



# Simulating Brown hare (*Lepus europaeus* Pallas) dispersion: a tool for wildlife management of wide areas

Raffaele Pelorosso<sup>1</sup>, Lorenzo Boccia<sup>2</sup>, Andrea Amici<sup>3</sup>

<sup>1</sup>Dipartimento di Tecnologie, Ingegneria e Scienze dell'Ambiente e delle Foreste.  
Università della Tuscia, Viterbo, Italy

<sup>2</sup>Dipartimento di Ingegneria Agraria e Agronomia del Territorio.  
Università di Napoli "Federico II", Napoli, Italy

<sup>3</sup>Dipartimento di Produzioni Animali. Università della Tuscia, Viterbo, Italy

*Corresponding author:* Prof. Lorenzo Boccia. Dipartimento di Ingegneria Agraria e Agronomia del Territorio. Università di Napoli "Federico II". Via Università 100, 80055 Portici (NA), Italy - Tel. +39 081 2539425 - Fax: +39 081 2539412 - Email: lorenzo.boccia@unina.it

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## ABSTRACT

The second half of the 20<sup>th</sup> century was characterised by intense processes of urbanisation, industrialisation and agricultural mechanisation, leading to a fragmentation of the agricultural and forest landscape. This, in turn, reduced the bio-permeability of the territory and affected the dispersion of many wild species. Brown hare (*Lepus europaeus*) dispersion is dramatically affected by habitat fragmentation, presence of predators, intense tillage and elevated hunting pressure. Consequently, the only stable populations of hare are often in no-hunting areas where wildlife management is efficient. It is necessary, therefore, to identify not only additional areas suitable for reproduction, but also the most suitable dispersion pathways for hares, in order to optimise management.

In the present study, by means of a Geographic Information System (GIS), a deterministic hare suitability model was developed on the basis of a multicriterial approach and fuzzy logic. Subsequently, a friction surface was derived from the suitability map in order to describe the land bio-permeability. Finally, on the basis of species potential, the spread of hares from stable population areas (source areas) to the remaining territory was simulated. The area of study was the province of Viterbo (central Italy).

The suitability map showed good discrimination ability (ROC=0.705). The hare dispersion simulation map allowed the potential spreading of this species throughout the provincial territory to be analysed. Isolated or less connected zones were highlighted, allowing the distribution of habitat enhancements, and/or the institution of new no-hunting areas devoted to the reproduction and consequent spread of hares throughout the territory, to be localised.

The presented flexible and reiterable methodology could prove useful for wildlife management and hunting planning over a wide area. It would thus provide an important contribution to reducing the importance of animal translocation and favouring an increase in native resources spontaneously spreading throughout a territory. In a more general sense, this study is in accordance with the sustainable land management perspective, meeting the requirements of environmental protection, without compromising the anthropic development of non-urban areas.

*Key words:* Landscape fragmentation, Multicriterial evaluation, Wildlife management, Brown hare, Dispersion.

## RIASSUNTO

SIMULAZIONE DELLA DIFFUSIONE DELLA LEPRE (*LEPUS EUROPAEUS PALLAS*):  
UNO STRUMENTO PER LA GESTIONE DI AREA VASTA DELLA FAUNA SELVATICA

La seconda metà del XX° secolo è stata caratterizzata da intensi processi di urbanizzazione, industrializzazione e meccanizzazione agricola che hanno prodotto una frammentazione dei paesaggi agricoli e forestali. I caratteri di bio-permeabilità del territorio e la diffusione di varie specie di selvatici sono stati quindi ridotti. La sopravvivenza e la diffusione della lepre (*Lepus europaeus*) è drammaticamente influenzata dalla frammentazione degli habitat, dalla presenza dei predatori, dalle coltivazioni intensive e dall'elevata pressione venatoria. Di conseguenza, spesso, le uniche popolazioni stabili di lepre risiedono nelle aree protette, dove esiste una appropriata gestione faunistica e la caccia è regolata. Per una corretta gestione della lepre è perciò fondamentale caratterizzare, oltre alle aree più idonee per la riproduzione, anche le possibili vie di diffusione nel territorio.

In questo studio, con l'uso dei Sistemi Informativi Geografici (GIS), è stato costruito un modello deterministico d'idoneità ambientale per la lepre secondo un approccio multicriteriale e una logica fuzzy. Successivamente è stata derivata una superficie di frizione utile a descrivere la bio-permeabilità del territorio. Infine, sulla base delle potenzialità della specie, è stata simulata la diffusione della lepre dalle aree con popolazioni stabili (aree sorgenti) nel restante territorio. L'area di studio è stata la Provincia di Viterbo (Italia centrale).

La mappa di idoneità ambientale ha presentato una buona capacità discriminante del territorio ( $ROC=0,705$ ). La mappa finale di simulazione della diffusione della lepre, ha permesso di analizzare la potenziale diffusione della lepre nell'intero territorio provinciale. I territori isolati o scarsamente connessi con le aree sorgenti sono stati individuati, permettendo, quindi di localizzare la distribuzione degli interventi di miglioramento ambientale e/o l'istituzione di nuove aree protette, destinate alla riproduzione e alla conseguente diffusione di questa specie nel territorio.

