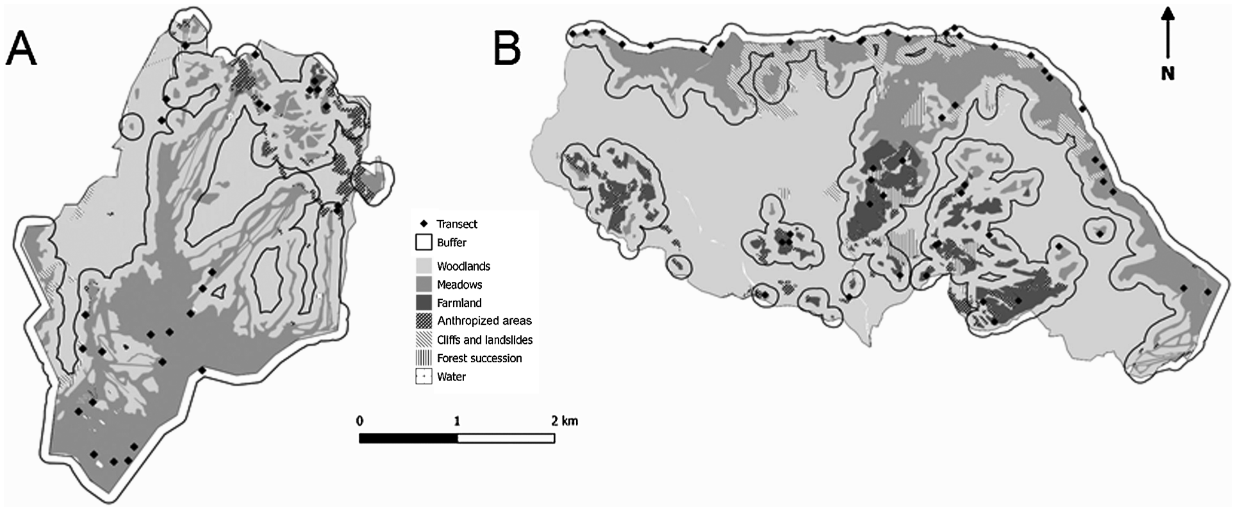

Fig. 3. Study area representing the Western (a) and Eastern (b) hunting areas on the Tuscan Apennine, Italy. The figure represents the land uses, whereas the outline indicates the 100 meters buffer zone around the considered patch with open vegetation.

density estimator; it is a non-invasive method used to estimate the density of a wildlife population, counting the number of droppings on the ground (Lioy et al. 2015). These are then linked to the defecation rate and the decomposition rate of the target species, governing the pellets' production and disappearance (Putman 1984). For this study, we used the Faecal Accumulation Rate (FAR) technique to estimate the density of European hares. It assessed the daily accumulation of pellets through two visits at the sampled area and took into account only the accumulation rate as the parameter, avoiding accounting for the decomposition rate (Neff 1968; Bailey and Putman 1981; Mayle et al. 1999; Campbell et al. 2004). The FAR method measures the accumulation rate of faecal pellets between two points in time on a given area and aims to detect the pellets before their degradation, setting a time interval between sampling events which is shorter than their degradation time, yet long enough to allow new accumulation (Mayle 1996; Laing et al. 2003). During the first visit, all faecal traces encountered within each plot were removed, whereas the land use and direction were recorded. The second survey took place 24 days after the first survey for the protected areas, and 20 days after for both the hunting areas. Following the guidelines of previous research, we carried out the second visit after approximately 20 days, since degradation time for European hares has been assessed to be completed at 35 days (Langbein et al. 1999). Additionally, we conducted the survey during the summer due to the meteorological conditions and the geomorphological features of the study location. In fact, in winter, the snow and the presence of landslides make it difficult to explore the area, whilst the abundance of the precipitations in autumn and spring makes the decomposition rate higher compared to the summer months, which are dryer (Forys and Humphrey 1997).

