



Feeding preferences in dry season of the Italian hare (*Lepus corsicanus*) in two sites of Corsica

Gabriella Rizzardini¹ · S. Fascetti¹ · C. Pietri² · F. Riga³ · C. Cosentino¹ · P. Freschi¹

Received: 19 September 2018 / Revised: 21 February 2019 / Accepted: 23 April 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

In this research, the diet composition and feeding selection of the Italian hare were evaluated and compared in two sites of Haute-Corse region localised in the territories of Tallone and Aleria. The present study is the first considering feeding selection of *Lepus corsicanus*. The considered period ranged from June to October. Quadrat method was used to assess plant frequency, while diet composition was determined by microhistological analysis of faecal pellets collected monthly. Grasses represented the basis of the diet, with frequencies around 50% in both study areas, followed by non-leguminous forbs with an incidence of 29% in Aleria and over 31% in Tallone. Leguminous forbs and shrubs complemented its diet. Poaceae resulted to be the most preferred and selected family in the diet in both sites. In the diet, we observed 79 species, but only a few of them were in percentages greater than 5%. The most utilised species in the diet were *Brachypodium sylvaticum*, *Briza maxima*, and *Trifolium angustifolium* in Aleria and *Digitaria sanguinalis*, *Briza maxima*, and *Daucus carota* in Tallone. Our study evidenced that in the considered areas, characterised also in the dry period by wide plant diversity, the Italian hare behaved as generalist. Significant differences in the diet composition and in the diversity index between the two sites showed the adaptability of the Italian hare to different habitats and the influence of the vegetation on feeding habits of the species.

Keywords Italian hare · Feeding preferences · Diet

Introduction

The Italian hare (*Lepus corsicanus* De Winton, 1898) was introduced from central Italy to Corsica no later than the XIV century for hunting purposes (Vigne 1999) and, although alien, it spread widely mainly in the northern half of the island. The legal status of *L. corsicanus* varies as follows: in Corsica

and in Sicily it is a game species, whereas in peninsular Italy, the *taxon* is protected but the difficulty of distinguishing it from the European hare (*Lepus europaeus* Pallas, 1788) produces remarkable problems for its effective protection (Trocchi and Riga 2001). In this area, the species is classified as ‘vulnerable’ by the International Union for Conservation of Nature (IUCN)’s Red List of Threatened Species and, in the absence of adequate conservation measures, it could risk extinction in the coming decades (Angelici et al. 2008; Rondinini et al. 2013).

To date, the distribution of *L. corsicanus* in continental Italy is greatly fragmented and extends from Tuscany southward to Calabria, while it is widespread throughout Sicily (Trocchi and Riga 2001). In Corsica, the existence of at least three populations is evidenced: the smallest at the tip of Cap Corse, the largest of the three that spread over almost all the northern part of Corsica (Haute-Corse), and the third on the west coast around Sagone, where hybrids with *L. europaeus* and with Iberian hare (*Lepus granatensis* Rosenhauer, 1856) were identified (Pietri 2015). The ecological distribution of the *taxon* highlights the preference for the Mediterranean environment, though it is present in areas up to 1900 m a.s.l. on

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s10344-019-1284-4>) contains supplementary material, which is available to authorized users.

✉ Gabriella Rizzardini
gabriella.rizzardini@unibas.it

¹ School of Agricultural, Forestry, Food and Environmental Sciences (SAFE), University of Basilicata, Viale dell’Ateneo Lucano 10, 85100 Potenza, Italy

² Fédération Départementale des Chasseurs de Haute-Corse (FDCHC), Résidence Nouvelle-Corniche, St Joseph, 20600 Bastia, France

³ Istituto Superiore Protezione e Ricerca Ambientale (ISPRA), Rome, Italy

the Apennines Mountains, and up to 2400 m a.s.l. on Mount Etna (Trocchi and Riga 2001).

Recently, at areal level, with the exception of Haute-Corse region and Sicily, the consistence of populations and the range distribution of *L. corsicanus* have undergone a drastic decrease because of predation, poaching, hunting, habitat fragmentation, and of possible competition with *L. europaeus*. In Corsica, the Italian hare also competes with *L. granatensis* that was introduced in the southern part of Corsica (Corse-du-Sud) in the 1984–2000 periods (Pietri 2007). The restocking with *L. europaeus* still occurs but it stopped in Haute-Corse in 1995; Pietri (2007) estimated the amount of released European hares to be approximately 4500 individuals, of which a thousand in Haute-Corse.

Studies on the biology and ecology of *L. corsicanus* play a key factor in the conservation of the species. In particular, the feeding ecology is important to evaluate the resources utilised within an ecosystem according to food availability and to establish specific habitat suitability models. Moreover, knowledge of the diet of this vulnerable *taxon* is essential to assess the species' role in the ecosystem and might have a far-reaching impact on the development of management plans (Trocchi and Riga 2001; Cristóbal-Azkarate and Arroyo-Rodríguez 2007; Duffy et al. 2007). Food habits of several *Lepus* spp. have successfully brought about focused and comprehensive conservation management strategies. Moreover, they have significantly contributed to the knowledge of the functioning of the ecosystem as a whole. In detail, feeding behaviour was investigated on *Lepus timidus hibernicus* Bell, 1837 (e.g. Hewson and Hinge 1990; Tangney et al. 1995; Wolfe et al. 1996; Dingerkus and Montgomery 2001), on *L. europaeus* (e.g. Frylestam 1986; Chapuis 1990; Wray 1992; Puig et al. 2007; Kontsiotis et al. 2011), on *Lepus californicus* Gray, 1837 (e.g. Uresk 1978; Johnson and Anderson 1984; Hoagland 1992), on *Lepus arcticus* Ross, 1819 (e.g. Klein and Bay 1994), on *L. granatensis* (e.g. Paupério and Alves 2008), on *Lepus flavigularis* Wagner, 1844 (e.g. Lorenzo et al. 2011), and on *L. starcki* Petter, 1963 (e.g. Mekonnen et al. 2011). These studies found graminoids life form to be the main component of the diet of genus *Lepus*. To date, information on feeding ecology of the Italian hare is only known in one site on Mount Etna slopes in Sicily (De Battisti et al. 2004) and in a few other areas located in continental Italy (Freschi et al. 2014, 2015, 2016; Buglione et al. 2018). Moreover, no studies on the dietary preferences and selection are available for this species. In this paper, we report the first results of a research conducted in two areas of the central eastern part of Corsica. The present study is the first considering feeding selection of *L. corsicanus*, and our aim was to evaluate diet composition in relation to vegetation and to its feeding selection in dry season.