La metodologia presentata, flessibile e reiterabile, se inserita nella gestione faunistica e venatoria di area vasta, potrà contribuire alla riduzione della pratica della traslocazione degli animali a favore della naturale diffusione della fauna nativa nel territorio e, in senso più ampio, a coniugare le esigenze di protezione ambientale con lo sviluppo antropico delle aree rurali.

Parole chiave: Frammentazione del paesaggio, Analisi multicriteriale, Gestione faunistica, Lepre comune, Dispersione.

**Introduction**

The processes of urbanisation, industrialisation and agricultural mechanisation which characterized the second half of the 20<sup>th</sup> century, led to a fragmentation of the agricultural and forest landscape producing artificial, banal and discontinuous ecological mosaics and a general reduction of bio-permeability. The concept of bio-permeability is useful in representing the study of landscape fragmentation in a medium-large territory. Romano (1996; 2000) defined bio-permeability as the geography of non-urbanised spaces or spaces that are not used for intensive settlements or far-

ming. Instead, Bona *et al.* (2006) defined a bio-permeability map as a map that illustrates the ability of focal species to pass through or to adapt to a given vegetation or land-use category. Bio-permeability, therefore, can be defined as a characteristic of the land that describes its capacity to be passed through by a given species. The characteristics that affect bio-permeability are strongly diversified and they influence the ability of various wild animal species to spread. (Broekhuizen and Maaskamp, 1982; Romano, 2000; Rühle and Hohmann, 2004; Bona *et al.*, 2006). In the past few years, several Geographic Information Systems (GIS) based methodologies and studies of territorial

analysis have been developed to show the level of fragmentation and connectivity of the land mosaic in order to draw up management plans for wildlife.

The hare is a mammal of the order Lagomorphs, present in Italy with four different species. The most widespread is the European Hare (*Lepus europaeus*), otherwise called the Common or Brown Hare, and it is present throughout the Italian peninsula except in Sicily. The hare is a hunting species and represent an important part of the hunting bag. The management of this species is mainly based on restocking, that is to say, the translocation of animals from one area to another. These animals suffer translocation stress, which reduces their adaptability to the new environment (Trocchi and Riga, 2005). Therefore, during these operations death may occur and stress can play a role in the development of disease in the released hares (Paci *et al.*, 2006). For hare management, it is fundamental to characterise not only suitable reproduction areas, but also possible pathways for dispersion throughout the territory. Hare restocking is very difficult due to dramatic problems of adaptation to the new environment and the consequent low rate of survival of released animals. For these reasons, management practices able to favour reproduction in natural conditions have been widely studied.

Habitat fragmentation, the presence of predators, intense tillage and elevated hunting pressure are the main reasons for the disappearance of the hare; stable hare populations are relegated only to protected areas and no hunting areas that represent the so called Source Areas (SA) in the ecological network. Where source (used in a demographic sense) describes a habitat in which local reproduction or restocking exceeds mortality (Hess and Fischer, 2001). These areas are those from which animals can spread into adjacent areas. They should

therefore be managed carefully to allow the conservation of the species. Wildlife and hunting management plans identify the areas most suitable for focal species on the basis of the ecological requirements and ethological traits of each species (Schröpfer and Nyenhuis, 1982; Tapper and Parsons, 1984; Tonolli, *et al.*, 2002; Boccia *et al.*, 2003; Trocchi and Riga, 2005). Nevertheless, such models are unable to give information on the possibility of guaranteeing the spread of the target animal in the land.

The dispersion of native Brown hare was studied by some authors in the last decades (Pielowsky, 1972; Rühle and Hohmann, 2004; Trocchi and Riga, 2005; Bray *et al.*, 2007). Some studies was devoted to study the effect of landscape fragmentation, land use and farmland structure. This study represent an example showing the potential effect of no-hunting areas as a source of animals for adjacent hunting areas and, consequently, to plan wildlife habitat enhancements and the institution of no-hunting areas devoted to the reproduction and consequent spread of this species throughout the territory.

The bio-permeability of a given territory is in relation to its habitat suitability, in fact unfavourable habitat conditions reduce the possibility that a species will spread throughout the area. The habitat suitability of the area can be identified using a deterministic model.

Deterministic models are based on expert knowledge and scientific literature. Different scores are attributed to biotic and abiotic factors influencing the species. The sum of the different layers, followed by adequate reclassification, lead to a habitat suitability model. Deterministic models need to be validated with field data, according to Guisan and Zimmermann (2000). Deterministic models are often used in wildlife management and ecological networks, thanks to

the ease with which they can be calculated (Boitani *et al.*, 2002; Amici *et al.*, 2004).

Usually, in deterministic models the classification is based on Boolean logic, and an area is either accepted or rejected (i.e. classified as suitable or not suitable) on the basis of a given threshold value. When the threshold value is not precise, loss of information or error propagation may occur. Using this method any possibility for examining which of the areas fulfilling the criteria are the most appropriate for the purpose is impaired, in addition is impossible to state which areas are the best beyond the feasible areas (Store and Kangas, 2001).