For this research, we counted hare pellets over 117 plots of 25 m^2 (25 × 1 m), in a 100 m buffer around open areas, which was arbitrarily set. According to literature, hares primarily occupy patches with open or sparse vegetation, where they mainly feed and defecate, whereas areas with dense vegetation appeared to be the least preferred ones, with hares spending little time or generally displaying a considerable decrease in their abundance (Smith et al. 2005a). Hence, we surveyed within the 100 m buffer because we primarily focused on open areas, where hares forage at night and produce their pellets (Langbein et al. 1999), yet with no exclusion of the forests. Therefore, the selection of 100 meters as a threshold for the buffer zone appeared appropriate since such distance allowed to survey both the outer parts of the forest and the inner parts yet avoiding the core of the forest patches. Thus, this choice maximized the efficiency of data collection without providing a significant bias in terms of density estimation. The transects were placed within the buffer area on points randomly generated with the opensource software QGIS (QGIS Development Team). We set 40 plots in the protected area, 25 in the Western area and 52 in the Eastern area, with the randomisation stratified according to land cover (Figs. 2, 3a, and 3b). The direction of the plots was set to follow the isoline. Hence, through the use of CORINE Land Cover (Copernicus Land Monitoring Service) shapefile, we combined the land use into seven main categories, which were: woodland (n = 23), meadows (n = 15), grasslands (n = 13), forest succession stages meant as patches with sparse vegetation (n = 23), farmlands (n = 28), cliffs and landslides (n = 12), and anthropized areas (n = 3).

Statistical analyses

To estimate the density of the European hare population, we used the following formula (Forys and Humphrey 1997):

$$N/\mathrm{ha} = \frac{\Sigma P}{T * F * A} * 10{,}000$$

With N/ha representing the density expressed as the number of individuals per hectare, ΣP referred to the total sum of the faecal pellets, T describing the accumulation time, F representing the defecation rate, and A indicating the total area covered by the transects where pellets were surveyed. The area was expressed in m^2, and the 10 000 multiplication allowed the conversion from m^2 to ha. The specific defecation rate for the target species was estimated by Cerri et al. (2015), which equals to 394.9 pellets per day for the European hare. Finally, to obtain km^2 from ha, we then multiplied the outcome by 100.

We then used a Random Forest algorithm (James et al. 2013; Liaw and Wiener 2014) to estimate which characteristics of the transects were associated with the presence of hares. Predictors included the land cover, the exposure, and terrain slope, and the occurrence into a hunting-free area. Notably, the exposure, the slope, and the altitudinal values were extracted on QGIS using a Digital Elevation Model (DEM). We used half of our sampling points to train the Random Forest (n = 58), then we used the remaining half to test its predictive power. Predictive accuracy was measured through the Area Under the Receiver-Operator Curve (AUC and ROC). Values of the AUC greater than 0.80 indicate that the model has good predictive power. We also used the Mean Decrease in the Gini Index to test the contribution and the relative importance of each predictor for model fitting. All the statistical analyses were computed using the opensource software R (R Core Team 2019, version 3.6.0).

Results

A total of 213 pellets were counted in the protected area, within a total sampled area of 1000 m^2. Applying the formula, we found a density equals to 22 individuals/km^2. For the Western area we counted 113 pellets over a total sampled area of 625 m^2 and an estimated density of 23 individuals/km^2, whereas for the Eastern area we counted 162 hare's pellets over a total sampled area of 1300 m^2 and an estimated density of 16 individuals/km^2.

