



## Original Investigation

Habitat selection and activity patterns in Alpine mountain hare (*Lepus timidus varronis*)

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## ABSTRACT

We investigated activity patterns and habitat use of 34 radio-tracked mountain hares (*Lepus timidus*) in the Italian Alps. We first showed that hares were nocturnal and that activity patterns changed seasonally in parallel with circadian rhythms. We predicted that day home ranges will include suitable resting (shelter) habitats, and night home ranges will primarily include suitable foraging habitats. A hare's night-range was larger than its day-range. On average, night and day ranges overlapped by 36%, suggesting that selective pressures affecting space use were, at least partly, different at night than day. Dwarf mountain-pine was the most preferred habitat in all seasons and was selected both for active behaviour (night) and resting (day) and hares avoided the most open habitats. Exploring the effects of season, time of day (day vs. night) and site, we found that habitat use by mountain hares did not differ between seasons or between the active (night) and resting (day) period of circadian cycle. Also, we found no effects of differences in landscape structure (habitat patchiness and heterogeneity) on the patterns of habitat selection. Hares always preferred the dense, forested habitats, which seemed to provide food resources as well as shelter from predators throughout the year.

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## Introduction

Animals make habitat choice as a result of balance between the costs and benefits perceived by the animal (Lima and Dill 1990; Lima and Bednekoff 1999). Habitat use is driven by habitat-related variation in factors such as forage quality and availability, shelter, presence of predators and mating system (e.g. Creel et al. 2005; Kuijper and Bakker 2008; Godvik et al. 2009). In fact, one of the most common trade-off faced by herbivores is when open habitats provide good forage and closed habitats provide shelter vs. predators (Godvik et al. 2009). The relative importance of finding food, mates and avoiding predators will change across different species of herbivores, but may also vary in space and time within populations of a single species (Rettie and Messier 2000).

Mammals have a 24-h activity rhythm, based on the endocrine melatonin rhythm of the pineal gland, synchronised with the environment by means of the light/dark cycle (Bartness and Goldman 1989). Since all activities carried out during the circadian cycle have fitness costs and benefits (Daan and Aschoff 1982),

and if different habitats have differential survival costs/benefits for active behaviour than for resting/sleeping, an individual's space and habitat use is likely to differ between the active and the inactive part of the circadian cycle (e.g. Lima and Dill 1990; Hughes et al. 1994; Halle 2000). Hares do not have true nests, but use shelters under bushes, in fields, near rocks or even in snow (Angerbjörn and Flux 1995). Hence, hares might use some habitat types only for shelter and others only for foraging.

Habitat use of mountain hare (*Lepus timidus*) has been studied in Northern Europe (Hewson 1988, 1989; Hiltunen et al. 2004; Dahl 2005), but there is little information for Alpine populations (Genini-Gamboni et al. 2008). In Europe, the mountain hare is predominantly a species of mixed forest (Naumov 1947), although it reaches the highest densities in transition zone with open clearings (Lindlof et al. 1974) or in moorlands as in Scotland (Watson and Hewson 1973). In landscapes in Scotland with a mosaic of open habitats suitable for feeding (e.g. pastures) and sheltered habitats (moorland) mountain hares tend to vary space and habitat use between day (resting) and night (foraging), using smaller night than day ranges (Flux 1970a,b; Hewson 1988). In contrast, in Ireland (Wolfe and Hayden 1996) and in Scotland (Rao et al. 2003), in less patchy landscapes with extensive areas of suitable foraging habitats day- and night ranges were similar and hares used the dominant habitat for both feeding and resting.

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In this study, we investigate habitat use of mountain hare in alpine ecosystem at three different time scales. Since the mountain hare is primarily nocturnal (Angerbjörn and Flux 1995), we expect that day home ranges include suitable resting (shelter) habitats, and night home ranges will primarily include suitable foraging habitats. Therefore, in a preliminary step we analysed activity patterns to determine when hares shifted from active to non-active behaviour. Next, we analysed habitat selection in two populations in areas with different habitat structure and composition, at different scales: First, we studied general habitat use on an annual basis. Second, since home-range size of mountain hare varies in relation to season (Bisi et al. 2011), we explored seasonal variation in habitat use. Third, we compared habitat use between day- and night ranges to explore whether habitats most preferred for shelter (day) were different from those preferred for feeding (night). Based on the studies carried out in Scotland, we predicted that day- and night habitat use will be similar in the study site dominated by a single extensive area of dwarf mountain pine, while different habitats will be used for resting (day) and foraging (night) in the 'patchy' study site.