In order to overcome the problems consequent to Boolean logic, a multicriterial approach based on fuzzy logic (Gahler *et al.*, 1998; Steinhardt, 1998) can be adopted. In a multicriterial evaluation, each factor is characterised by its own variability and contributes in a definite proportion in relation to the other factors considered. In Boolean logic everything must be expressed in binary terms (e.g. 0 or 1). In fuzzy logic, on the contrary, classical truth-values are replaced with degrees of truth that range between 0 and 1. In consequence, the factors that contribute to a habitat suitability model are considered as continuous factors and both linear and non-linear functions can be used to describe the relationships between the factors and habitat suitability. This reduces information loss and error propagation, while increasing the model's robustness.

In this paper a methodology was elaborated to study the dispersion of the hare in the Province of Viterbo (central Italy). By means of multicriterial evaluation of habitat suitability and a scenario of land bio-permeability, a simulation of the dispersion of the Brown hare was performed. The methodology presented could represent a useful contribution to wildlife and hunt-

ing management plans with the aim of increasing native resources by a spontaneous spreading throughout the territory.

## Material and methods

### *Study area*

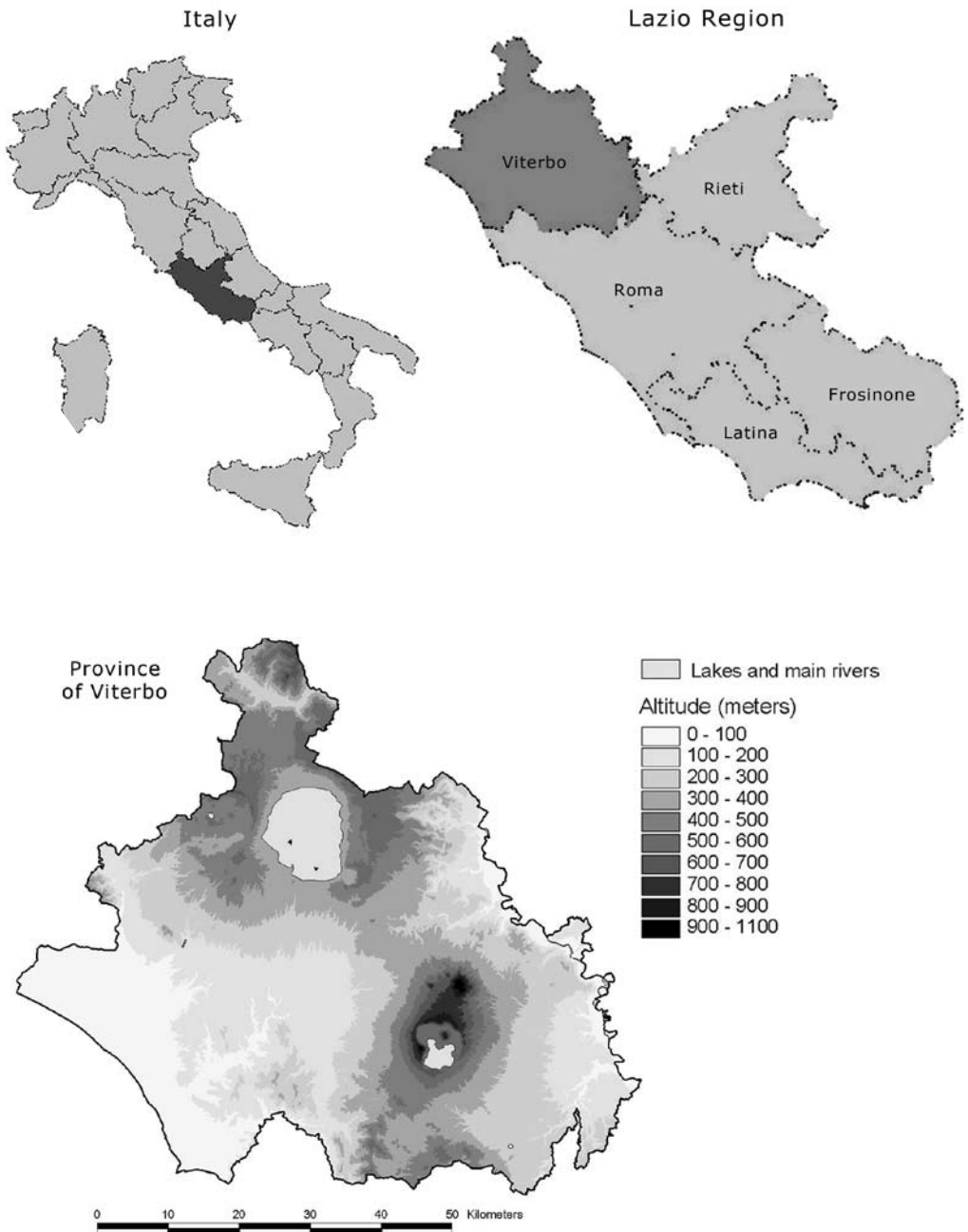
The study area chosen was the Viterbo Province (Figure 1), located in the north of the Lazio Region (Central Italy). The Province covers 3614 square kilometres and it is characterised by extensive agricultural activities and hill landscapes. The exception to this, are the Cimini Mountains (1005 m) and the Rufeno Mountains (850 m), which are mainly covered by mixed broadleaf and coniferous forests. The main water sources in the province are represented by the volcanic lakes, Bolsena and Vico, and by the Tevere river that runs along the eastern provincial border. Other rivers and torrents flow directly into the Tyrrhenian Sea, but they have smaller capacities (e.g. the Marta river and the Fiora river). The area is mainly devoted to agriculture and animal husbandry, and the average farm dimensions are approximately 5 hectares. The diffuse anthropic areas and the road network greatly contribute to the increase of fragmentation in the area.