Materials and methods

Study area

The study was conducted in Corsica in two sites located in Aleria and in Tallone districts (Fig. 1). The site in Aleria (42.07 N, 9.49E) covers about 69 ha and lies at 15 m a.s.l. The site in Tallone (42.18 N, 9.49E) occupies about 63 ha and lies at 65 m a.s.l. Previous studies based on the identification of species with genetic and physical criteria verified the absence of hybrids in the districts of Aleria and Tallone (Pietri et al. 2011), or located their presence close to the boundary with Corse-du-Sud (Pietri 2015). Rabbit (*Oryctolagus cuniculus* Linnaeus, 1758) does not inhabit the study area (Mitchell-Jones et al. 1999).

According to Mitrakos (1980), the area that includes Aleria and Tallone shows a climatic pattern, which is mesothermic Mediterranean. The annual average rainfall is 846 mm, the wettest month is November (109 mm) and the driest is July (25 mm). More than 80% of the total rainfall is concentrated in autumn-winter period. The annual average temperature is 17.4 °C. The hottest months are July and August (26.5 °C) and the coldest is January (10 °C) (Climate-Data.Org. 2017). The macrobioclimate results Mediterranean, mostly meso-Mediterranean bioclimatic belt (Rivas-Martinez et al. 2004). The potential vegetation is the evergreen forest dominated by *Quercus suber* (*Quercion suberis*) referred to Habitat 9330—*Quercus suber* forests, Tyrrhenian cork-oak forests (The Council of the European Union 1992). The two sites are characterised by different floristic and vegetational shapes (Online Resource 1). In the territory of Aleria, the current vegetational landscape is characterised by residual sclerophylle evergreen forests with a prevalence of *Q. suber*, often degraded to phytocoenosis of scrubland with *Erica arborea*, *Calicotome spinosa*, and *Arbutus unedo* (*Ericion arboreae*) and garrigue with *Cistus* spp. (*Cisto-Lavanduletea*) (Gamisans 2012). In the Tallone area, in the humid depressions and along the watercourses, meso-hygrophilus bushes with *Ulmus minor*, *Salix* spp., *Rubus* spp., and *Prunus spinosa* are widespread. Anthropogenic forest vegetation is present with reforestation areas with a prevalence of *Eucalyptus* spp., and *Pinus* spp.

In both sites, *L. corsicanus* is preyed by stray dog (*Canis lupus familiaris* Linnaeus, 1758), stray cat (*Felis silvestris catus* Linnaeus, 1758), fox (*Vulpes vulpes* Linnaeus, 1758), weasel (*Mustela nivalis* Linnaeus, 1758), hooded crow (*Corvus cornix* Linnaeus, 1758), buzzard (*Buteo buteo* Linnaeus, 1758), and kite (*Milvus milvus* Linnaeus, 1758).

Sampling and sample processing

To assess relative frequencies of plant species, 3 permanent transects were surveyed for each study area in the dry season



Fig. 1 Map showing the study areas in Corsica

(June–October 2016). Quadrat method was used to assess plant frequency (Bonham 1989); transects were located in order to cover all the types of vegetation present in the study area. Each transect (100 m) was separated from one another by more than 100 m. Along each transect, plant species were listed in 50 quadrats (sized 1 m²) arranged at a distance of 1 m from each other. The collected specimens were identified according to *Flora Europaea* (Tutin et al. 1993) and to *Flora Gallica* (Tison and de Foucault 2014). Floristic nomenclature followed Reveal (2011) and Banfi et al. (2018). Specific updates followed Bartolucci et al. (2018). Species were grouped into four life forms: grasses (graminoid plants) (G), leguminous forbs (LF), non-leguminous forbs (NLF), and shrubs (S).

Faecal sampling took place monthly (from June to October 2016) along 5 replicate and permanent transects (2 × 100 m) spatially distributed throughout each study site, distant at least 100 m from each other, in order to reduce the probability to collect pellets from the same animal. All the pellets collected were fresh (i.e. bright brown faeces) and, for each collection, in order to maximise the probability of sampling different individuals, a minimum of 6 pellets per transect (over 30 for each site) of various sizes and morphology were mixed to form a single composite sample (Chapuis 1990; Puig et al. 2007; Paupério and Alves 2008). In this way, a total of 10 composite samples were analysed (5 months × 2 sites), for a total of at least 150 pellets for each site.

As a first step, faecal pellets were hydrated, homogenised, and placed in sodium hypochlorite (NaClO) for 4 h in order to allow the discoloration of plant fragments. Successively, fragments were washed with water and collected with 400- μ m filter paper. The filtrate was dried at 50 °C for 90' and mounted in glycerol gelatine on microscope slides. For each composite sample, 10 microscope slides were mounted. The slides were examined by light microscopy using the image analyser Leica Q500 IW, obtaining 200 readings for each sample, and counting non-overlapping plant fragments in systematic transects across a slide along alternate rows. Identification of plant species was effected by comparing the different characteristics of the epidermal cells and other structures (e.g. stomates and trichomes) with those of the plant reference collection built by collecting the plants found in the study site monthly. This reference material is available at the Laboratory of Environmental and Applied Botany, University of Basilicata.

Statistical analysis

Relative frequencies (*rf*) of plant species, families, and life forms were calculated dividing the total number of fragments attributed to a given taxon by the total number of identified fragments.

To compare vegetation similarity between the study areas, two similarity indices were computed: Sorensen similarity

index (C_S) (Sørensen 1948) and Morisita-Horn index (C_M) (Morisita 1959) (Online Resource 2).

C_S only considers the presence or absence of a species, instead C_M considers the abundance of different species. Those indices vary between 0 (no similarity) and 1 (complete similarity). Morisita-Horn index values are classified as follows: $0 < C_M \leq 0.29$ small overlap, $0.30 \leq C_M \leq 0.59$ medium overlap, and $C_M \geq 0.60$ high overlap (Langton 1982).

Species diversity in diet was assessed using four different indices (Online Resource 2): Shannon diversity index (H) (Shannon and Weaver 1949) considers both the number of species and the distribution of individuals among species, value usually ranges between 1.5 and 3.5 (Margalef 1972); Simpson index (D) (Simpson 1949) for species diversity; Margalef index (d) for species richness in which the higher value the greater the species richness (Margalef 1958); Buzas and Gibson evenness index (Buzas and Gibson 1969). Diet indices differences were tested by Student's t test.

Diet composition was analysed by multivariate analysis. Similarity matrices were constructed by using averages of the Bray-Curtis similarity coefficient (Clarke and Warwick 2001). Analysis of similarities (ANOSIM) was performed to test diet differences among sites using 999 permutations (Warton et al. 2012).

