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DO SOILS AFFECT BROWN HARE *LEPUS EUROPAEUS* ABUNDANCE IN AGRICULTURAL HABITATS?

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ABSTRACT - In recent years, much research on brown hare (*Lepus europaeus,* Pallas 1778) ecology has been conducted in Europe to identify habitat-species relationships and the reasons for the decline in hare populations that have occurred since the 1960s. However, very few studies have considered the influence of soil texture on the abundance of this species in agricultural habitats. In this paper we examine the relationship between winter brown hare density in protected areas (game refuges) in four provinces of the Tuscany region (central Italy) and soil texture. Results show that hares reach higher densities in areas characterized by "loam" soils compared to areas where soils are richer in clay. Although this relationship is probably complex, soil texture may indirectly affect brown hare populations by influencing the temperature and moisture of the ground and influencing the timing of farming operations (tillage).

Key words: soil texture, farmland, hare density, central Italy

RIASSUNTO - ***Il suolo influenza l'abbondanza della lepre* Lepus europaeus *negli ambienti agricoli?*** Negli ultimi anni sono state effettuate numerose ricerche sull'ecologia della lepre europea *Lepus europaeus*, al fine di evidenziare le relazioni fra questa specie ed il tipo di habitat e di comprendere i motivi del declino avvenuto a partire dagli anni '60. Cionononostante pochi studi hanno preso in considerazione l'influenza del tipo di suolo sulla consistenza di questo lagomorfo negli ambienti agricoli. Nel presente lavoro viene esaminata la relazione fra la densità invernale della lepre all'interno delle zone di ripopolamento e cattura di quattro province toscane e la tessitura del suolo di queste aree. E' stato riscontrato che le lepri raggiungono densità più elevate in aree dove predominano i suoli franchi rispetto ad aree dove risultano più argillosi. Sebbene questa relazione sia probabilmente complessa, la tessitura del suolo potrebbe influenzare indirettamente le popolazioni di lepre sia modificando la temperatura e l'umidità del terreno sia influendo sulla tempistica delle lavorazioni agricole.

Parole chiave: Lepus europaeus, tessitura del suolo, aree agricole, densità, Italia centrale

INTRODUCTION

Soils are a fundamental component of the ecosystem, directly or indirectly influencing the distribution and abundance of wildlife. One of the most important features of soil is texture, which depends on the content of sand, clay and silt. Because of the different nature of each textural group, many wild species have developed associa-tions with specific soil conditions. Many of these relationships are indirect and usually concern vegetation, whilst for others, the associations are more direct, especially for species living on the ground (Robinson and Bolen, 1989). As an example, in its native European range the grey partridge *(Perdix perdix*) is associated with sandy or other well drained soils (Dale, 1942, 1943).

Because of the value of the brown hare (*Lepus europaeus*) as a game species, much research has been conducted in various European countries to identify habitat-species relationships and, in particular, to evaluate the effect of agricultural intensification (Baldi and Farago, 2007; Schmidt *et al.,* 2004, Smith *et al*., 2005). Nevertheless, very few studies have considered the effect of soil type on hare density. In Germany, brown hare abundance was found to be associated with soil fertility, which is probably linked with permeability (Schröpfer and Nyenhuis, 1982).

In a study carried out in large enclosures (semi-natural rearing), hare productivity was negatively affected by the clay content (%) and positively by the sand content of the soil (Santilli *et al.,* 2004).

To verify the effect of soil texture on hare abundance in natural conditions, we examined the relationship between soil texture and winter brown hare density in agricultural habitats in central Italy.

STUDY AREA AND METHODS

We used data on hare density from 133 protected areas (average surface 706.6 ha, SD = 282.65) scattered in four provinces of the Tuscany region: Florence (N=38; period: 2000-04), Pisa (N=24; 1999-04), Siena (N=48; 1996-04), and Grosseto (N=23; 2001-04). The habitat characteristics of the protected areas, obtained by Corine Land Cover 2000 (http://dataservice.eea.europa.eu/dataservice/) are reported in Table 1.

These areas, managed for small game species reproduction (pheasant *Phasianus colchicus* and brown hare), are used for restocking hunting areas by natural spreading

Table 1 - Habitat characteristics of the protected areas of the four provinces considered (Corine Land Cover 2000); W = woodlands; AL = arable lands; C = Annual crops associated with permanent crops; CP = Complex cultivation patterns; V = vineyards; OG = Olive grows; PG = pastures and grasslands.

Province	W (%)	AL (%)	C (%)	CP (%)	V (%)	OG (%)	PG (%)
Florence	22.5	28.9	0.6	20.1	11.5	15.1	1.3
Pisa	10.2	71.9	0.9	10.8	1.5	0.7	4.1
Siena	11.8	57.5	0.3	15.7	5.8	1.8	7.1
Grosseto	12.5	55.0	1.5	23.6	0.4	3.8	3.3

and/or by capture and relocation (Santilli and Galardi, 2006). Brown hares were counted every winter using spotlights as described by Frylestam (1981) and Barnes and Tapper (1985). Density data were obtained by the Game and Wildlife Offices of the four provinces. Using GIS software (Arcview 3.2 ESRI 1996) the shape file of the protected areas was overlapped on a soil texture map downloaded by the web site of the Tuscany Region Map Department (http://sit.lamma.rete.toscana.it/websuoli/).