In this study, in accordance with Store and Kangas (2001), a multicriterial evaluation procedure was adopted, and a habitat suitability model was computed to estimate the connection between Brown hare Source Areas, using the bio-permeability criteria. This methodology was proposed to simulate the spreading of Brown hare in field conditions and to check the effectiveness of hunting plans.

The simulation study was performed in three subsequently steps:

- data collection;
- computation of the habitat suitability model;

Figure 1. Study area.



- computation of the bio-permeability model and Brown hare dispersion simulation.

#### *Data collection and software*

The informative layers utilised for the study were:

- the Lazio region Land-Use Map produced by Lazio Region in the year 2000. This map was produced interpreting digital colour orthophotographs on a scale of 1:10.000 referring to the years '98 and '99, and Landsat 7 ETM images. The minimum linear dimensions for insertion of data into the map were 25 m x 250 m, while the minimum area was 1 ha (Lazio Regional Administration, 2003). The format of this map is vectorial.
- a Digital Elevation Model with a resolution of 40 x 40 m.
- digital aerial orthophotographs of 1999 with a pixel resolution of 1 m.
- the Province's borders, natural protected areas and wildlife and hunting plans in vectorial format.
- road and rail networks produced on the basis of Regional Topographic Map scale 1:10000 and digital aerial orthophotographs of 1999 with a resolution of 1 m. This vectorial information includes motorways, highways, secondary asphalted roads and railroads.

The informative layers were developed in a GIS environment using Arcview 3.1 and imported into the raster format IDRISI 32, with a cell resolution of 40x40m. The coordinate system of all the layers was UTM 33N Datum ED50.

#### *Habitat suitability model computation*

The computation of a habitat suitability model with multicriterial evaluation requires data on the biotic and abiotic factors influencing the presence or abundance of focal species and their relative weight

for habitat suitability (Boitani *et al.*, 2002; Amici *et al.* 2004).

As elsewhere underlined, the choice of the model to be implemented is always a compromise between accuracy and cost (Store and Kangas, 2001). In other words, it is impossible to include in the model all the biotic and abiotic factors influencing the habitat selection of the focal species when modelling on a wide scale. The presence of the Brown hare, for example, is positively influenced by organic farming (Tapper and Barnes, 1986) and negatively by intense livestock grazing (Karmiris and Nastis, 2007). Unfortunately these information are rarely available for habitat modelling on a large scale (Cardillo *et al.*, 1999).

The factors included in calculating the suitability model were, for this study, land use, altitude, slope, environmental diversity and anthropic disturbance.

Land use is the main factor influencing the presence or absence of the hare. The Brown hare prefers an extensive agricultural system, crops and pasture where food and shelter can be found throughout the year (Smith *et al.*, 2005). Woodlands and urbanised areas are not suitable for the Brown hare (Hewson, 1977; Frylestam, 1992; Reitz and Leonard, 1994; Tollet, 1996; Ruhe, 1999; Paci and Bagliacca, 2003; Vaughan *et al.*, 2003). Table 1 shows the suitability score attributed to each land use on the basis of literature and expert knowledge.

Altitude and slope are two morphological characteristics of the landscape, obtained by means of a Digital Elevation Model. For the Brown hare, altitude is considered as optimal in the range 0 to 600 m, and tending to unsuitable in the range 600 to 2000. (Farina, 1991; Panek and Kamieniarz, 1999; Pfister *et al.*, 2003; Boitani *et al.*, 2002). Slope is considered optimal in the range 0 to 30% (Farina, 1991, Panek and Kamieniarz, 1999; Pfister *et al.*, 2003; Boitani *et al.*, 2002).

Table 1. Land use and score of suitability for the brown hare.

Corine Code	Land use classes	Score
11	Residential areas	0
12	Productive built up areas, private and public services, transport networks and infrastructures	0
131	Mining areas	0
1321	Opencast and underground mining, industrial and public waste dumps and deposits	0
1322	Open air scrap heaps	0
1331	Building sites and excavations	0
1332	Artificial and reworked surfaces	0
141	Urban parks and gardens	0
1421	Campsites, holiday villages with bungalow type accommodation	0
1422	Sports facilities	0
1424	Archeological sites	0
143	Cemiteries	0
2111	Arable crops in non-irrigated land	4
2112	Nurseries in non irrigated land	2
2113	Market gardening in irrigated areas: in fields, green-houses, under protective plastic sheeting	3
2121	Arable crops in irrigated land	3
2122	Nurseries in irrigated land	1
2123	Market gardening in irrigated areas: in fields, green-houses, under protective plastic sheeting	1
221	Vineyards	3
222	Fruit trees and berry plantations	2
223	Olive groves	3
22411	Poplars stands, willow stands and other broadleaf trees	2
2242	Sweet chestnut groves	1
231	Areas of dense grass cover	3
241	Temporary cultivation associated with permanent cultivation	3
242	Complex particle and cultivation patterns	2
243	Areas mostly used for agriculture with important natural spaces	3
311	Broadleaf woodlands	0
312	Conifer woodlands	0
313	Mixed conifer and broadleaf woodlands	0
321	Natural pasture and high altitude meadows	4
322	Scrub land and shrubs	3
323	Sclerophyllous vegetation	2
3241	Natural recolonisation areas	2
3242	Artificial recolonisation areas	1
331	Beaches, dunes and sand	0
332	Bare rock, cliffs, outcrops	0
333	Areas of sparse vegetation	1
411	Inland wetlands	0
412	Saline	0
511	Water courses	0
512	Water bodies	0
521	Lakes, lagoons and coastal marshes	0