The Random Forest analyses displayed that the model stabilised the out-of-bag error curve after about 40 trees, decreasing the errors from 0.45 to 0.30, although remaining with minor fluctuations. The estimation of the predictive power of the model displayed a good level of prediction, with AUC value equals to 0.81. The relative importance of the predictors underpinned that they contributed differently to the model, having a specific degree of importance. Specifically, the higher the Mean Decrease in the Gini index, the greater the importance of a predictor. Mainly, the most important predictor was the land cover with values of Mean Decrease in the Gini Index of 6.87. Other relevant predictors were the slope and the exposure, with values of 6.53 and 5.71, respectively; whereas being within a hunting-free area, thus having a hunting ban, appeared to be the least significant predictor (Mean Decrease in the Gini Index of 1.02). Notably, the habitats with the highest presence of pellets were those with sparse vegetation along with arable lands, in fact, 28.30% of the total pellet was found in forest succession stages and 26.41% in farmlands (Table 1). Areas with sparse vegetation (65%), grasslands (69%), and cliffs and landslides (rocky patch, 58%) had the highest probability of finding hare pellets (Table 1). Conversely, woodlands had the lowest presence probabilities than the average, with the 0% of pellets found there (Table 1). Additionally, the highest values of faecal pellet were found between 1501 and 1850 m a.s.l., and between 867 and 1370 m a.s.l. (Table 2), with a maximum presence of hare's pellets especially concentrated between 1631 and 1750 m a.s.l., with the pellet presence that increased steadily with the altitude of each location. Furthermore, when considering the slopes and the exposure of the terrain where each plot was placed, we found that pellets' presence became progressively unlikely for steeper slopes (Fig. 4), as well as on western-faces plots and for SW and NE exposures (Fig. 5).

Table 1. Land use in relation to the presence of hare pellets found within the plots

Land use	N. plots with pellets	% pellets found	N. plots without pellets	% pellets absent	% Probability of finding pellets
Meadows	6	11.32	9	14.06	40
Farmlands	14	26.41	14	21.87	50
Woodlands	0	0	23	35.94	0
Forest succession stages	15	28.30	8	12.50	65
Anthropized areas	2	3.77	1	1.56	67
Grasslands	9	16.98	4	6.25	69
Cliffs and landslides	7	13.21	5	7.81	58
Total:	53	100	64	100	

The table shows the number of plots where pellets were found, the number of plots without the presence of pellets, the respective percentage of pellet presence and absence in relation to the total number of transects and finally the probability of finding hare pellets.

Table 2. Altitude in relation to the presence of pellets found within the plots

Plot altitude m a.s.l.	N. plots with pellets	% pellets found	N. plots without pellets	% of absence	% Probability of finding pellets	Land use
611–866	0	0	8	12.60	0	Meadows
867–1370	22	41.20	38	59.40	37	Forest succession stages & Anthropized areas & Meadows & Farmlands & Woodlands
1371–1500	0	0	4	6.20	0	Woodlands & Farmlands
1501–1850	31	58.80	14	21.80	84	Cliffs/landslides & Grasslands & Forest succession stages
Total:	53	100	64	100		

The table displays the number of plots where pellets were found, the number of plots without the presence of pellets, the respective percentage of pellet presence and absence in relation to the total number of transects, the probability of finding hare pellets and the land cover associated to each altitudinal level.

Discussion

The population density of the European hare is currently declining throughout Europe (Smith and Johnston 2008), whilst in Italy its density is relatively stationary and generally affected by a trade-off between the reintroduction of farm-reared hares and the hunting activity. Overall, at the national level, this leads to a population which is increasing (Trocchi and Riga 2005). Nonetheless, quantitative information is not homogeneous, and no data are available over the mountainous territories of the Italian Apennine. According to our findings, the overall density on the Tuscan Apennine appeared to be high (22 individuals/km^2 in the protected area, 23 individuals/km^2 and 16 individuals/km^2 in the hunting areas) considering that the study was carried out on a mountainous environment, although it is usually addressed as extreme/non-favourable for the European hare due to the climatic conditions and the presence of suboptimal habitats. In Italy, the densities for the European hare in a non-favourable environment usually range from 5 to 10 individuals/km^2 in autumn and less than 5 individuals/km^2 in spring (Spagnesi and Trocchi 1993), and thus, they are considerably lower than the results reported on this research.