Diet selection was estimated for life forms and for shared plant families in vegetation and diet by Resource selection ratio (w_i) (Manly et al. 2004) (Online Resource 2). Expected vs. observed outcomes were tested by χ^2 test (Zar 1999). Data were analysed by R software, version 3.5.0 (R Core Team 2017).

Results

Botanical composition of cover

Availability of plant species within these vegetation types was based on percentage cover by transects established in 2016. Relative frequency of the plant species and their families composing vegetation cover are in Table 1 and in Online Resource 3. In Aleria, 85 plant species belonging to 30 families were identified. The most abundant families resulted to be Asteraceae (15.0%), Rosaceae (9.9%), and Poaceae (9.2%). Among inventoried species, the most representative were *Plantago lanceolata* (5.8%), *Erica arborea* (4.9%), *Cistus monspeliensis* (4.5%), and *Carex distachya* (4.2%).

In Tallone, 86 species attributed to 34 families were identified. Poaceae was the most available family (20.7%), followed by Asteraceae (15.2%) and Geraniaceae (7.8%). The most abundant species were *Erodium cicutarium* and *Portulaca oleracea* (6.2% in both species), *Cistus monspeliensis* (5.4%), and *Paspalum* spp. (4.7%).

Regarding life forms in vegetation, the most abundant was non-leguminous forbs (41.0% in Aleria and 49.4% in Tallone), followed by shrubs (40.1% in Aleria and 26.3% in Tallone), grasses (14.6% in Aleria and 21.1% in Tallone), and leguminous forbs (4.3% in Aleria and 3.2% in Tallone) (Fig. 3).

Sorensen (C_S) and Morisita-Horn (C_M) similarity indices respectively evidenced a medium (0.319) and a high (0.693) overlap between the vegetations of the two sites.

Diet composition and selectivity

In the faecal pellets of *L. corsicanus*, 79 taxa were found belonging to 30 families on 131 plant species available in the two sites (Table 1, Online Resource 3). Unidentified vegetal fragments were 8.5%. The number of determined species was higher in Tallone (60) than in Aleria (54). Overall, in the two sites, 54 of the 79 found taxa were ingested in low percentages ($\leq 1\%$), giving 20.8% of the total. The five most representative genera covered 37.0% of the diet: *Brachypodium* (9.5%), *Briza* (8.3%), *Trifolium* (8.0%), *Rubia* (5.6%), and *Cichorium* (5.5%). The incidence of the species belonging to the most representative families, Poaceae, Asteraceae, and Fabaceae, amounted to over 69.4% of the diet.

Considering the two sites, Poaceae was the most abundant family in the diet (Aleria, 43.6%; Tallone, 48.3%); followed by Fabaceae (14.4%) and Asteraceae (13.7%) in Aleria, and Asteraceae (11.6%) and Fabaceae (7.2%) in Tallone. In Aleria, the most consumed species were as follows: *Brachypodium sylvaticum* (10.2%), *Briza maxima* (9.6%), *Trifolium angustifolium* (9.1%), *Rubia peregrina* (8.2%), and *Dactylis glomerata* (6.3%). In Tallone, instead, the most utilised species were as follows: *Digitaria sanguinalis* (8.5%), *Briza maxima* (7.0%), *Daucus carota* (5.5%), *Cichorium intybus* (5.2%), and *Avena barbata* (5.2%).

Differences in diet richness and evenness between the two study areas were not statistically significant. Shannon and Simpson diversity indices differed significantly ($p \leq 0.05$) between the two sites (Table 2). Also, diet composition differed between Aleria and Tallone ($p \leq 0.01$) (Fig. 2).

In both sites, grasses were the most utilised life form followed by non-leguminous forbs. In Aleria, leguminous forbs and shrubs complemented the diet in decreasing order. Whereas, in Tallone, shrubs were preferred to leguminous forbs. The Italian hare showed a positive selection in the Aleria site for grasses and leguminous forbs; instead, in the Tallone site, only grasses were selected. Non-leguminous forbs and shrubs were avoided in both sites (Figs. 3 and 4). The families positively selected ($p \leq 0.01$) were Poaceae, Rubiaceae, and Fabaceae in Aleria and Poaceae in Tallone. Instead, 12 families were consumed below their availability ($p \leq 0.01$) in Aleria (Apiaceae, Asteraceae, Cistaceae, Ericaceae,

Table 1 Frequency (%) of plant families and life forms for the two study areas in vegetation (availability) and in diet (ingested)

Family	Life form	Aleria		Tallone	
		Availability	Ingested	Availability	Ingested
Amaranthaceae	NLF	0.00	0.00	0.81	0.44
Amaryllidaceae	G	0.21	0.65	0.00	0.88
Anacardiaceae	S	1.79	0.11	0.00	0.44
Apiaceae	NLF	5.38	1.41	0.35	5.52
Araliaceae	S	0.53	0.00	0.00	0.00
Asparagaceae	S/NLF	2.74	1.52	0.12	0.00
Asphodelaceae	NLF	1.79	0.00	0.35	0.00
Asteraceae	S/NLF	14.98	13.74	15.21	11.60
Boraginaceae	NLF	0.00	0.00	0.46	1.22
Brassicaceae	NLF	0.00	0.00	0.46	0.00
Caprifoliaceae	NLF	0.84	0.22	0.12	0.00
Caryophyllaceae	NLF	0.11	0.00	2.76	1.22
Casuarinaceae	S	0.00	0.00	0.12	0.00
Chenopodiaceae	S/NLF	0.00	0.00	5.64	0.22
Cistaceae	S/NLF	6.43	1.08	6.34	2.10
Colchicaceae	G	0.95	0.00	0.00	0.00
Convolvulaceae	NLF	0.00	0.00	0.12	0.88
Cyperaceae	G	4.22	4.22	0.35	3.09
Ericaceae	S	7.81	0.76	3.34	1.10
Fabaceae	S/LF	6.54	14.39	5.76	7.18
Fagaceae	S	5.06	0.11	0.46	0.33
Geraniaceae	NLF	0.95	0.11	7.83	0.99
Hypericaceae	NLF	3.38	0.97	0.00	0.00
Lamiaceae	S/NLF	0.84	2.16	4.38	3.87
Linaceae	NLF	0.74	0.00	0.00	0.00
Malvaceae	NLF	0.00	0.76	0.12	2.32
Myrtaceae	S	0.74	0.22	0.92	0.11
Oleaceae	S	3.27	0.11	0.46	0.44
Onagraceae	NLF	0.11	0.00	0.00	0.00
Orobanchaceae	NLF	1.38	0.00	2.07	0.00
Oxalidaceae	NLF	0.00	0.00	1.15	0.00
Papaveraceae	NLF	0.00	0.00	0.58	0.00
Plantaginaceae	NLF	5.91	1.38	5.65	0.77
Poaceae	G	9.18	43.61	20.74	48.29
Polygonaceae	NLF	0.63	0.11	2.19	1.55
Portulacaceae	NLF	0.00	0.00	6.22	0.00
Ranunculaceae	NLF	0.00	0.00	0.12	0.00
Rosaceae	S/NLF	9.92	2.92	2.76	0.77
Rubiaceae	NLF	2.64	8.23	1.50	4.09
Solanaceae	NLF	0.00	0.00	0.46	0.11
Thymelaeaceae	S	0.84	0.11	0.12	0.44
Zygophyllaceae	NLF	0.11	0.11	0.00	0.00