The Shannon index was chosen to represent environmental diversity (Tapper and Barnes, 1986; Smith *et al.*, 2004; Farina, 2007). As is well known habitat diversity is positive for Brown hares, since it offers resting sites and food resources throughout the year (Stott, 2003; Vaughan *et al.*, 2003). As reported in literature the average hare has home range was supposed of 50 ha (Broekhuizen and Maaskamp, 1982; Reitz and Leonard, 1994; Rühle and Hohmann, 2004; Bray *et al.*, 2007), the Shannon index was calculated on a geometric window of 17x17 cells (each cell 40 x 40 metres), only in non-urban areas of the land use map. The software used was LaDy (Ricotta *et al.*, 2003).

To simulate the negative effect of traffic and human activity on the hare, a 50 metres buffer was drafted around the road and rail networks and urbanised areas. Road and rail networks, urbanised areas and buffers were merged together to identify the anthropic disturbance (Trombulak and Frissel, 2000; Lundström-Gilliéron and Schlaepfer, 2003). Urban and very busy roads were computed as highly negative in comparison to the remaining roads and the rail network.

Each factor was evaluated through fuzzy logic, creating fuzzy sets. Fuzzy sets are classifications of data in which the boundaries between classes are not distinct; that is, the transition between membership and non-membership of a location in the set is gradual. A Fuzzy Set is characterised by a fuzzy membership grade (also called a possibility) that can range from 0.0 to 1.0 (or from 0 to 255 in byte format), indicating a continuous increase from non-membership to complete membership (Eastman, 2001). According to literature and expert knowledge, membership function, threshold values and a law of variation were chosen in order to explain the change in habitat suitability of each factor.

Figure 2 shows the fuzzy membership

functions of land use, altitude, slope, environmental diversity and anthropic disturbance. Land use and anthropic disturbance are categorical factors; therefore, the scores attributed were converted to range 0-255, dividing by the maximum value and multiplying by 255 (Figures 2a, 2d). The fuzzy sets of altitude, slope, and environmental diversity were created using the FUZZY tool IDRISI 32. Altitude (Figure 2b) and slope (Figure 2c) were associated with a sigmoidal membership function decreasing monotonically, while environmental diversity (Figure 2e) was associated with a linear membership function, increasing monotonically.

Finally, weights, or priority, were attributed to each fuzzy-set (Table 2) and the multicriterial evaluation was run, producing a land wildlife suitability classification. The suitability map obtained was assessed in terms of area under a relative operating characteristic (ROC) curve (Pearce and Ferrier, 2000). This index analyses the discrimination capacity e.g. the ability to correctly distinguish between occupied and unoccupied sites. ROC does not rely on the essentially arbitrary choice of a threshold probability to determine whether or not a site is predicted as being occupied. It measures discrimination capacity, relating relative proportions of correctly and incorrectly classified predictions over a wide and continuous range of threshold levels. ROC analysis is therefore independent of both species prevalence and decision threshold effects. The ROC of the hare suitability map was computed using IDRISI, taking Source Areas (without urban and woodlands) as reference areas (occupied sites).

#### *Bio-permeability model computation and Brown hare dispersion simulation*

A naturally occurring spread of the hare throughout a territory is possible from areas with elevate densities (Matthysen,



Figure 2. Fuzzy membership function of factors included in the multicriterial evaluation.