The present study was carried out in summer (June–August), whereas peaks of population densities are usually recorded in autumn, where the density often doubles (Spagnesi and Trocchi 1993). The high abundance of European hare found in this study could be explained considering the vast heterogeneity of land use presented in the Tuscan Apennine, with the many extensive cultivations and arable lands (including alfalfa, tubers, and crops growing cereals), fields of natural open vegetation, and pastures. The diversity of land uses over the Tuscan Apennine might promote a higher density of European

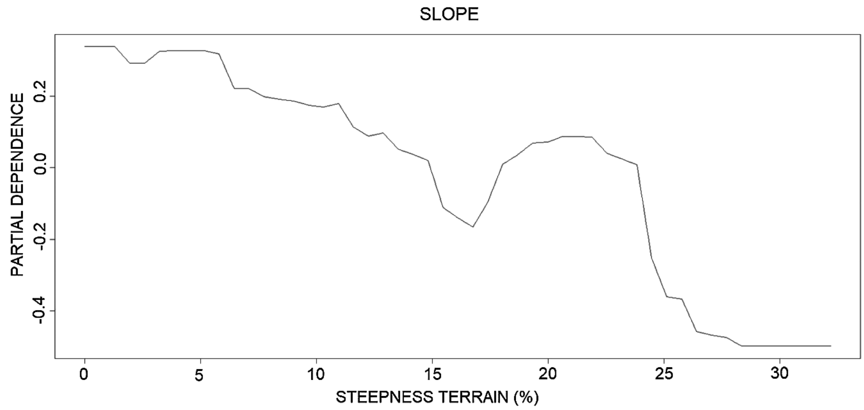

Fig. 4. Partial dependence plot for the evaluation of the marginal effects of the predictor "slope" of the Random Forest model. It represents the estimated marginal effect of the variable when all the other variables are held at their average. The graph displays the probability of finding hare pellets in relation to the steepness of the terrain. The steepest the terrain, the more unlikely it is to find hare pellets.

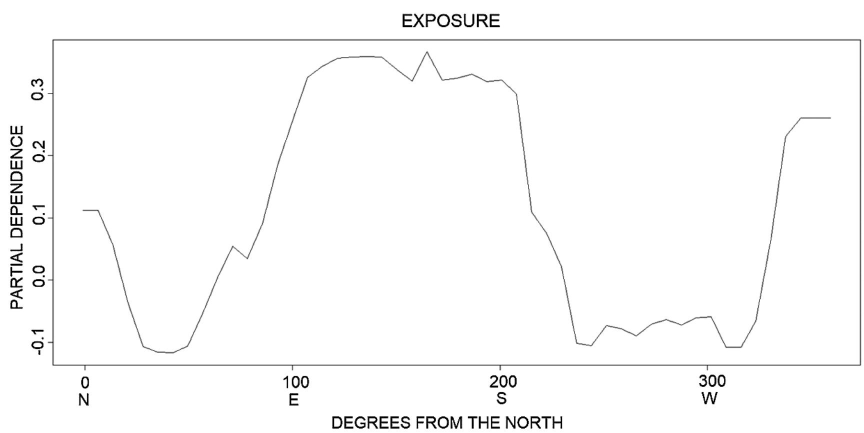

Fig. 5. Partial dependence plot for the evaluation of the marginal effects of the predictor "exposure" of the Random Forest model. It represents the estimated marginal effect of the variable when all the other variables are held at their average. The graph displays the probability of finding hare pellets in relation to the exposure of the terrain. On West-faced plots and NE and SW exposures, the probability of finding hare pellets is unlikely.

hares, with the arable fields providing food resources all the year-round, while woodlands and patches with dense vegetation are potentially providing shelter and coverage against predators (Reichlin et al. 2006; Vidus Rosin et al. 2010). Such habitat diversity could supply a patchy distribution of sheltering and food sites, a various diet provided by the different cultivations, and access to resources available also in wintertime (Santilli et al. 2004; Smith et al. 2005a; Santilli 2007). Hence, the ideally non-favourable mountainous environment might be a potential good-quality habitat for the European hare.