Every protected area was classified in six soil texture categories according to the USDA classification (Fig. 1) (Soil Survey Division Staff, 1993). Where two or more kinds of soil were recorded we classified the area according to the most represented. Those areas lacking a predominant kind of soil were discarded. Raw frequency data of the different kind of soils in the protected areas of the four provinces were analysed using the Chi-square test (Tab. 2).

Data were analysed considering Soil Texture and Province as independent categorical variables (interaction was checked and found not significant) and hare density as the dependent variable (two-way ANOVA). Since the years considered are not the same for all provinces, this factor was nested within Soil Texture. Tukey's multiple comparison of means was carried out to identify significant differences between means for Soil Texture and Province ($P < 0.05$) (SAS, 2002).

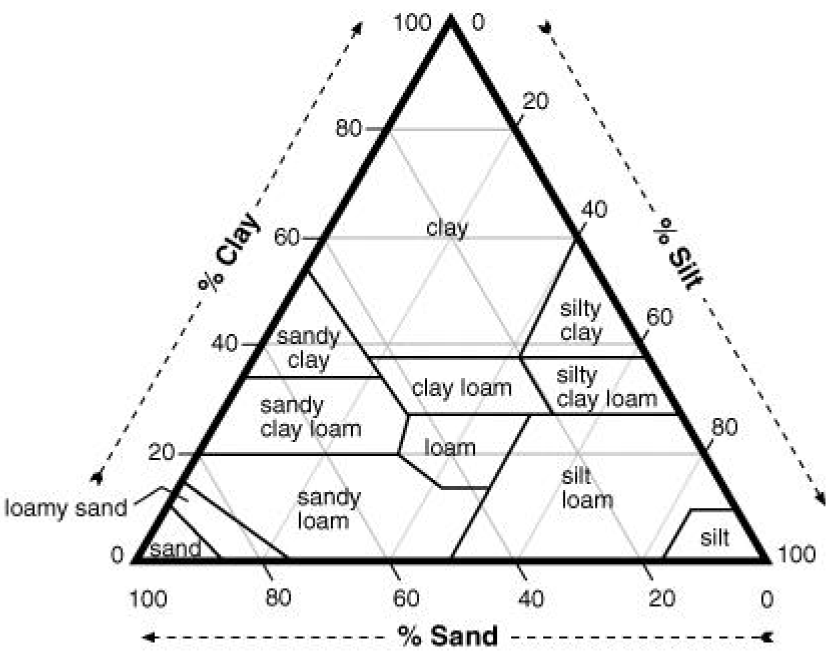

Figure 1 - Triangle of soil texture classes (USDA Classification; Millar *et al.*, 1958).

Table 2 - Frequencies of the different kinds of soil in the protected areas of the four considered provinces. Means within the same row with different letters are significantly different (P<0.01).

Provinces	Florence (%)	Grosseto (%)	Pisa (%)	Siena (%)	χ^2	P
Silty-clay	7.9 A	13.0 A	58.3 B	33.3 B	22.21	<0.001
Loam	21.1	0.0	8.3	14.6	6.27	N.S.
Clay-loam	34.2 A	60.9 A	12.5 B	22.9 AB	15.13	<0.001
Silty-loam	7.9	0.0	0.0	0.0	7.37	N.S.
Silty-clay-loam	21.1	13.0	8.3	20.8	2.43	N.S.
Sandy-loam	7.9	13.0	12.5	8.3%	0.75	N.S.

RESULTS

The result of the nested analysis of variance showed a significant effect of both Province and Soil texture on brown hare density (Tab. 3).

Brown hare density was significantly higher in the protected areas of the Florence province (35.3 hares/km^2). In the province of Siena hare density (16.5 hares/km^2) was significantly higher than in the Grosseto province (9.0 hares/km^2), but not compared to Pisa province (9.1 hares/km^2).

With regard to soil texture, the highest hare density was found in the areas with a prevalence of Loam soil (23.87, SE 2.374), followed by Silty-Clay Loam soil (21.25, SE 1.737), Sandy-Loam soil (20.70, SE 2.572), Clay-Loam soil (17.71, SE 1.590), Silty-Loam soil (15.09, SE 4.316), and Silty-Clay soil (9.49, SE 1.634) (Fig. 2). Only the density registered as Silty-Clay soil differed significantly from the others.

Table 3 - Analysis of variance for estimating the effect of Province and Soil Texture on brown hare density in the protected areas of central Tuscany (R^2 = 0.413).