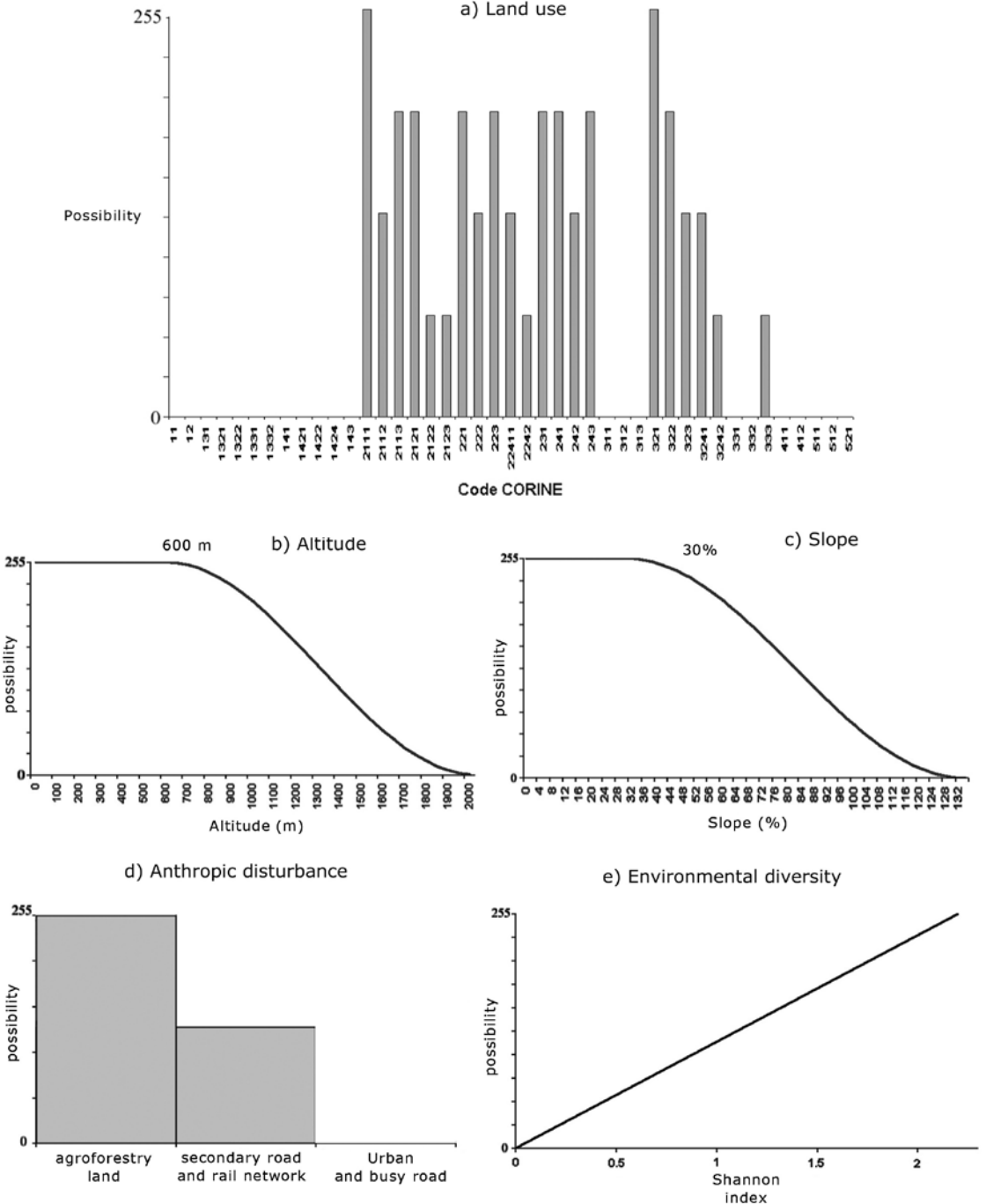


Table 2. Fuzzy sets used in the multicriterial evaluation (MCE) and relative weight.

Fuzzy sets	Weight in the MCE
Land use	0.70
Altitude	0.10
Slope	0.05
Environmental diversity (Shannon Index)	0.05
Anthropic disturbance	0.10
Total	1

2005). This normally happens in no-hunting areas (e.g. Oases and Protected Areas), Private hunting Farms (AFV) and the Zones of Restocking and Capture (ZRC). The Protected Areas, Oases, AFV and ZRC showing a high level of habitat suitability for Brown hare were selected on the basis of the stable presence of the species and abundance data reported in Viterbo wildlife and hunting management plan. Although abundance data are non-exhaustive and unable to cover the entire surface of these areas, capture practices were considered as an indicator of the stable presence of the hare. For the same reasons, it was impossible to classify the areas on the basis of abundance. All the no-hunting areas with the above-mentioned characteristics were classified as the Source Areas of natural spread (SA).

Movement in space implies a cost, which is a function of the standard (or base) costs associated with movement, and also of frictions and forces that impede or facilitate that movement. The computed suitability of the land is quantified for every cell through a numerical value that increases with suitability. Assuming the spread of hares throughout the territory as a function of habitat suitability, it was possible to derive a friction surface by an inversion of the suitability map. The areas less favourable to the hare, that is to say, those with

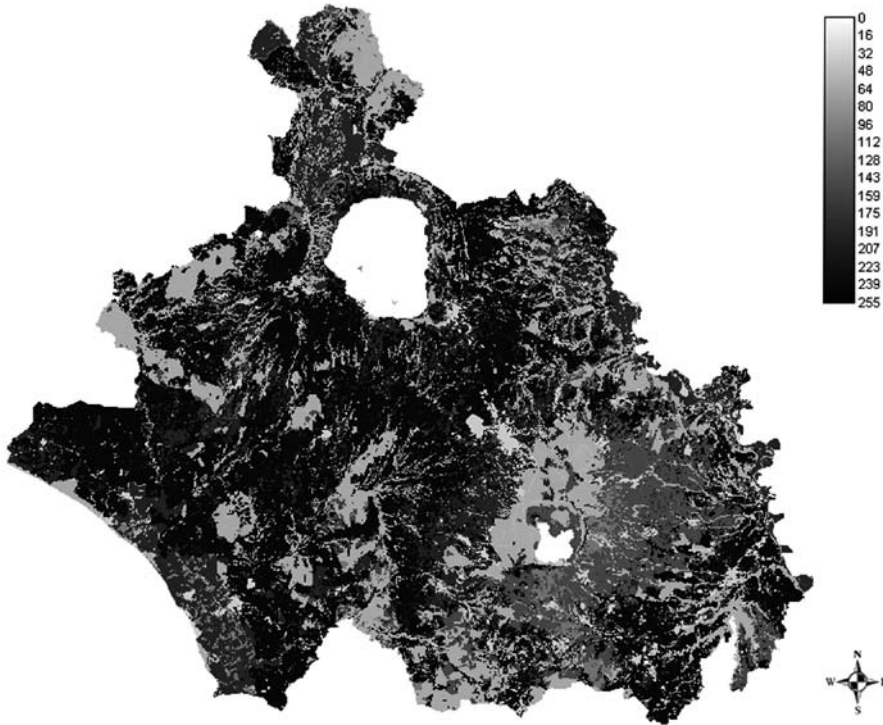
a low level of suitability, were computed as highly unfavourable for the spread of the hare.