According to our study, the highest concentration of hares corresponded to the presence of areas with sparse vegetation (forest succession stages) and arable lands (Table 1). Our results seemed consistent with previous studies that also supported the importance of fertile crop rotation systems, which is usually positively associated with the presence of the European hare. Hence, extensive cultivations and patches with sparse vegetation, or generally open areas, represent the most suitable habitats for this target species (Tapper and Barnes 1986; Smith et al. 2005a). Furthermore, the land cover, the slope, and the exposure appeared to be the environmental factors mainly affecting the presence and distribution of the European hare in the Apennine areas. Specifically, habitat selection according to the land use appeared to influence the altitudinal distribution of the European hare across the mountain. The Gini Index analyses also underpinned that the land cover was the most important predictor in the model. In fact, the highest presence of pellets was found between 1501 and 1880 m a.s.l., which corresponded to open areas, in particular to forest succession stages, grasslands, and rocky patches (cliffs and landslides). Here, we have found the 58.80% of hares' pellets in approximately only 400 meters of elevation range (Table 2). Likewise, the altitudinal zone ranging between 867 and 1370 m a.s.l., which presented a variety of land cover including arable lands as main land use, also displayed a high presence of hares, with the 41.20% of hares' pellets found here (Table 2). On the other hand, no signs of presence were found between 611–866 m a.s.l. and 1371–1500 m a.s.l.; particularly, the latter range was mostly covered by woodlands, supporting the thesis that woods and patches with dense vegetation are the least preferred habitats. Hence, land use could play a pivotal role, since habitat selection seems to affect the altitudinal distribution of the species. Particularly, suitable habitats corresponded to areas with the typical ridge vegetation at high elevation and arable fields, even though cultivations are quite limited on mountainous territories. We also found that the probability of finding hare pellet decreased with the increase of the steepness of the terrain, since places with steep slope might be a dangerous location for hares to venture.

We found no remarkable difference between the density in the protected area and the one in the two hunting sites, with a density of 22 hares and 16–23 hares per km^2, respectively. These results suggest that the hunting activity might not affect the density nor the process of habitat selection, dramatically. In fact, considering the density found in the area, the hunting pressure appeared to be low, with approximately 30 hares hunted per year (M. Ferretti personal communication). Additionally, the hunting ban was the least important parameter in the model. Such results could be addressed considering that the Italian Apennine presents geomorphological features and environmental conditions that could make the mountain hardly accessible for hunters, especially on the ridge sections where we have found the highest presence of pellets. Moreover, mountainous territories and their physical characteristics might offer to the European hare better opportunities to hide or higher chances for escaping, which would make the chasing harder. An additional factor promoting such a high density in the hunting area might be that the human population density on the Tuscan-Emilian Apennine is reasonably low (about 30 000 inhabitants over 26 000 ha), with consequently few potential hunters practicing in the area and low hunting pressure. Furthermore, the difference in the density between the two hunting areas might be primarily connected to the proportion of wooded area inside the study sites.

For this research, all the analyses were based on the pellets found on the transects using the pellet-count method (FAR). The FAR method appeared to be an optimal technique providing a sensitive index of population density (Parkes 2001). The performance of a count-based sampling method depends on two crucial issues, which are the efficacy of the sampling and the efficacy of the visibility (Aubry et al. 2012). In this context, the pellet-count method could represent the tool of choice especially when the survey is performed on mountainous territories since it allows to reach remote areas, requires minimum equipment, can be carried out by foot, and provides reliable outcomes. We suggest using the pellet-count method when sampling over mountains because it can be performed at daytime in regard to the geomorphological environmental conditions of the study area, and importantly it enables to sample in different habitat types.

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