G, grasses; *LF*, leguminous forbs; *NLF*, non-leguminous forbs; *S*, shrubs

Fagaceae, Geraniaceae, Myrtaceae, Oleaceae, Plantaginaceae, Polygonaceae, Rosaceae, and Thymelaeaceae) and 8 families

in Tallone (Asteraceae, Cistaceae, Geraniaceae, Myrtaceae, Plantaginaceae, Polygonaceae, and Rosaceae) (Table 3).

Table 2 Diet biodiversity indices (mean \pm SE) in Aleria and in Tallone

Index	Aleria		Tallone		<i>p</i>
	Mean	SE	Mean	SE	
Shannon, <i>H</i>	2.931	\pm 0.030	3.102	\pm 0.055	*
Simpson, <i>D</i>	0.922	\pm 0.003	0.938	\pm 0.005	*
Margalef, <i>d</i>	5.978	\pm 0.135	6.424	\pm 0.245	
Buzas and Gibson, <i>E</i>	0.584	\pm 0.016	0.651	\pm 0.028	

* $p \leq 0.05$

Discussion

A wide spectrum of plant species composed the diet of the Italian hare: 79 of the 131 species identified in vegetation were eaten. Grasses represented the basis of the Italian hare diet, with frequencies near to 50%. Highest frequencies of this life form in the diet (over 60%) were observed in Iberian hare in Portugal by Paupério and Alves (2008), in European hare in England by Wray (1992), and in Ethiopian highland hare (*L. starcki* Petter, 1963) by Mekonnen et al. (2011). Non-leguminous forbs appeared in the second rank of frequency in the diet (30%), followed by shrubs and leguminous forbs that were not consumed in large quantities. The high prevalence of grasses observed in the diet could also be related to the differential digestion of the plant species due particularly to the fibre content, which influences digestibility of forage. So that, using faecal pellet microscopic analysis to study the diet, the grass and browse species, which are the richest in fibre, tend to be overestimated, while the forbs are generally underestimated (Holechek et al. 1982). Nevertheless, microscopic examination is still widely used to investigate food habits, especially when the studied species is endangered like the Italian hare. This method depends heavily upon the skills and the experience of the person identifying the species that, if not sufficiently trained, could inaccurately interpret the diagnostic taxonomic characteristics. For this reason, diet

analysis based on faecal DNA metabarcoding will supplant, in the near future, microscopic analysis. This innovative technique has been accepted in the field of ecology as a noninvasive, accurate, time, and cost-effective tool to reveal some important aspects of wildlife management, e.g. in food selection of endangered species and to reveal detailed mechanisms of niche partitioning in multiple sympatric species (Pompanon et al. 2012; Kartzinel et al. 2015; Buglione et al. 2018; Ferreira et al. 2018). Nevertheless, Ando et al. (2018) evidenced that in the various components of metabarcoding diet analysis from sampling to bioinformatics, optimization of the method has not been sufficiently attempted, and indicated among the most critical aspects the contamination of faecal DNA with non-food DNA. In the present study, the preferential foraging on herbaceous plants, grasses in particular, is consistent with previous contributes on the species (De Battisti et al. 2004; Trocchi and Riga 2005; Freschi et al. 2014, 2015, 2016). This feeding pattern was also observed in *L. europeus* (Puig et al. 2007; Karmiris et al. 2011; Kotsiotis et al. 2011; Süel et al. 2017), in *L. granatensis* (Carro 2005; Paupério and Alves 2008), and in *L. flavigularis* (Lorenzo et al. 2011). Poaceae, Asteraceae, and Fabaceae constituted the bulk of the diet in dry season. Buglione et al. (2018), utilising the DNA-barcoding technique, identified Poaceae and Fabaceae as the most representative families in the diet of Italian hare. Among Asteraceae, *Cichorium intybus* was the most preferred species (more than 5% in both sites), probably for its palatability or for its water content, higher than in most of the plants composing the diet in dry season. Rubiaceae were abundantly grazed by *L. corsicanus* in Corsica, while in South Italy the preferences for this family were different, depending on the considered areas: these herbs were grazed in Abruzzo and Campania (Buglione et al. 2018), and not utilised in Basilicata (Freschi et al. 2014, 2015, 2016). Nevertheless, it must be highlighted that the lack of information on vegetation composition in studies on diet of Italian hare, this study being the first, complicates the comparison with other studies.

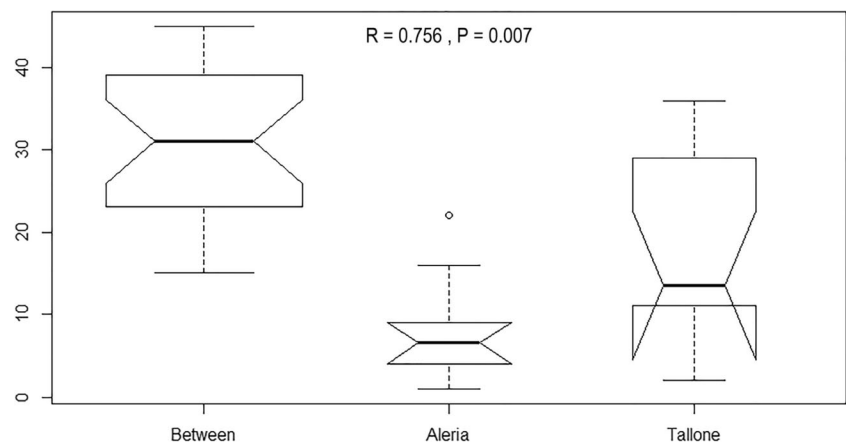
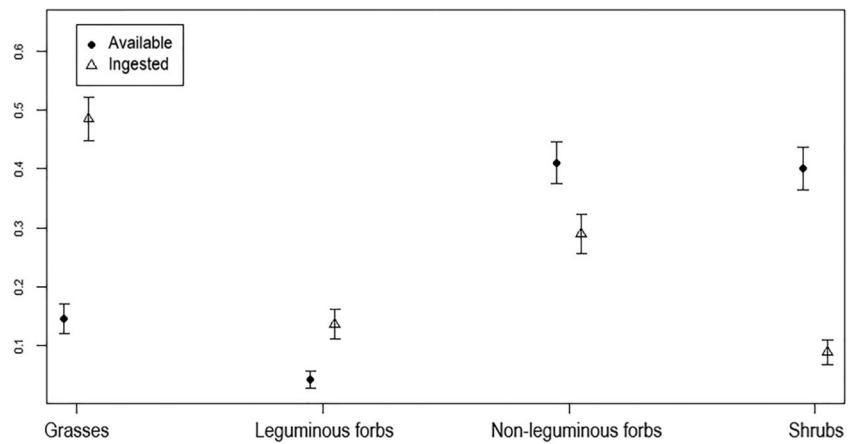
Fig. 2 Analysis of similarities of diet between and within sites