Moreover, to standardise the values, the map was subdivided by minimum friction value. In this way, the minimum cost of moving through the cell was fixed as 1. A friction of 1, therefore, is assigned to very high suitability land (e.g. areas used for crops with high environmental diversity, distant from roads and urban areas and under 600 m a.s.l.). A friction of 2 indicates twice the base cost to move through that cell, and is assigned to lower suitability territory. A value of 3 indicates a triple cost to move, and so on.

Particular attention was given to the elements that allow the animals to move through the road and rail networks (e.g. bridges and galleries) and those that instead render it uncrossable (e.g. new-jersey type street barriers). These structures were identified examining orthophotographs, in order to update the friction surface determining the position of impenetrable barriers on the road and rail networks for hares. Barriers, like urban areas and highways were assigned a value of -1 in the friction maps.

The connectivity between the various SA was calculated by means of a COST GROW routine, using the IDRISI 32 software. COST GROW generates a distance/

Figure 3. Brown hare habitat suitability map.



proximity surface (also referred to as a cost surface) where distance is measured as the least cost (in terms of effort, expense, etc.) in moving over a friction surface. SA was used as source feature image, and the inverse suitability map, updated with barriers, was used as friction surface image.

### Results and discussion

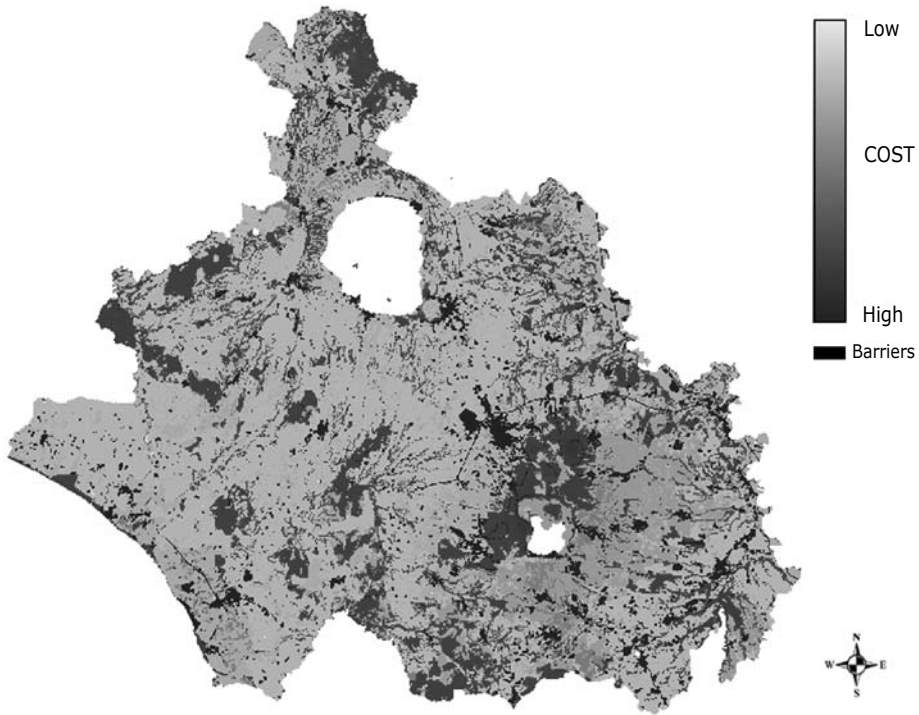
The hare habitat suitability map for the Province of Viterbo, derived from MCE, is reported in figure 3. The suitability map has a score that ranges from 1 to 255 where higher values correspond to high suitability for the hare. The most suitable areas cor-

respond to the cells in which the factors of land use, altitude, slope, environmental diversity and anthropic disturbance are most favourable to the presence and abundance of the hare.

The ROC value for the hare suitability map was 0.705. This value is in the range between 0.7 and 0.9 indicating a reasonable discrimination ability (Pearce and Ferrier, 2000). Indeed, any value above 0.5 is sufficient, the limit below which random allocation of suitability is determined.

The habitat suitability map for the hare was obtained with a limited use of resources. The choice of the factors and weights to be considered in the multicriterial analysis

Figure 4. Friction surface derived from suitability map and updated with barriers.