## Material and methods

### Study sites

Mountain hares (*Lepus timidus varronis*) were studied in central Italian Alps in two different study sites. San Giacomo di Fraele (SG: elevation 1950–2500 m a.s.l., 46° 32' N, 10° 16' E) in the Stelvio National Park is dominated by a homogeneous dwarf mountain pine (*Pinus mugo*) woodland with trees of both prostrate and arboreal habit (hereinafter called 'mountain pine site'). The undergrowth is composed of heather (*Erica carnea*), juniper (*Juniperus communis*), blueberry (*Vaccinium myrtillus*) and lingonberry (*Vaccinium vitis-idaea*). The second study site is in the nearby Vezzola (VZ) valley at 1700–2500 m a.s.l., approximately 6 km from SG. (46° 29' N, 10° 16' E). The habitat is a mixture of forest patches of different size and composition (hereinafter called 'patchy site') with similar proportions of Norway spruce (*Picea abies*), Arolla pine (*Pinus cembra*) and larch (*Larix decidua*) and an homogeneous central patch of mountain pine (*Pinus mugo*). The undergrowth is composed mainly of heather (*Erica carnea*) and rhododendron (*Rhododendron ferrugineum*) with juniper (*Juniperus communis*) and blueberry (*Vaccinium myrtillus*). Composition of habitat types for both sites is shown in [supplementary materials \(Table S1\)](#). Landscape structure analysis (McGarigal and Marks 1994) showed that the patchy site has more fragmented habitat with more and smaller patches than the mountain pine site, indicating that the latter has a more homogeneous habitat structure. The mountain pine site also has a lower habitat diversity than the patchy site ([supplementary materials, Table S1](#)).

### Trapping and radio-tracking

Between March 2005 and March 2008, we trapped 34 mountain hares using Tomahawk single door cat/rabbit collapsible traps (66 cm × 25 cm × 25 cm, model 205, Tomahawk Live Trap Co., Tomahawk, WI, USA) and long nets. During 2005 we tested traps in SG area and long nets in VZ (Nodari et al. 2005), as traps were more efficient in successive years we used only traps in both sites. In each study site, 25 traps were placed in a grid (5 × 5) spaced 70 m apart, for a total effort of 1383 trap-nights (2005, SG: 210; 2006, SG: 198, VZ: 248; 2007, SG: 203, VZ: 143; 2008, SG: 207, VZ: 174). Traps were covered with a synthetic tissue and a smaller wire mesh 1 cm × 1 cm to keep predators out. Traps were locked open and pre-baited for at least one week with dry "alfalfa" (trade name of a *Medicago sativa*

based food preparation). The trapping period changed each year depending on snow cover, usually from the beginning of January to the end of March, the traps were set at dusk and checked at dawn (Nodari et al. 2005). We trapped and radio-tagged 21 adult hares (10 males and 11 females), and 13 subadults (6 males and 7 females). We radio-collared the hares with ATS adjustable necklace transmitters weighing 35 g with a 24 h set mortality sensor (M1930 transmitters, Advanced Telemetry Systems Inc., Isanti, MN, USA). Hares were sexed and aged (subadult, under 7–8 months old, or adult) by observation of external genitals and by Stroh's tubercle palpation (Stroh 1931). Radio tagged hares were located through triangulation techniques.

Radio-tracking was carried out as in Bisi et al. (2011). At each fix, a hare's location and activity (active, not active) were recorded. Activity was determined based on the variation in signal intensity over a 1-min period: when hares were resting (motionless) intensity remained stable, while the signal of active hares (moving or changing body position) was characterised by marked variation in intensity. Signal intensity was observed both acoustically and visually using the signal strength indicator (DC milliamperes indicator).

### Activity patterns

To analyse activity patterns, we calculated the proportion of active fixes 5 h before and 5 h after sunrise and sunset. Arcsin of the square root of proportion active fixes per hour was used as dependent variable in two Linear Mixed Models (LMM) one explored changes in activity with respect to sunrise, the second with respect to sunset. Hour with respect to sunrise (from –5 to +5) or to sunset (from –5 to +5), season and their interaction were included as fixed effects. Since data of a single individual were used in different periods (seasons), we used individual as a repeated measure to account for pseudo-replication, analysis were performed using R package lme4 (Bates et al. 2011). The distribution of the residuals was explored using the Shapiro–Wilk statistic and did not deviate from normality. Interpretation of pairwise differences was based on Differences of Least Squares Means.

### Home range analysis

For each year, we estimated seasonal home range size: winter (December–March, ground continuously covered with snow), spring–summer (April–August, defined "breeding season", this is the season with vegetation growth, mating and breeding activity), and autumn (September–November, post-breeding season, with no vegetation growth and no continuous snow cover, from Bisi et al. 2011). In the next step we separated locations taken during the day (day-ranges) from those taken at night (night-ranges), within each season and year, and estimated size of day- and night home ranges separately (between 20 and 599 fixes used per range estimate). Dividing an animal's day- from night-range was based on the exact hour of sunrise and sunset per day at the latitude of our study sites (day fixes between sunrise and sunset, night fixes between sunset and next sunrise).

Home range size was estimated with the 95% fixed Kernel Density Estimator as explained in Bisi et al. (2011) using R package Adehabitat (Calenge 2006). Individual variation in home range size was investigated using GLMM with individual added as a repeated measure to account for pseudo-replication. We started from a saturated model with dependent variable Ln-transformed KDE95%, and number of fixes, day–night, season, age, sex, study site and their interactions as fixed effects. Data on home range size met assumptions of homogeneity of variances after Ln-transformation. The distribution of the residuals was explored at each model step using the Shapiro–Wilk statistic and did not deviate from normality. Using a stepwise backward procedure we identified the final

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