Fig. 3 Aleria—Manly’s selection ratio w_i (use relative to availability) of life forms



According to with previous studies on diet composition of Italian hare, the current research found that, despite the wide range of identified plant species in the diet, only a small fraction of them was ingested at relatively high rates. This evidence explains the differences in diversity indexes observed between sites. A similar feeding pattern was observed during the warm and dry seasons in the European hare (e.g. Green et al. 2013; Sokos et al. 2015), in the Black-tailed jackrabbit (*L. californicus*) (e.g. Wansi et al. 1992) and in the Iberian hare (e.g. Paupério and Alves 2008). These studies found evidence in wide diet breadth with only few species forming the bulk.

The most observed *taxa* in this study were as follows: *Brachypodium sylvaticum*, *Trifolium angustifolium*, *Rubia peregriana*, and *Briza maxima*. The diet of *L. corsicanus* in Corsica has similarities with that observed in the same *taxon* in Basilicata region, reflecting a preference for *Brachypodium* spp. and *Trifolium* spp. (Freschi et al. 2014, 2015, 2016). Fedele et al. (1993), studying the palatability in goats of over 50 plant species of a natural pasture, evidenced that *Brachypodium* spp. were among the most grazed. Probably, *L. corsicanus*, as with larger herbivores (Gebert and Tixier 2001; Freschi et al. 2017), prefers these species for their wide availability in all seasons. According to Sokos et al. (2015),

the breadth of the diet is inversely related to the quantity and availability of preferred species: herbivores do not need to search and to consume more plant species if the few preferred species are sufficiently abundant and well distributed. Selection could also be influenced by forage biomass or by the plants reaction to browsing those changes along vegetative phases (e.g. defensive activity of tannins against herbivores) (Bernays et al. 1989; Argenti et al. 2017). The palatability of forage is one of the factors not yet investigated to explain diet preferences in genus *Lepus*. Greenhalgh and Reid (1971) defined palatability as the dietary characteristics that stimulate a selective response by the animal. In the case of forage, sensorial perceptions are principally linked to the presence of plant volatile molecules (e.g. terpenes, ternary compounds). The role of sensorial perceptions in feed selection and intake has been investigated principally on domestic herbivores (Greenhalgh and Reid 1971; Pickersky et al. 2006; Cannas et al. 2009). These studies put in relation to the sensorial perception of plants to the presence and concentration of plant volatiles odours highlighting that olfaction is the first sense used as a gauge in food preference. The complex and not well-known response in wild mammals to plant scents was investigated by Llusia et al. (1996) on hares and on deer pointing

Fig. 4 Tallone—Manly’s selection ratio w_i (use relative to availability) of life forms

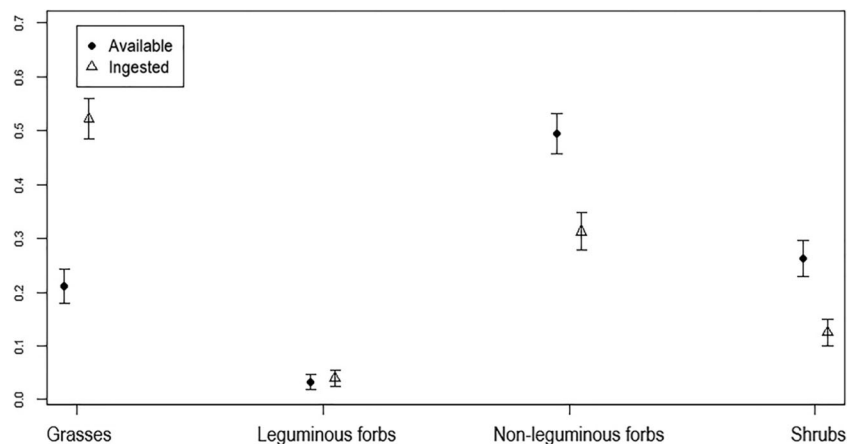


Table 3 Resource selection ratio (w_i) on botanical families in Aleria and in Tallone

Family	Aleria		Tallone	
	w_i	Feeding behaviour	w_i	Feeding behaviour
Apiaceae	0.235	A ***	12.814	I
Asteraceae	0.817	A *	0.612	A ***
Cistaceae	0.151	A ***	0.266	A ***
Cyperaceae	0.897	I	7.176	I
Ericaceae	0.087	A ***	0.265	A ***
Fabaceae	1.974	P ***	1.000	A
Fagaceae	0.019	A ***	0.577	A
Geraniaceae	0.102	A ***	0.102	A ***
Lamiaceae	2.301	I	0.708	A
Myrtaceae	0.263	A ***	0.096	A ***
Oleaceae	0.030	A ***	0.769	A
Plantaginaceae	0.284	A ***	0.489	A **
Poaceae	4.263	P ***	1.867	P ***
Polygonaceae	0.153	A ***	0.567	A **
Rosaceae	0.264	A ***	0.224	A ***
Rubiaceae	2.798	P **	2.188	I
Thymelaeaceae	0.115	A ***	3.075	I

* $p \leq 0.05$; * $p \leq 0.01$; *** $p \leq 0.001$. Feeding behaviour: P preference, I indifference, A avoidance

out the inhibiting activity of monoterpenes on digestion due to their suppressing activity on digestive microorganisms.

Overall, we observed that feeding preference of the Italian hare varied across different habitats, with only Poaceae family always being selected positively. Other species of the same genus, in particular *L. europaeus*, showed the same preference for Poaceae in lower Austria (Reichlin et al. 2006), in Greece (Sokos et al. 2015), and in Northern Patagonia (Puig et al. 2007). The explication of the preference for plants of this family can be found in their good palatability and in their great cellulose content that can be a useful reserve of energy for hares (Beaumont et al. 2007; Secombe-Hett and Turkington 2008). We found positive selection for Fabaceae and Rubiaceae families in the Aleria site. According to Paupério and Alves (2008) and Kuijper et al. (2004), many species of Fabaceae family are important as food sources for different herbivores, because of their higher protein content and for their lower fibre content in comparison with grasses in which fibre incidence increases more during dry season compared with herbs and shrubs.