Factors	d.f.	F	P
Province	3	165.59	<0.001
Year within Soil Texture	45	1.15	N.S.
Soil Texture	5	20.47	<0.001

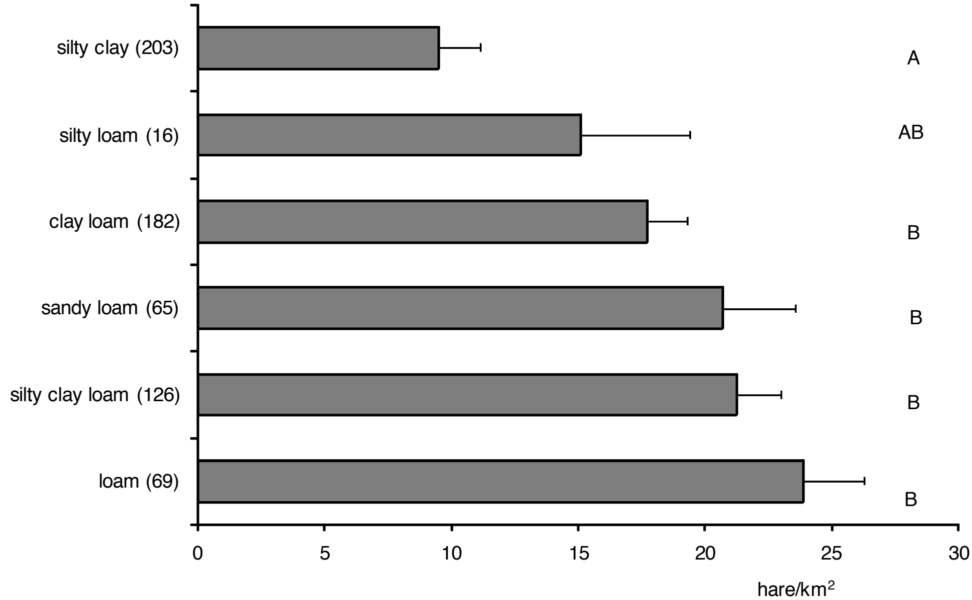

Figure 2 - Average brown hare density (hares/km^2) and SE according to soil texture. Different letters mean significant differences (P< 0.01).

DISCUSSION

The differences found in hare density between the protected areas of the four provinces probably depend on both environmental and management factors.

Brown hares seem to reach the highest density in areas where the soil can be basically defined as "loam", which generally is fertile and well drained, compared to areas where soils have a higher content of clay and a lower content of silt and/or sand. Accordingly, brown hares reach the highest density in the protected areas of the province of Florence, where Silty-clay soils (the most clayey among those available in our study area) showed the lowest incidence.

Soils with a high content of clay tend to maintain a high moisture level, especially during autumn and winter when rainfall is more frequent and intense, and lose more easily the "crumb structure" obtained by tillage, reducing permeability. Soil humidity, together with low temperatures, can favour various diseases, enhancing hare mortality and lowering their reproductive success (Spagnesi and Trocchi, 1992; Lamarque *et al.*, 1996; Lavazza and Capucci, 1996; Santilli *et al.,* 2004). Moreover, after rainfall clay soils tend to form a muddy, sticky layer which may be unsuitable for a running species such as the brown hare.

Soil texture may also affect hare density indirectly by influencing farming techniques: soils with a high content of clay (defined as “heavy” by farmers) are generally more difficult to till and need to be ploughed early before seeding. Consequently cereal stubbles are often ploughed just after the harvest, dramatically reducing food and cover for hares and much other wildlife.

However, the relationship between brown hare abundance and soil texture is probably complex and other indirect effects of soil texture, such as the type and structure of vegetation in still available natural patches, are probably involved.

Since detailed land use maps of the protected areas are still not available we are not able to fully consider agro-environmental factors. However, in the protected areas of the province of Florence (Tab. 1) there is a higher incidence of habitats favourable to brown hares, such as vineyards, which have been proved to influence positively the bag record of this species in Tuscany (Santilli and Galardi, 2006) and may partially explain the higher density registered in this province.

The provinces of Siena, Grosseto and Pisa have a quite similar agricultural habitat, but in the Siena province, protected areas are always game-managed by full-time professional personnel, whereas in the other two provinces this activity is generally carried out by part-time or volunteer game-keepers. Consequently, predator and poaching control is more effective in this province than in the others. It is known that predators (particularly the red fox *Vulpes vulpes*) can be a limiting factors for brown hare abundance (Lyndstrom *et al*., 1994, Reynold and Tapper, 1995, Vaughan *et al*., 2003, Schimdt *et al*., 2004). Accordingly, hare populations have been observed to increase in numbers subsequent to predator control by humans (Stoate, 2006; Tapper *et al*., 1991).

The results of the present study suggest that soil texture, even though it is only one of the many environmental factors that can affect brown hare populations, should be considered as a significant variable in building a predictive model of habitat quality and to program management and conservation actions specifically for enhancing hare reproduction in those landscapes deeply modified by agricultural practices.

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