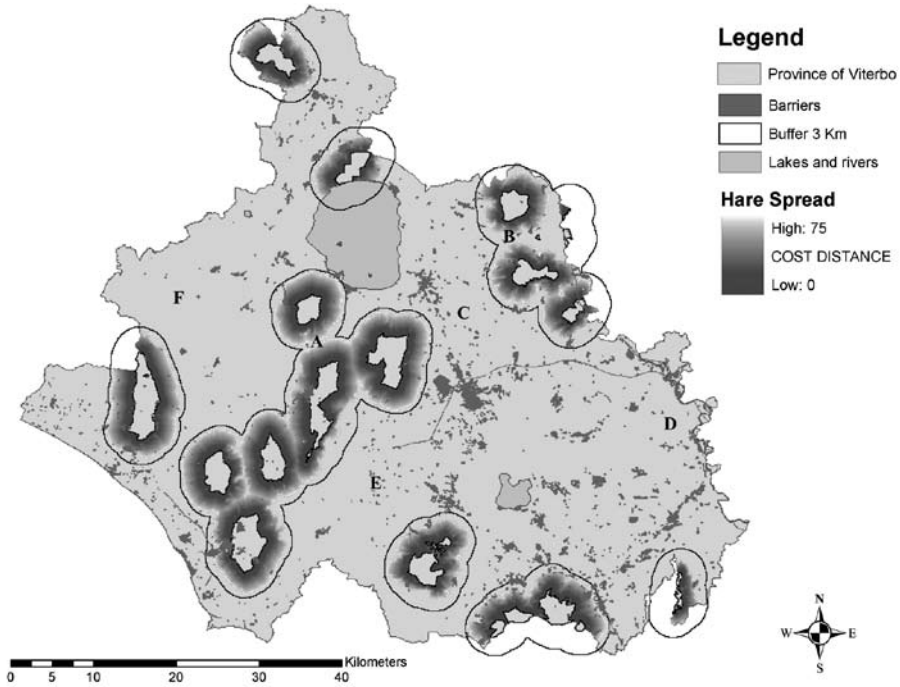
derives from a deep knowledge of the species and the territory. Thus, collaboration between various actors (planners and wildlife managers) is important.

The friction surface (Figure 4) derives from the suitability map previously computed. This innovative approach allows the biopermeability of the land for the hare to be determined on the basis of different factors influencing the presence and spreading of animals as land use, altitude, slope, environmental diversity and anthropic disturbance.

The spreading of hares reared in captivity, or captured and translocated, is well known thanks to several telemetry and ear-tagging studies since 80 ths (Ricci, 1983; Pepin and Cargnelutti, 1985; Fiechter,

1988). The spreading of native adult hares in natural conditions has been studied by few authors in the last decades. Pielowsky (1972) reported a recapture range between 500 and 1000 meters for 90% of the animals, and 2000 to 4000 meters for the remaining 10%. Bray *et al.* (2007) reporting that native males dispersed more frequently than females, although females moved over longer distances. The dispersion of sub-adult (juvenile) hares was studied by Bray *et al.* (2007), who reported that the mean dispersal rate was 43%. The median natal dispersal distances were 209 m for philopatric hares and 1615 m for dispersers. Concerning the Brown hare density around the borders of no-hunting areas, a rapid decrease was

Figure 5. Hare dispersion simulation from source area in the provincial territory.



The letters A, B, C, D, E, F indicate zones that are not connected.

reported 500 to 1000 meters from the no-hunting borders (Rühe and Hohmann, 2004; Trocchi and Riga, 2005).

Figure 5 represents the ecological connectivity between the SA (cost surface) or, in other words, the ecological network and the preferential dispersion pathways of the hare in the provincial territory. The 3000 metre buffer around the SA (black line) represents the maximum Euclidean distance achievable by the hare. When the friction value is 1, the maximum spread of the hare in natural conditions is estimated as approximately (3000:40) 75 cells or cost value. Since the friction values are often higher than 1, the estimated spread distance always resulted

lower than 3000 meters, impairing the connectivity between SA (e.g. zones A and B, Figure 5).

The connection map constitutes an important support for wildlife management on a provincial scale. In this case, it was possible to explain and confirm the scarce abundance, or the absence, of hares in some areas, potentially suitable from a habitat point of view, due to a lack of connectivity between SA. In these areas it would be opportune to plan wildlife oriented environmental management (e.g. non harvested cultivations, maintenance of the hedge and residual of cultivation etc.), limited hunting quotas, restocking of animals or the consti-

tution of other Source Areas (e.g. zones C, D, E and F, Figure 5).

## Conclusions

The present study was performed in order to produce a tool able to simulate the spread of the Brown hare in the Province of Viterbo, showing the potential effect of no-hunting areas as a source of animals for adjacent hunting areas. This tool could be used as a support in decision-making, in order to plan wildlife habitat enhancements and the institution of no-hunting areas devoted to the reproduction and consequent spread of this species throughout the territory. This study, in accordance with wildlife management perspectives, reduces the importance of animal translocation and favours the increase in native resources by a spontaneous spreading throughout the territory.

However, it would be opportune to deepen the analysis of some factors. More detailed information on land use would allow the fragmentation and the bio-permeability of the land to be represented better. The abil-

ity to spread of the species, moreover, could be enhanced by employing greater resources for the collection of information on the presence of animals in the territory and realising stochastic habitat suitability models. These models, therefore, could be useful for both start point for better friction surfaces and defining new factors, scores and weight in the multicriterial analysis.

Nevertheless, the presented methodology is flexible, and reiterable using an updated database. The methodological approach presented in this paper could be useful for wildlife management and hunting planning over wide areas. In addition, it is able provide an important contribution to meeting the requirements of environmental protection without compromising the anthropic development of non-urban areas.

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