According to Shipley et al. (2009), mammalian herbivores are considered as feeding generalists or specialists if the incidence of a family plant in the diet is below or over 60%, respectively. In the current study, Italian hare behaved as generalist revealing its capability of exploiting several plant species and of exhibiting opportunistic behaviour in relation to

food resource availability. Significant differences in the diet composition and in the diversity index between the two study sites showed the adaptability of the species to different habitats and the influence of the vegetation on its feeding habits.

This current paper is the first considering food availability and food selection in *L. corsicanus*. Preference of plant species is very difficult to interpret and to understand as the factors involved vary spatially and in time, as well as to the availability and to the relative abundance to associated species. On the other hand, some species which are normally avoided could be grazed under compulsion due to scarcity of food in the area. Further studies will investigate diet selection in relation to the amount and distribution of vegetation present at a site, as well as the seasonal variation in plant resources, in order to comprise the relationship between preference and plant phenology. Feeding habit studies could greatly improve the success of conservation efforts, allowing the identification of the ecological requirements of endangered species. Furthermore, human-mediated climate changes affect the distribution of suitable habitat for many species. Even in the case of generalist species, such as hare, habitat transformation and fragmentation could affect the survival of small and endangered populations. In particular, conservation of *L. corsicanus* populations in Corsica could be greatly improved by the knowledge of the species diet; in fact, it could drive habitat restoration programs, preservation of important feeding habitat, reintroduction feasibility studies, and improvement of corridors and ecological net. However, our results could be useful to plan conservation actions in Italy, especially for the endangered continental populations. In fact, among all, major threats for the species are habitat degradation and population fragmentation

References

- Ando H, Fujii C, Kawanabe M, Ao Y, Inoue T, Takenaka A (2018) Evaluation of plant contamination in metabarcoding diet analysis of a herbivore. *Sci Rep* 8:15563. <https://doi.org/10.1038/s41598-018-32845-w>
- Angelici FM, Randi E, Riga F et al (2008) *Lepus corsicanus*. The IUCN Red List of Threatened Species. <http://www.iucnredlist.org/details/full/41305/1>
- Argenti G, Racanelli V, Bartolozzi S, Staglianò N, Sorbetti Guerri F (2017) Evaluation of wild animals browsing preferences in forage resources. *Ital J Agron* 3:208–214. <https://doi.org/10.4081/ija.2017.884>
- Banfi E, Galasso G, Bartolucci F (2018) Nomenclatural novelties for the Euro Med flora. *Nat Hist Sci* 5(1):53–57. <https://doi.org/10.4081/nhs.2018.365>
- Bartolucci F, Peruzzi L, Galasso G, Albano A, Alessandrini A, Ardenghi NMG, Astuti G, Bacchetta G, Ballelli S, Banfi E, Barberis G, Bernardo L, Bouvet D, Bovio M, Cecchi L, di Pietro R, Domina G, Fascetti S, Fenu G, Festi F, Foggi B, Gallo L, Gottschlich G,

- Gubellini L, Iamónico D, Iberite M, Jiménez-Mejías P, Lattanzi E, Marchetti D, Martinetto E, Masin RR, Medagli P, Passalacqua NG, Peccenini S, Pennesi R, Pierini B, Poldini L, Prosser F, Raimondo FM, Roma-Marzio F, Rosati L, Santangelo A, Scoppola A, Scortegagna S, Selvaggi A, Selvi F, Soldano A, Stinca A, Wagensommer RP, Wilhelm T, Conti F (2018) An updated checklist of the vascular flora native to Italy. *Plant Biosyst* 152(2):179–303. <https://doi.org/10.1080/11263504.2017.1419996>
- Beaumont M, Austen J, Atkins D et al (2007) Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. *Mar Pollut Bull* 54:253–265. <https://doi.org/10.1016/j.marpolbul.2006.12.003>
- Bernays EA, Cooper Dryver G, Bilgener M (1989) Herbivores and plant tannins. *Adv Ecol Res* 19:263–302
- Bonham CD (1989) Measurements for terrestrial vegetation. Wiley, New York
- Buglione M, Maselli V, Ripa D, de Filippo G, Trapanese M, Fulgione D (2018) A pilot study on the application of DNA metabarcoding for non-invasive diet analysis in the Italian hare. *Mamm Biol* 88:31–42. <https://doi.org/10.1016/j.mambio.2017.10.010>
- Buzas MA, Gibson TG (1969) Species diversity: benthonic foraminifera in western North Atlantic. *Science* 163:72–75. <https://doi.org/10.1126/science.163.3862.72>
- Cannas A, Meri A, Decandia M et al (2009) Role of sensorial perceptions in feed selection and intake by domestic herbivores. *Ital J Anim Sci* 8(29):243–251. <https://doi.org/10.2527/jas.2009-1851>
- Carro F (2005) Historia natural de la liebre-iberica (*Lepus granatensis* Rosenhauer, 1856) en el Parque Nacional de Doñana. PhD thesis, University of Santiago de Compostela
- Chapuis JL (1990) Comparison of the diets of two sympatric lagomorphs, *Lepus europaeus* (Pallas) and *Oryctolagus cuniculus* (L.) in an agroecosystem of the Ile-de-France. *Z Säugertierkd* 55:176–185
- Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Lab, Plymouth Climate data.org (2017) <https://fr.climate-data.org>
- Cristóbal-Azkarate J, Arroyo-Rodríguez V (2007) Diet and activity pattern of howler monkeys (*Alouatta palliata*) in Los Tuxtlas, Mexico: effects of habitat fragmentation and implications for conservation. *Am J Primatol* 69:1013–1029. <https://doi.org/10.1002/ajp.20420>
- De Battisti R, Migliore S, Masutti L et al (2004) The diet of the Italian hare *Lepus corsicanus* on Etna Mountain, Sicily. Proceedings of the 2nd World Lagomorph Conference, Porto 1:157
- Dingerkus SK, Montgomery WI (2001) The diet and landclass affinities of the Irish hare *Lepus timidus hibernicus*. *J Zool (Lond)* 253:233–240. <https://doi.org/10.1017/S0952836901000206>
- Duffy JE, Cardinale BJ, France KE, McIntyre PB, Thébault E, Loreau M (2007) The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Ecol Lett* 10:522–538. <https://doi.org/10.1111/j.1461-0248.2007.01037.x>
- Fedele V, Pizzillo M, Claps S, Morand-Fehr P, Rubino R (1993) Grazing behaviour and diet selection of goats on native pasture in Southern Italy. *Small Rumin Res* 11:305–322. [https://doi.org/10.1016/0921-4488\(93\)90002-Y](https://doi.org/10.1016/0921-4488(93)90002-Y)
- Ferreira CM, Sabino-Marques H, Paupério J et al (2018) The applicability of non-invasive genetic sampling for monitoring small mammal metapopulations. *Eur J Wildl Res* 64:46. <https://doi.org/10.1007/s10344-018-1188-8>
- Freschi P, Fascetti S, Musto M, Mallia E, Blasi AC, Cosentino C, Paolino R (2014) Diet of the Apennine hare in a Southern Italy Regional Park. *Eur J Wildl Res* 60(3):423–430. <https://doi.org/10.1007/s10344-014-0799-y>
- Freschi P, Fascetti S, Musto M, Mallia E, Cosentino C, Paolino R (2015) Diet of the Italian hare (*Lepus corsicanus*) in a semi-natural landscape of southern Italy. *Mammalia* 79(1):51–59. <https://doi.org/10.1515/mammalia-2013-0117>
- Freschi P, Fascetti S, Musto M, Cosentino C, Paolino R, Valentini V (2016) Seasonal variation in food habits of the Italian hare in a south Apennine semi-natural landscape. *Ethol Ecol Evol* 28(2):148–162. <https://doi.org/10.1080/03949370.2015.1022906>
- Freschi P, Fascetti S, Riga F, Cosentino C, Rizzardini G, Musto M (2017) Diet composition of the Italian roe deer (*Capreolus capreolus italicus*) (Mammalia: Cervidae) from two protected areas. *Eur Zool J* 84(1):34–42. <https://doi.org/10.1080/11250003.2016.1268655>
- Frylestam B (1986) Agricultural land use effects on the winter diet of Brown hares (*Lepus europaeus* Pallas) in southern Sweden. *Mammal Rev* 16:157–161. <https://doi.org/10.1111/j.1365-2907.1986.tb00037.x>
- Gamisans J (2012) Le paysage végétal de la Corse. *Strade* 20:25–36
- Gebert C, Tixier VT (2001) Variations of diet composition of Red Deer (*Cervus elaphus* L.) in Europe. *Mammal Rev* 31(3):189–201. <https://doi.org/10.1111/j.1365-2907.2001.00090.x>
- Green K, Davis NE, Robinson WA, McAuliffe J, Good RB (2013) Diet selection of European hares (*Lepus europaeus*) in the alpine zone of the Snowy Mountains, Australia. *Eur J Wildl Res* 59(5):693–703. <https://doi.org/10.1007/s10344-013-0723-x>
- Greenhalgh JFD, Reid GW (1971) Relative palatability to sheep of straw hay and dried grass. *Br J Nutr* 26:107–116. <https://doi.org/10.1079/BJN19710013>
- Hewson R, Hinge MDC (1990) Characteristics of home range of Mountain hare. *J Appl Ecol* 27:651–666. <https://doi.org/10.2307/2404309>
- Hoagland D (1992) Feeding Ecology of an Insular Population of the Black-Tailed Jackrabbit (*Lepus californicus*) in the Gulf of California. *The Southwestern Naturalist*, 37(3), 280–286. <https://doi.org/10.2307/3671870>
- Holeček JL, Vavra M, Pieper RD (1982) Botanical composition determination of range herbivore diets: a review. *J Range Manag* 35:309–315. <https://doi.org/10.2307/3898308>
- Johnson RD, Anderson JE (1984) Diets of black-tailed jackrabbits in relation to population density and vegetation. *J Range Manag* 37: 79–83. <https://doi.org/10.2307/3898830>
- Karmiris I, Platis PD, Kazantzidis S, Papachristou TG (2011) Diet selection by domestic and wild herbivore species in a coastal Mediterranean wetland. *Ann Zool Fenn* 48:233242. <https://doi.org/10.5735/086.048.0404>
- Kartzinel TR, Chen PA, Coverdale TC, Erickson DL, Kress WJ, Kuzmina ML, Rubenstein DI, Wang W, Pringle RM (2015) DNA metabarcoding illuminates dietary niche partitioning by African large herbivores. *Proc Natl Acad Sci* 112(26):8019–8024 <http://www.pnas.org/cgi/doi/10.1073/pnas.1503283112>
- Klein DR, Bay C (1994) Resource partitioning by mammalian herbivores in the high Arctic. *Oecologia* 97:439–450. <https://doi.org/10.1007/BF00325880>
- Kontsiotis VJ, Tsiompanoudis AC, Bakaloudis DE (2011) The influence of habitat structure on the European brown hare *Lepus europaeus* food habits in mountainous areas of northern Greece. *Mammalia* 75: 389–394. <https://doi.org/10.1515/MAMM.2011.050>
- Kuijper DPJ, van Wieren SE, Bakker JP (2004) Digestive strategies in two sympatrically occurring lagomorphs. *J Zool (Lond)* 264:171–178. <https://doi.org/10.1017/S0952836904005722>
- Langton RW (1982) Diet overlap between Atlantic cod, *Gadus morhua*, silver hake, *Merluccius bilinearis*, and fifteen other Northwest Atlantic finfish. *Fish Bull* 80:745–759
- Llusia J, Estiarte M, Peñuelas J (1996) Terpenoids and plant communication. *Bull Inst Cat Hist Nat* 64:125–133
- Lorenzo C, Carrillo-Reyes A, Gómez-Sánchez M, Velázquez A, Espinoza E (2011) Diet of the endangered Tehuantepec jackrabbit, *Lepus flavigularis*. *Therya* 2:67–76. <https://doi.org/10.12933/therya-11-33>

- Manly BFJ, McDonald LL, Thomas DL et al (2004) Resource selection by animals: statistical design and analysis for field studies, 2nd edn. Kluwer Academic Publishers, Dordrecht
- Margalef R (1958) Information theory in ecology. *Gen Syst* 3:36–71
- Margalef R (1972) Interpretation not strictly statistical of representation of biological entities in multifactorial space. *Investig Pesq* 36:183–190
- Mekonnen T, Yaba M, Bekele A, Malcolm J (2011) Food selection and habitat association of Starck's hare (*Lepus starcki* Petter, 1963) in the Bale mountains national park, Ethiopia. *Asian J Appl Sci* 4:728–734. <https://doi.org/10.3923/ajaps.2011.728.734>
- Mitchell-Jones AJ, Amori G, Bogdanowicz W et al (1999) The atlas of European mammals. T & AD Poyser, Calton
- Mitrakos K (1980) A theory for Mediterranean plant life. *Acta Oecol* 1: 245–252
- Morisita M (1959) Measuring of interspecific association and similarity between communities. *Mem Fac Sci Kyushu Univ E (Biol)* 3:65–80
- Paupério J, Alves PC (2008) Diet of the Iberian hare (*Lepus granatensis*) in a mountain ecosystem. *Eur J Wildl Res* 54:571–579. <https://doi.org/10.1007/s10344-008-0181-z>
- Pickersky E, Noel JP, Dudareva N (2006) Biosynthesis of plant volatiles: nature's diversity and ingenuity. *Science* 311:808–811. <https://doi.org/10.1126/science.1118510>
- Pietri C (2007) Caccia e protezione delle popolazioni di lepree (*Lepus* sp.) in Corsica. In: De Filippo G, De Riso L, Riga F, Trocchi V, Troisi SR (eds) Conservazione di *Lepus corsicanus* De Winton, 1898 e stato delle conoscenze. IGF, Napoli, pp 52–62
- Pietri C (2015) Range and status of the Italian hare *Lepus corsicanus* in Corsica. *Hystrix Ital J Mamm* 26(2):166–168. <https://doi.org/10.4404/hystrix-26.2-11412>
- Pietri C, Alves PC, Melo-Ferreira J (2011) Hares in Corsica: high prevalence of *Lepus corsicanus* and hybridation with introduced *L. europaeus* and *L. granatensis*. *Eur J Wildl Res* 52:313–321. <https://doi.org/10.1007/s10344-010-0430-9>
- Pompanon F, Deagle BE, Symondson WOC et al (2012) Who is eating what: diet assessment using next generation sequencing. *Mol Ecol* 21:1931–1950. <https://doi.org/10.1111/j.1365-294X.2011.05403.x>
- Puig S, Videla F, Cona MI, Monge SA (2007) Diet of the brown hare (*Lepus europaeus*) and food availability in northern Patagonia (Mendoza, Argentina). *Mamm Biol* 72:240–250. <https://doi.org/10.1016/j.mambio.2006.08.006>
- R Core Team R (2017) A language and environment for statistical computing. R Foundation for Statistical Computing. <https://www.R-project.org>
- Reichlin T, Klansek E, Hacklander K (2006) Diet selection by hares (*Lepus europaeus*) in arable land and its implications for habitat management. *Eur J Wildl Res* 52:109–118. <https://doi.org/10.1007/s10344-005-0013-3>
- Reveal JL (2011) Summary of recent systems of angiosperm classification. *Kew Bull* 66:5–48
- Rivas-Martinez S, Penas A, Diaz TE (2004) Biogeographic map of Europe. Cartographic Service, University of León
- Rondinini C, Di Marco M, Visconti P (2013) Update or outdate: long-term viability of the IUCN Red List. *Conserv Lett* 7(2):126–130. <https://doi.org/10.1111/conl.12040>
- Secombe-Hett P, Turkington R (2008) Summer diet selection of snowshoe hares: a test of nutritional hypotheses. *Oikos* 117:1874–1884. <https://doi.org/10.1111/j.1600-0706.2008.16773.x>
- Shannon CE, Weaver W (1949) The mathematical theory of communication. Dissertation, University of Illinois
- Shiple LA, Forbey JS, Moore BD (2009) Revisiting the dietary niche: when is a mammalian herbivore a specialist? *Integr Comp Biol* 49: 274–290. <https://doi.org/10.1093/icb/icmp051>
- Simpson EH (1949) Measurement of diversity. *Nature* 163:688
- Sokos C, Andreadis K, Papageorgiou N (2015) Diet adaptability by a generalist herbivore: the case of brown hare in a Mediterranean agroecosystem. *Zool Stud* 54:27. <https://doi.org/10.1186/s40555-014-0095-2>
- Sørensen TA (1948) A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on. *Danish Commons KDVS* 5:1–34
- Süel H, Akdemir D, Kiraç A et al (2017) The indicator plant species of wild animals in the Gidengelmez mountains district. *J Environ Biol* 38:991–998. [https://doi.org/10.22438/jeb/38/5\(SI\)/GM-16](https://doi.org/10.22438/jeb/38/5(SI)/GM-16)
- Tangney D, Fairley J, O'Donnell G (1995) Food of Irish hares *Lepus timidus hibernicus* in western Connemara, Ireland. *Acta Theriol* 40:403–413. <https://doi.org/10.4098/AT.arch.95-37>
- The Council of the European Union (1992) Council directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm
- Tison JM, de Foucault B (2014) *Flora Gallica*. Meze: Biotope éditions, France
- Trocchi V, Riga F (2001) Piano d'azione nazionale per la Lepre italiana (*Lepus corsicanus*). Quaderni di Conservazione della Natura, 9. Ministero dell'Ambiente, INFS http://www.minambiente.it/sites/default/files/archivio/biblioteca/protezione_natura/qcn_lepre.pdf
- Trocchi V, Riga F (2005) I Lagomorfi in Italia. Linee guida per la conservazione e gestione. Ist Naz Fauna Selvatica. Documenti Tecnici 25:1–128
- Tutin TG, Burges NA, Chater AO et al (1993) *Flora Europaea*. Cambridge University Press, Cambridge
- Uresk DW (1978) Diets of the black-tailed hare in steppe vegetation. *J Range Manag* 31:439–442. <https://doi.org/10.2307/3897202>
- Vigne JD (1999) The large “true” Mediterranean islands as a model for the Holocene human impact on the European vertebrate fauna? Recent data and new reflections. In: Benecke N (ed) The Holocene history of European vertebrate fauna. Modern aspects of research. Deutsches Archäologisches Institut Eurasien-Abteilung, Verlag Marie Leidorf, Rahden, pp 295–322
- Wansi T, Pieper RD, Beck RF, Murray LW (1992) Botanical content of black-tailed jackrabbit diets on semidesert rangeland. *Great Basin Nat* 52(4):300–308
- Warton DI, Wright ST, Wang Y (2012) Distance based multivariate analyses confound location and dispersion effects. *Methods Ecol Evol* 3: 89–101. <https://doi.org/10.1111/j.2041-210X.2011.00127.x>
- Wolfe A, Whelan J, Hayden TJ (1996) The diet of the mountain hare (*Lepus timidus hibernicus*) on coastal grassland. *J Zool (Lond)* 240: 804–810. <https://doi.org/10.1111/j.1469-7998.1996.tb05327.x>
- Wray S (1992) The ecology and management of European hares (*Lepus europaeus*) in commercial coniferous forestry. PhD thesis, Department of Zoology, University of Bristol
- Zar JH (1999) *Biostatistical analysis*, 4th edn. Pearson Prentice-Hall, Upper Saddle River

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.